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ITU Kaleidoscope 2015

Trust in the Information Society

Barcelona, Spain, 9-11 December 2015

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Foreword

Chaesub Lee
Director
ITU Telecommunication Standardization Bureau

"If I have seen further it is by standing on the shoulders of giants." These words famously used by Isaac Newton in a very humble examination of his achievements remind us that the creation of knowledge is an iterative process built on the collective efforts of an ecosystem of thinkers and innovators. Many of the best-known developments in information and communication technology (ICT) found their roots in the research community and, in the interests of the ICT ecosystem, ITU continues to make great efforts to encourage the participation of academic and research institutes in our work.

The Kaleidoscope conference is ITU's flagship academic event. Now in its seventh edition, the conference has matured into one of the highlights of ITU's calendar of events. These peer-reviewed academic conferences increase dialogue between academics and experts working on the standardization of ICTs, uncovering research at an early stage to assist the diffusion of research findings through the development of internationally recognized ITU standards.

Kaleidoscope 2015: *Trust in the Information Society* called for research into means of increasing the degree to which we can trust in the security of our exchanges within the Information Society. Achieving fair return on our financial and intellectual investment in ICTs will demand an ICT environment deserving of our trust. Visions of the socio-economic benefits to be enacted by ICTs assume a degree of trust in the Information Society that we have yet to achieve. This was the challenging task put to the participants in Kaleidoscope 2015; to interrogate the obstacles to be overcome if ICTs are to fulfill their potential in improving our quality of life.

I would like to thank Kaleidoscope's participants for all they have done to drive the series' success. The ITU academic membership category introduced in January 2011 was a natural formalization of academia's contribution to the work of ITU. Academic and research institutes are now able to join all three sectors of ITU for a single fee, and more than 100 academia members are participating in ITU's expert groups alongside industry-leading engineers, policymakers and business strategists.

On behalf of ITU, I thank our generous host, Universitat Autònoma de Barcelona; our technical co-sponsors, the Institute of Electrical and Electronics Engineers (IEEE), IEEE Communications Society, and the Institute of Electronics, Information and Communication Engineers of Japan (IEICE); our supportive partners, Waseda University, the Institute of Image Electronics Engineers of Japan (I.I.E.E.J.), the European Academy for Standardization (EURAS), the University of the Basque Country, the Chair of Communication and Distributed Systems at RWTH Aachen University, and the Universidad Politécnica de Cartagena; our dedicated Steering Committee and Technical Programme Committee members; and, of course, our distinguished Chairman, Pilar Dellunde, Vice-Rector of Universitat Autònoma de Barcelona.

Chaesub Lee
Director
ITU Telecommunication Standardization Bureau

Chair's Message

Pilar Dellunde
General Chair

The ITU Kaleidoscope series of conferences, launched in 2008, has grown into a well-recognized platform for the exchange of knowledge between researchers and standardization experts in the field of information and communication technology (ICT). The ITU academia membership category has reinforced the cause of the Kaleidoscope series and the conference is gaining in importance as academia increases its engagement in ITU work. I would like to express my appreciation to ITU for selecting Universitat Autònoma de Barcelona as this year's host as well as the collaborative spirit with which ITU organized the event.

It has been a privilege to chair Kaleidoscope 2015: *Trust in the Information Society*. The conference's theme was a very topical one. ICTs have become so pervasive that the associated implications for our economies and societies will feature as a theme common to a variety of academic disciplines for years to come. Universitat Autònoma de Barcelona was glad to assist ITU in offering a platform to debate this important issue.

The Kaleidoscope 2015 Technical Programme Committee, chaired by Kai Jakobs of RWTH Aachen University in Germany, selected 31 papers from the 96 submissions received from 30 countries. The committee selected papers on the basis of double-blind reviews with the help of over 100 international experts, and also took on the challenging task of identifying candidate papers for awards. I offer my sincere thanks to all reviewers and members of the Technical Programme Committee for their generous contribution of time and expertise.

A side-event held the day prior to the Kaleidoscope conference, a Consultation on ITU-Academia Collaboration, encouraged an exchange of views on the form of ITU services best-suited to meeting the needs and expectations of ITU Academia members.

Kaleidoscope 2015 featured four distinguished keynote speakers in Enrique Blanco, Global Chief Technology Officer of Telefónica, Spain; Jan Färjh, Global Head of Standardization and Member of the Technology Leadership Team at Ericsson, Sweden; Siani Pearson of the HP Security and Cloud Research Labs in Bristol, UK; and Eric Viardot of the Business School of Barcelona, Spain.

In addition to selected papers, Kaleidoscope 2015 hosted two invited papers.

The first invited paper – authored by Tai-Won Um of Korea's Electronics and Telecommunications Research Institute (ETRI); Gyu Myoung Lee of the Liverpool John Moores University (LJMU), United Kingdom; and Jun Kyun Choi of the Korea Advanced Institute of Science & Technology (KAIST) – analyzed the concept of trust as it relates to future cyber-physical-social systems, in addition proposing a generic architectural framework for trust provisioning and the associated requirements on supporting standardization work.

The second – authored by Antonio Skarmeta of Spain's University of Murcia – responds to the urgent need to address trust in the context of the Internet of Things (IoT), proposing an integrated design to manage security and privacy concerns through the lifecycle of smart objects. Skarmeta's approach is framed within an ARM-compliant (ARM processors require fewer transistors than typical processors, which reduces costs, heat and power use) security framework intended to promote the design and development of secure, privacy-aware IoT-enabled services.

Jules Verne's corner (JVc) at this year's Kaleidoscope conference asked futurists to forecast the future of data, exploring the new frontiers becoming within reach thanks to advances in data collection and analysis. JVc at Kaleidoscope 2015: *Preparing for the Data Deluge* featured two speakers with 60 years of academic and industry experience between them: Prof. Jun Kyun Choi of Korea's Advanced Institute of Science and Technology, and Prof. Mahmoud Daneshmand of the Stevens Institute of Technology in New Jersey, US.

Thanks to an ITU agreement with IEEE Communications Society, selected papers from each year's Kaleidoscope conference are considered for publication in a special-feature section of *IEEE Communications Magazine*. In addition, special issues of the International Journal of Technology Marketing (IJTMKT), the International Journal of IT Standards and Standardization Research (IJITSR), and the Journal of ICT Standardization are interested in publishing extended versions of Kaleidoscope papers.

All accepted and presented papers are accessible in the IEEE *Xplore* Digital Library. The Conference Proceedings from 2009 onwards can be downloaded free of charge from http://itu-kaleidoscope.org.

In closing, I would like to thank our technical co-sponsors, the Institute of Electrical and Electronics Engineers (IEEE), IEEE Communications Society, and the Institute of Electronics, Information and Communication Engineers of Japan (IEICE); our supportive partners, Waseda University, the Institute of Image Electronics Engineers of Japan (I.I.E.E.J.), the European Academy for Standardization (EURAS), the University of the Basque Country, the Chair of Communication and Distributed Systems at RWTH Aachen University, and the Universidad Politécnica de Cartagena; and, Alessia Magliarditi and her team from ITU for playing the leading role in the year-on-year progression of the Kaleidoscope series. Finally, I would also like to express my gratitude to the two colleagues of UAB who have worked in this event: Remo Suppi from the Department of Operating Systems and Computer Architecture and Pilar Orero from the Department of Translation.

Pilar Dellunde
General Chair

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KEYNOTE SUMMARIES

THE NETWORKED SOCIETY – CHALLENGES AND OPPORTUNITIES

Jan Färjh

Global Head of Standardization and Member of the Technology Leadership Team,
Ericsson, Sweden

The Networked Society introduces many challenges but even more opportunities for our industry. When everyone and everything is connected, the demand on e.g. capacity, coverage, flexibility and quality on the networks will increase as will that on security, data protection and privacy.

The growth of Mobile Broadband and an environment for open innovation will provide systems that can deliver services and applications with high quality to many different industry-segments that will be useful and beneficial.

Global standardization is a key part of the success of current global mobile broadband systems and will also in the coming years play an extremely important role. Instead of fragmentation, convergence and alignment will continue to be instrumental going further when different industries get digitalized and using mobility as a core necessity.

Evolution of technology and society will make the Networked society possible. In many aspects this evolution is positive but it will also open up for possible threats that needs to be handled carefully and in a pro-active way.

In parallel with the evolution of technology, eco-systems and business models more sophisticated threats and attacks will evolve. Networks, devices, applications and data are all part of a chain that will be exposed and need to be secured.

The journey to the Networked Society has started and to continue this journey it is important that people, business and society can trust that our communication networks are secure, reliable and that information carried over the networks are not manipulated or miss-used.

In this talk an overview of what currently is happening in our industry, a vision of the future and some important technical challenges will be presented.

ACCOUNTABILITY IN THE CLOUD

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ABSTRACT

Accountability is a complex notion used across different domains, for which there is no commonly agreed definition. In data protection regulation since the 1980s, accountability has been used in the sense that the 'data controller' is responsible for complying with particular data protection legislation and, in most cases, is required to establish systems and processes which aim at ensuring such compliance. This paper assesses this notion in the context of cloud computing and explains how accountability can be used to help overcome barriers to trust. Furthermore, a description is given of how better and more systematic accountability might be provided.

Keywords— Accountability, cloud computing, data protection, privacy, strong accountability, trust

1. INTRODUCTION

Accepting responsibility, providing accounts and holding to account are central to what is meant by *accountability*. The latter can play an important role in enhancing trust in information society; however, the relationship between the two concepts is complex because in some contexts accountability may be neither a necessary nor a sufficient condition for trust. For example, deployment of certain security or privacy techniques (such as strong encryption with the keys controlled by the user) may engender trust without the need to trust the service provider (although accountability can provide evidence about the usage of such techniques). Conversely, it might be claimed that an accountability-based approach was being adopted, but this could be a smokescreen for weak privacy, perhaps even compounded by collusion in the verification process and the downplaying of data subjects' expectations, wishes and involvement in the service provision. In order to strengthen the link between accountability and trust, we propose a number of trustworthy mechanisms that support accountability, and argue for the notion of *strong accountability*, which encourages ethical characteristics (such as high transparency in balance with other interests) with trustworthy mechanisms for producing and verifying logs and adequate enforcement, in order to provide much stronger grounds for trustworthiness.

The focus of this paper is on accountability for data protection in cloud computing. Some European context is very relevant to note. Since the introduction of the legislative framework for protection of personal data in the European Union (EU) in 1995 [1], there has been a fast pace of technological change. In 2003 this was complemented by the e-privacy Directive [2], which, amongst other things, placed traffic and location data into the category of personal data subject to the regime. Web 2.0 and the rise of social networks shifted the balance of generation of Internet content from service providers to users, and thereby blurred the distinction between the data controller (who determines the means and purposes of processing of personal data) and the data subject (the individual whose data are being processed). Furthermore, over time, metadata is increasingly viewable as personal data, de-anonymisation has been made much easier, storage costs have decreased, the dangers of profiling have become evident, large-scale collection of personal data using opt out mechanisms has been carried out and differences between legislation applying where the data controller and data subject are in different countries could cause difficulties or potential harm to either (particularly in the sense of solutions being either ineffective or difficult to implement). As a result, a major revision of European data protection legislation is currently under discussion, called the General Data Protection Regulation (GDPR), which would introduce uniform requirements in all Member States [3]. This will include a new data protection principle: the principle of accountability. Data controllers will be compelled to adopt policies, organisational and technical measures to ensure and be able to demonstrate compliance with the legal framework. The expected benefits are threefold: to foster trust in personal data management practices of data controllers, to increase visibility of personal data processing activities and to raise data controllers' privacy awareness. Furthermore, the European Commission (EC) is driving a number of initiatives around harmonisation across the member states for cloud [3-7]. These reflect concerns about trust in cloud computing [8], and include standards and mechanisms for interoperability and data portability, security, cloud and compliance. New requirements are coming through for cloud providers, for example with regard to breach notification and cyber incident notification, penalties are increasing and business environments are getting more complex.

The structure of the paper is as follows. The meaning of accountability will be discussed in more detail in Section 2, both in the data protection and other contexts. The relationship between accountability and trust is discussed in Section 3, with particular emphasis on the cloud computing context that will be the focus of this paper, including an

assessment of how accountability might be used to help organisations realise the benefits of cloud computing. Section 4 considers accountability relationships within cloud service provision ecosystems, and the accountability-related roles and responsibilities of the various cloud actors involved. One important aspect is how legal restrictions on processing of personal data mean that it can be very hard to be compliant in cloud service provision ecosystems, even for those companies that put significant effort into this. Section 5 moves on to consider accountability at a number of levels and present a model for accountability that elucidates what is involved in being accountable. In this context some of the work being carried out within the Cloud Accountability Project (A4Cloud) [9] is positioned. Finally, conclusions are given in Section 6.

2. THE CONCEPT OF ACCOUNTABILITY

Accountability is a complex notion for which there is no commonly accepted definition. Furthermore, the understanding of the term is evolving; in the data protection context, this evolution is towards an end to end data stewardship regime in which the enterprise that collects personal and business confidential data is responsible and liable for how the data is shared and used, including onward transfer to and from third parties. In this section an overview is given of the concept, with a focus on data protection but also considering its usage more broadly, and further analysis is provided that is useful to take into consideration especially when considering trust issues.

2.1. Accountability for Data Protection

Accountability (for complying with measures that give effect to practices articulated in given guidelines) has been present in many core frameworks for privacy protection, most notably the Organisation for Economic Cooperation and Development (OECD)'s privacy guidelines (1980) [10], Canada's Personal Information Protection and Electronic Documents Act (2000) [11], and Asia Pacific Economic Cooperation (APEC)'s Privacy Framework (2005) [12]. More recently, governance models are evolving to incorporate accountability and responsible information use, and regulators are increasingly requiring that companies prove they are accountable. In particular, legislative authorities are developing frameworks such as the EU's Binding Corporate Rules (BCRs) [13] and APEC's Cross Border Privacy Rules [14] to try to provide a cohesive and more practical approach to data protection across disparate regulatory systems. Accountability's significance and utility in introducing innovations to the current legal framework in response to globalisation and new technologies is increasingly recognised, including in the current proposals under discussion for the GDPR [3], which build upon the recommendations of the Article 29 Working Party (WP) (for example, [15,16]). In particular, Article 29 WP 173, Opinion 3/2010 on the Principle of Accountability [16] highlights how data protection must move from 'theory to practice' and stresses (i) the need for a data controller to take appropriate and effective measures to implement data protection principles, as well as (ii) the need to demonstrate upon request that appropriate and effective measures have been taken. The data controller therefore needs to provide evidence of (i) above.

2.2. Accountability in Other Domains

Accountability is used in different sectors with a slightly different focus [17,18]. The notion can play an essential role across a range of sectors, including corporate social responsibility, public management and financial services regulation; in these sectors, organisations are expected to act responsibly by considering the impact of their activities towards individuals and society. Furthermore, to be accountable, adequate incentives and structures must be in place to enable traceability of decisions and decision-making processes [19]. In public services environments, there may be different types of accountability mechanisms for different layers of public accountability, but due to the relative lack of sanctions, accountability is often more akin to answerability, or story-telling. Enforcement strategies in the financial sector could be compliance-based (without sanctions) or deterrence-based (with sanctions). Data controllers, policymakers, civil society groups and regulators play complementary roles in fostering cultures of accountability [19].

2.3. Further Analysis of the Concept

From the above, together with an analysis of the usage of the term 'accountability' in different fields [17], we propose the following definition:

Accountability: *State of accepting allocated responsibilities (including usage and onward transfer of data to and from third parties), explaining and demonstrating compliance to stakeholders and remedying any failure to act properly. Responsibilities may be derived from law, social norms, agreements, organisational values and ethical obligations.*

Thus, accountability relationships reflect legal and business obligations, and also can encompass ethical attitudes of the parties involved. Our analysis actually combines and extends two aspects, based upon ideas coming from the social sciences [20, 43] such that both commitment and enforcement are involved in accountability. Thus, the concept of accountability includes a normative aspect, whereby behaving in a responsible manner is perceived as a desirable quality and laid down in norms for the behaviour and conduct of actors. This can be applied to steer accountable behaviour of actors *ex ante*. We extend the type of approach developed for public actors to private actors, including cloud service providers and organisational cloud customers. Accountability also encompasses institutional mechanisms in which an actor can be held to account by a forum, that involve an obligation to explain and justify conduct and ensure the possibility of giving account *ex post facto* (via accountability tools). We broaden the notion of a forum to that of an accountee in a service provision chain, as explained further in Section 4. Commitment from organisations is needed for the first part. Regulators would typically need strong enforcement powers for the second

part, to encourage organisations to adopt business models aligning with the first part.

Accountability complements privacy and security, rather than replacing them. As shown in Figure 1, organisations operate under many norms, reflecting obligations and stakeholder expectations.

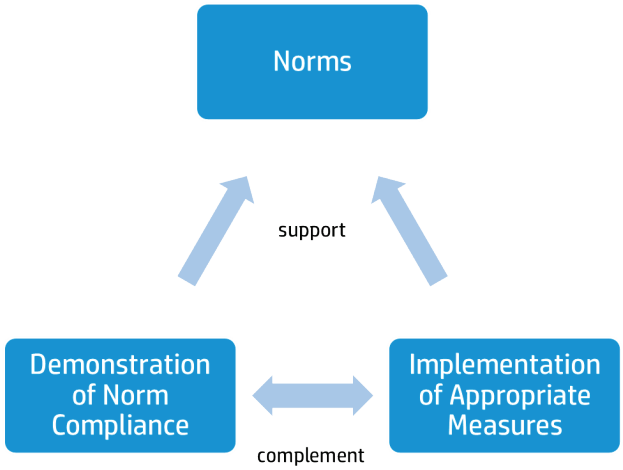

Fig. 1. Context

These can be societal, regulatory or contractual in nature. They need to implement appropriate measures to comply with these norms and manage risks, and this information stewardship should involve privacy by design, adopting appropriate security controls and planning for remediation. So for example, accountability does not itself directly address generic data confidentiality requirements, other than providing information about mechanisms used or helping deal with data breaches; for that, targetted security and privacy mechanisms (namely encryption and anonymisation technologies) are needed. In addition, a central part of accountability that increases transparency is to demonstrate how the norms are met and risks managed. This risk assessment should include not only the standard organisational security risk assessment but also an assessment of the potential harm to data subjects. It is possible indeed to incorporate the latter into the former [21] or carry out a separate Privacy Impact Assessment (PIA) or Data Protection Impact Assessment (DPIA).

In Section 4 we consider how this approach may be applied more specifically to the cloud context. First, we consider how accountability can, in certain circumstances, lead to increased trust.

3. THE RELATIONSHIP BETWEEN ACCOUNTABILITY AND TRUST

As mentioned in the introduction, the relationship between accountability and trust can be complex. In this section we will consider this in more detail. In particular, by enhancing accountability (including improved gathering and consideration of evidence relating to organisational practices, including at the operational level), an improved basis for trustworthiness can be created.

It could be argued that if technologies were deployed where the trust model involves minimal trust in service providers and other associated actors – that is to say, if a combination of privacy enhancing techniques and encryption were used – there would be no need for accountability, and accountability is only needed to fill the gap where some trust in the service provider is needed. However, there is a paucity of such 'minimal trust' cases occurring in practice and indeed potential for re-anonymisation using additional information and meta-information even in such cases, thus creating a role for accountability.

Trust and trustworthiness (related but conceptually different concepts [22]) are concerned with making decisions (in particular contexts or situations) and exhibiting behaviour. The relationship between risk and trust has been considered (in particular, from the social and policy perspectives) to underpin the governance of privacy [23]. Both risk (management) and trust (promotion) provide alternative viewpoints of analysis. Having recognised that "the problem of privacy is socially and politically constructed" [23], it is necessary to balance objective evidence with subjective perceptions while dealing with policy governance. Objective evidence is derived from mechanisms that can be implemented and monitored in the cloud. For instance, the work in [24] provides an example of a mechanism that may be implemented by service providers and used by their customers in order to gather objective evidence and obtain assurance about running services (e.g. assurance that the services comply with relevant national jurisdictions). Other similar mechanisms can be utilised to provide further transparency (which as explained in Section 5 is part of accountability) to service users.

Approaches promoting transparency (of information) would support "*better understanding of exposures to privacy dangers, the distribution of risks, and the patterning of trusting [that] may be worth seeking*" [23]. In this respect, accountability (as promoting transparency) is critical for supporting governance of privacy, data protection and security [25].

Trust is an important factor that has a close relationship with accountability, as for example a good accountability deployment into an organisation might increase its trustworthiness for potential clients. Trust has traditionally also been related to security, although trustworthiness is a much broader notion than security as it includes subjective criteria and experience, among other factors. For an organisation to be trusted, it should demonstrate accountable behaviour; defining governance, ensuring the implementation of trusted services, taking responsibility, remedying any failure, and being able to show justification of any action taken. Correspondingly, there exist both hard trust solutions (i.e. security-oriented trust focused on the degree to which a target object is considered secure e.g. credential-based authentication) and soft trust solutions (i.e. non-security oriented trust defined in terms of belief and behaviour and related to interaction records and reputation systems, for example, web of trust [26]).

Verification is needed to encourage trust within an environment of market compliance. Trust issues will arise if levels of verification are perceived to be low [27].

We now focus our discussion more specifically on the case of cloud computing. There can be a trust issue, due to uneasiness by potential cloud customers (and other involved parties) about switching from non-cloud to cloud environments.

Although cloud computing can bring many benefits for different parties, including for example decreased initial capital expenditure for cloud users and increased capacity for handling spikes in business demand, it can also bring new risks and vulnerabilities [28-30]. These increased risks are largely due to de-localisation and subprocessing (which of course may also happen in non-cloud environments), and there can be resultant worries from potential cloud users about lack of control and transparency, as well as about confidentiality [8]. As a result, organisations may be reluctant to let data flow outside their boundaries into the cloud, especially for public cloud, and are especially concerned in cloud environments with data breaches and data loss [31]. Issues include not only lack of consumer trust but also weak trust relationships between cloud actors and lack of consensus about trust management approaches to be used [30].

However, the perceptions of risk by organisations change over time: based on analysis carried out within different versions of the Cloud Security Alliance (CSA) top threats reports [31,32], there have been significant changes in ordering, including data breaches moving from fifth to the overall top threat between 2010 and 2013, and introduction of new threats, such as denial of service, which moved to be the fifth highest listed in 2013. And since then, fears about surveillance by foreign governments have had a big effect on customers' fears, making this issue rise up the list [33]. This was triggered by the Snowden revelations, including that the United States (US) National Security Agency (NSA) ran a surveillance programme known as PRISM, which collected information directly from the servers of big technology companies such as Microsoft, Google and Facebook [34].

3.1. Potential Provision of Increased Trustworthiness

As mentioned in the introduction, one of the main aims of the principle of accountability in the GDPR was to foster trust in personal data management practices of data controllers. Moreover, many of the requirements that need to be addressed in cloud environments are non-functional, as can be seen in Figure 2, which shows the top ranking of key actions to improve cloud adoption by business users, based on information from a recent International Data Corporation (IDC) report [35]. 80% of respondents nominated accountability, portability, connection or security certification within the top three proposed actions. Accountability was seen in this survey as the most important action of all to help improve cloud adoption [35].

3.2. Potential Provision of a False Basis for Trust

It is important to acknowledge however that accountability will not necessarily increase trust, or might support a false basis for trust (for example, in the case of collusion). People can worry for example about 'privacy whitewashing', whereby apparent accountability encourages a false basis for trust in data controllers by data subjects.

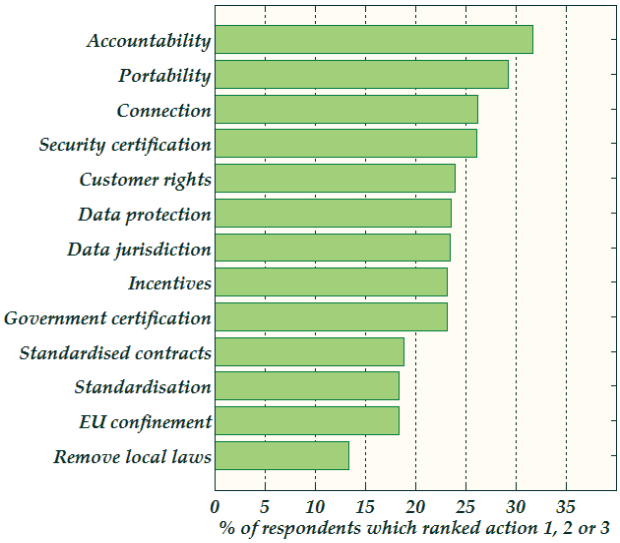

Fig. 2. Business Users' Ranking of Key Actions to Improve Cloud Adoption (based on data obtained from [35])

More specifically, an objection to accountability is that it could be a means to produce harmful effects for society [36]: Big Data and Accountability can be regarded as two cycles of policy manoeuvre to try to accomplish the abolition of purpose limitation in pseudonymous data. This objection relates to the effects on both individual and society of a transition to continuous and ubiquitous data collection. Irrespective of the rules or algorithms governing how that data is used, this obviously would have legal effects on universal privacy rights such as the EC Human Rights Act Article 7, as well as a general "panoptic" effect of knowing that a record of individual behaviour exists inescapably. This is an entirely different social, political, and phenomenological situation that is incomparable with life without such (involuntary) life-logging.

Even if this wider context is ignored or disputed, other routes to potential harm to society, and data subjects, may be considered. The trustworthiness of the process of verification of accounts produced *ex post facto* by that actor, and any associated remediation and penalties, are extremely important in affecting the strength of the accountability that evolves within a system. Moreover, there is a danger that individuals' viewpoints might be overlooked and their choice and control reduced [18].

Strong Accountability

To address these issues, we argue that an accountability-based approach should have the following characteristics:

- **Supporting externally agreed data protection approach:** Accountability should be viewed as a means to an end (i.e. that organisations should be accountable for the personal and confidential information that they collect, store, process and disseminate), not as an alternative to reframing basic privacy principles or legal requirements. Thus, the accountability elements in the GDPR provide a certain assurance of compliance with the data protection principles, but do not replace them.

- **Clarity and acceptance of responsibility:**, Organisations must clearly allocate privacy and security responsibilities across service provision chains (e.g. between cloud service provision actors)
- **Transparency:** this should be increased, in ways that do not decrease privacy or security. This includes the nature of accounts being public where possible, and the need for the commitments of the data controller to be properly understood by the data subjects (and other parties). Cloud computing not only affects customers and end users, but society at large. Transparency should therefore also be aimed at the general public and the regulator. This contributes to the maintenance of ethical standards, rather than stimulating a race to the bottom (of cost and privacy protection).
- **Trust in the verification process:** Accounts must be adequately verified. This requires sufficient resource, expertise and penalties in the external enforcement process. Collusion between the accountor, its partners and the accountee must be prevented, and trustworthy evidence needs to be produced. There needs to be a strong enough verification process to show the extent to which commitments have been fulfilled. Missing evidence can pose a problem, and guarantees are needed about the integrity and authenticity of evidence supporting verification. In addition, the actor carrying out the verification checks needs to be trusted by the data subject and to have the appropriate authority and resources to carry out spot checking and other ways of asking organisations to demonstrate compliance with regulatory and contractual obligation by providing accounts that may take various forms (e.g. certificates, seals and audit reports). This is why the data protection authorities will need to play a key role in the trust verification, for example in data protection certification. In terms of external governance mechanisms, strong enforcement strategies, not only in terms of verification, but also in terms of increasing the likelihood of detection of unlawful practices and strong penalties if caught, seem to be a necessary part of accountability. Data protection impact assessments, codes of conduct and certifications are proposed to increase trust in cloud providers who adhere to them. It is thus of the utmost importance that regulatory and supervisory bodies have a primary role in the verification of the level of compliance of these tools. Furthermore, to give data subjects back some control it would be another level of interaction if the data subjects' comments and needs receive a response and ideally even show some fundamental development in the application or organisational data processing. This form of feedback to the data subjects (in response to their feedback) is another form of verification.
- **Avoidance of increased risk:** Technical security measures (such as open strong cryptography involving secure logging techniques such as hash chains) can help prevent falsification of logs, and privacy-enhancing techniques and adequate access control should be used to protect personal information in logs. Note however that data that is collected for accountability might be itself data that can be abused and hence also needs to be protected. The potential conflict of accountability with privacy is somewhat reduced as the focus in data protection is not on the accountability of data subjects but rather of data controllers, which need to be accountable towards data subjects and trusted "intermediaries".
- **Avoidance of increased burden:** Accountability must deliver effective solutions whilst avoiding where possible overly prescriptive or burdensome requirements.
- **Avoidance of social harm:** Accountability should have democratic and ethical characteristics. Transparency should be as high as possible, in balance with other interests (as considered above while describing transparency). Mechanisms should also be developed to help regulators do their job, notably with respect to enhancement of the verification process as discussed above.

The term 'strong accountability' was recently been proposed by Butin and co-authors [37] to describe a similar approach in which the effectiveness of the processing of personal data can be overseen (stressing a distinction between 'reporting' and 'demonstrating'). This is supported by precise binding commitments enshrined in law and involves regular audits by independent entities. The proposers assert that this should not be contradictory with the need for flexibility that is required by the industry.

Thus, accountability should complement the usage of appropriate privacy and security controls in order to support democratically determined principles that reflect societal norms, regulations and stakeholder expectations. Governance and oversight of this process is achieved via a combination of Data Protection Authorities, auditors and Data Protection Officers within organisations, the latter potentially supplemented by private accountability agents acting on their behalf.

Although organisations can select from a variety of mechanisms and tools in order to meet their context, the choice of such tools needs to be justified to external parties. A strong accountability approach would include moving beyond accountability of policies and procedures, to accountability of practice giving accountability evidence. Accountability evidence can be defined as "*a collection of data, metadata, routine information, and formal operations performed on data and metadata, which provide attributable and verifiable account of the fulfilment (or not) of relevant obligations; it can be used to support an argument on the validity of claims about appropriate functioning of an observable system*." [38].

Accountability evidence needs to be provided at a number of layers. At the organisational policies level, this would involve provision of evidence that the policies are appropriate for the context, which is typically what is done when privacy seals are issued. But this alone is rather weak; in addition, evidence can be provided about the measures, mechanisms and controls that are deployed and their configuration, to show that these are appropriate for the context. For example, evidence could be provided that Privacy Enhancing Technologies (PETs) have been used to support anonymisation requirements expressed at the policy level. For higher risk situations continuous monitoring may be needed to provide evidence that what is claimed in the policies is actually being met in practice; even if this is not sophisticated, some form of checking the operational running and feeding this back into the accountability management program in order to improve it is part of accountability practice, as described above, and hence evidence will need to be generated at this level too. In particular, technical measures should be deployed to enhance the integrity and authenticity of logs, and there should be enhanced reasoning about how these logs show whether or not data protection obligations have been fulfilled. The evidence from the above would be reflected in the account, and would serve as a basis for verification and certification by independent, trusted entities. The actual assessment of the effectiveness of the IT controls is performed during the service's operation.

Different kinds of evidence need to be provided during the accountability lifecycle: in an initial phase of provisioning for accountability, assurance (based for example on assessment of capabilities) needs to be provided about the appropriateness and effectiveness of the cloud service providers under consideration; from an operational perspective, there needs to be both internal and external demonstration (to relevant stakeholders) that the organisation is operating in an accountable manner (for example, built on monitoring evidence and via accounts); external parties will be involved in audit and validation based on information made available to them. A connection between appropriateness and effectiveness can be made through the agreed service level agreement, which will contain committed security and privacy values relating to each metric selected [39].

4. ACCOUNTABILITY RELATIONSHIPS IN THE CLOUD

In this section we consider how accountability notions may be applied to the cloud context, and how this can affect trust in cloud computing. The National Institute of Standards and Technology (NIST) defines cloud computing as being "*a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction*" [40]. The service models defined by NIST are: *Software as a Service (SaaS),* where consumers use cloud service providers' (CSPs') applications running on a cloud infrastructure; *Platform as a Service (PaaS),* where consumers deploy (onto a cloud infrastructure run by a CSP) applications that have been created using programming languages and tools supported by that provider; *Infrastructure as a Service (IaaS),* where consumers deploy and run software, with a CSP controlling the underlying cloud infrastructure. Deployment models encompass private, community, public and hybrid clouds [40]. The combination of such cloud computing features enables different business models, and hence different types of cloud ecosystem.

A *cloud ecosystem* is a business ecosystem of interacting organisations and individuals − the actors of the cloud ecosystem – who provide and consume cloud services. These actors are controlled not only by internal factors of the system, such as codes of conduct and existing relations, but also by external factors such as regulations, the wider environment or even required skills. Within cloud ecosystems accountability is becoming an important (new) notion, defining the relations between various stakeholders and their behaviour towards data in the cloud.

Our approach is towards further operationalisation of the way accountability should be embedded in the cloud ecosystem's norms, practices and supporting mechanisms and tools. First, we steer accountability behaviour of cloud actors including cloud service providers *ex ante*. Second, we allow for a mechanism that entails the social relation between the accountor and accountee that involves an obligation to explain and justify conduct and ensures the possibility of giving account *ex post facto* (via accountability tools).

Our model is that an *accountor* is accountable to an *accountee* for:

- **Norms**: the obligations and permissions that define data practices; these can be expressed in policies and they derive from legislation, contracts and ethics.
- **Behaviour**: the actual data processing behaviour of an organisation.
- **Compliance**: entails the comparison of an organisation's actual behaviour with the norms.

Hence, accountability is broader than (but also includes) norm compliance. By the accountor exposing the norms it subscribes to and the things it actually does, an external agent can check compliance.

Typically in a cloud ecosystem in a data protection context, the accountors are cloud actors that are organisations (or individuals with certain responsibilities within those) acting as a data steward for other actors' personal data or business secrets. The accountees are other cloud actors, that may include private accountability agents, consumer organisations, the public at large and entities involved in governance. The respective responsibility of cloud customers and cloud providers will need to be defined in contracts and the definition of standard clauses by the industry, as validated by regulators, will help cloud customers with lower negotiation capabilities. The commitments of the data controller should include all

applicable legal obligations, together with any industry standards (forming part of the external criteria against which the organisation's policies are defined) and any other commitment made by the data controller.

4.1. Cloud Accountability Roles

There is a need to describe scenarios in terms of actors endorsing roles in a cloud provisioning ecosystem from an accountability-based perspective, using neutral terminology applicable both to data protection and business confidentiality domains. In the A4Cloud project, we created the following cloud accountability taxonomy composed of seven main roles:

1. **Cloud Subject:** An entity whose data are processed[1] by a cloud provider, either directly or indirectly. When necessary we may further distinguish between:
    a. Individual Cloud Subject, when the entity refers to a person.
    b. Organisational Cloud Subject, when the entity refers to an organisation.
2. **Cloud Customer:** An entity that (a) maintains a business relationship with, and (b) uses services from a Cloud provider. When necessary we may further distinguish:
    a. Individual Cloud Customer, when the entity refers to a person.
    b. Organisational Cloud Customer, when the entity refers to an organisation.
3. **Cloud Provider:** An entity responsible for making a (cloud) service available to Cloud Customers
4. **Cloud Carrier:** The intermediary entity that provides connectivity and transport of cloud services between Cloud Providers and Cloud Customers.
5. **Cloud Broker:** An entity that manages the use, performance and delivery of cloud services, and negotiates relationships between Cloud Providers and Cloud Customers.
6. **Cloud Auditor:** An entity that can conduct independent assessment of cloud services, information system operations, performance and security of the cloud implementation, with regards to a set of requirements, which may include security, data protection, information system management, regulations and ethics.
7. **Cloud Supervisory Authority:** An entity that oversees and enforces application of a set of rules.

We chose to extend the commonly adopted cloud supply chain taxonomy defined by NIST [41] because this has shortcomings in that parties that may be affected, own or be identified via data – and indeed the relevant supervisory authorities for a particular regulatory domain – are not adequately reflected in this taxonomy. Hence, in particular, we amended that taxonomy by adding the cloud subject and cloud supervisory authority as distinct actors. For example, Data Protection Authorities (DPAs) and telecom regulators (NRAs) have the distinct characteristic of holding enforcement powers. The proposed GPDR [3] also provides for a European Data Protection Board. In some cases, in order to facilitate the discussion, we found it useful to further distinguish both cloud subjects and cloud customers as individuals or organisations.

Furthermore, some actors may endorse more than one role. For example, in the original NIST model, cloud customers may also act as cloud providers. This is also true in our taxonomy where additionally cloud subjects may act as cloud customers, and the supervisory entity may act also as an auditor in some situations. Note that the original definition of cloud auditor proposed by NIST was altered to better encompass the scope of the A4Cloud project, which not only encompasses security but also compliance.

Table 1: Cloud Actor Roles

Extended NIST Cloud Roles	Data Protection Roles
Cloud subject	Data subject
Cloud customer	Data controller
Cloud provider	Data processor or joint controller
Cloud supervisory authority	Supervisory authority

The accountability relationships between actors in a cloud ecosystem depend upon the data protection roles (and indeed, other regulatory roles) that those entities take in a given scenario. Typical options showing data protection roles that entities may take (in scenarios where personal information is processed) are shown in Table 1.

To understand the table, at this point it is useful to explain some terminology commonly used in data protection. According to the current European data protection directive [1], a data controller (DC) essentially determines the purposes for which and the manner in which personal data is processed. A data processor (DP) processes personal data upon the instructions of the data controller. The data subject is the living person that can be identified by personal data, and the data protection authority (DPA) is the supervisory body. In other regulatory contexts, different roles may apply to entities, such as data owner, in a similar manner.

In the cloud context, cloud subjects may be data subjects, cloud customers and cloud providers would be Data Controllers (DCs) or Data Processors (DPs), and cloud carriers and cloud brokers (and indeed other cloud providers along the service provision chain) may be DPs, or possibly DCs or else fall outside the controller/processor distinction, depending upon their function. The organisational cloud customer (which is a business or a legal person) is in general considered to be the DC and is regulated by the DPA. Even though in most cases cloud customers are not in a position to negotiate with cloud providers, they may still choose amongst offerings and hence are still considered a DC [8]. An individual cloud customer (who is a natural person) is likely to be considered

[1] Where processed means "*any operation or set of operations which is performed upon data*", "*such as collection, recording, organisation, storage, adaptation or alteration, retrieval, consultation, use, disclosure by transmission, dissemination or otherwise making available, alignment or combination, blocking, erasure or destruction*". (Inspired from article 2 of Directive 95/46).

to be a data subject, although there are situations where they would be considered as a DC, for example where they use a cloud service for professional purposes involving processing data of other data subjects. Cloud providers are nearly always a DP but could be a DC (or even neither, in the case of cloud providers down the chain of service provision). They may need to assume co-controllership responsibilities, but may not know who the users are or what their services are being used for. If they process personal data which is not provided by a cloud customer, acting autonomously to define the means and the purpose of the processing, the cloud provider is a DC. On the other hand, the cloud provider is a DP if it processes personal data to provide a service requested by a cloud customer and does not further process the data for its own purposes. There are also cases where the cloud provider can be a joint DC, namely when it processes data to provide a service requested by a cloud customer but in addition further processes the data for its own purposes (e.g. advertising). In the proposed GDPR, DPs who process data beyond the DC's instructions would be considered as a joint DC, and this case might include changing security measures or data handling practices. However, cloud providers would prefer to be considered to be a DP rather than a joint DC. In general, the exact role of cloud brokers and cloud carriers in processing is not clear and they could both be considered as DPs or even third parties.

Every party of the cloud service is called to be accountable to other parties. There are different obligations according to the roles that apply in a given scenario, contractual agreements and promises made. The DC (normally the organisational cloud customer) is accountable for applicable data protection measures. The cloud service providers as DPs must provide security measures and be accountable to the DC, and their responsibilities in that regard will vary according to the combination of cloud service and deployment models, and be reflected in legal agreements. For example, in public cloud, there is a multi-tenant environment in which there is limited flexibility to customise the terms of the agreement with any specific customer, although customised changes may still be possible that do not affect how the public cloud operates or how the public cloud services are rendered. The cloud provider will still be accountable to the customer (DC) and will act on the DC's instructions, but for the interests of all consumers of cloud services on that public cloud, there are limits to customisation as mentioned above. There is also the possibility that physical media may have to be made accessible to authorised third parties in certain situations to access content (e.g. subpoena), thereby potentially compromising co-tenants' information.

In all cases it is important that privacy and security responsibilities are clearly allocated across the cloud service provision chain (for example, to avoid a loss of governance), and in addition the ramifications of incidents due to those actors can have legal, business and social consequences for other entities along the chain (notably, data controllers and data subjects). For more background about legal aspects of cloud computing see [42].

5. A MODEL OF ACCOUNTABILITY IN THE CLOUD

It is necessary to operationalise the way accountability should be embedded in the cloud ecosystem's norms, practices and supporting mechanisms and tools. In this section we present a model of accountability that explains how this can be done.

Our model (illustrated in Figure 3) describes accountability at different levels of abstraction. The top level is the definition of accountability in the cloud already given. Moving down the model in terms of becoming less abstract, the other layers correspond in turn to the following aspects, which will be considered in further detail below.

1. *Accountability attributes:* the central conceptual components of accountability, shown in Table 2.
2. *Accountability practices*: these define the central behaviour of an organisation adopting an accountability-based approach.
3. *Accountability mechanisms and tools*: these offer enhanced accountability, in the sense that they support the attributes and practices. They may form part of a selection of services from which organisations can choose as appropriate, be (extensions of) existing business processes like auditing, risk assessment and the provision of a trustworthy account, or be non-technical procedures such as certain forms of remediation.

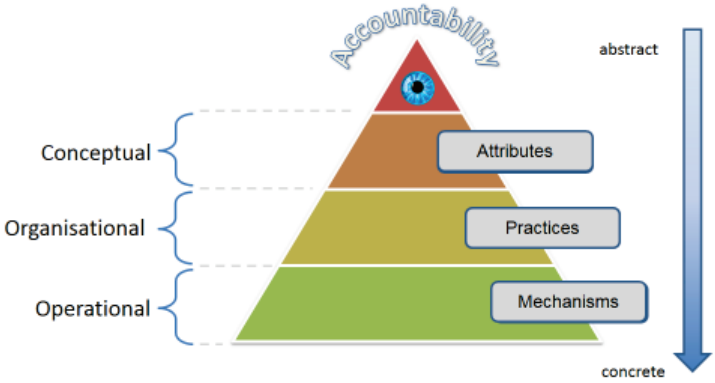

Fig. 3: Model of Accountability

We now consider these further in turn.

5.1. Accountability Attributes

Accountability attributes capture concepts that are strongly related to and support the principle of accountability. We propose a number of attributes, coming from our analysis at the topmost layer, i.e. from our definition and related literature. The core (key) attributes are: transparency, responsiveness, responsibility and remediability. In addition, as we shall see, verifiability is a key property of an object of accountability, and accountability indicators about the measures used by an organisation include the key attributes of appropriateness and effectiveness. Definitions are given in Table 2, and further analysis about attributes that we consider to be of secondary relevance, in the sense that they are not necessary elements of accountability or have a strongly overlapping meaning to a key attribute, can be found in [43].

With respect to transparency, a distinction can be made between *ex ante* transparency, which is concerned with "*the anticipation of consequences before data is actually disclosed (e.g. in the form of a certain behaviour)*" [44] and *ex post* transparency, which is concerned with informing "*about consequences if data already has been revealed*" [44]. Being transparent is required not only with respect to the identified objects of the cloud ecosystem (i.e. norms, behaviour and compliance) but also with respect to remediation.

Table 2: Attributes of Accountability

Core Attributes	
Transparency	The property of a system, organisation or individual of demonstrating and/or providing visibility of its governing norms, behavior and compliance of behavior to the norms
Responsiveness	The property of a system, organisation or individual to take into account input from external stakeholders and respond to queries of those stakeholders
Responsibility	The property of an organisation of individual in relation to an object, process or system of being assigned to take action to be in compliance with the norms
Remediability	The property of a system, organisation or individual to take corrective action and/or provide a remedy for any party harmed in case of failure to comply with its governing norms
Attributes of Accountability Objects	
Verifiability	The extent to which it is possible to assess norm compliance
Accountability Indicators	
Appropriateness	The extent to which the technical and organisational measures used have the capability of contributing to accountability
Effectiveness	The extent to which the technical and organisational measures used actually contribute to accountability

5.2. Accountability Practices

An accountable organisation should:

- Demonstrate willingness and capacity to be responsible and answerable for its data practices.
- Define policies regarding its data practices. The policies should incorporate relevant external norms, such as requirements derived from data protection regulation.
- Monitor its data practices.
- Correct policy violations.
- Demonstrate compliance to the cloud ecosystem's norms.

This characterisation aligns well with the outcomes of the CIPL Galway and Paris projects [45] and the recommendations of the Canadian privacy commissioners [46]. Similarly, the revised OECD privacy guidelines [47] state that a data controller should comply with three obligations to run a privacy management programme, demonstrate its effectiveness and provide data breach notification to DPAs and individuals.

In article 22 of the GDPR [1], the data controller is given the responsibility to ensure and demonstrate compliance, and to verify effectiveness of the implemented accountability measures. Such accountability mechanisms centre on an obligation for documentation (article 28), an obligation of security (article 30), carrying out a data protection impact assessment where applicable (article 33), appointment of an impartial data protection officer (article 35) and, where required, obtaining an authorising action from a DPA prior to processing operations (article 34). For further analysis about accountability obligations within the GDPR, see [48].

Moving away from a checkbox mentality for compliance is part of the way that organisations should be proactive in terms of what they do for data protection, as part of an accountability based approach. They need to ensure that they take appropriate and effective measures, and this might require some analysis to determine what would work best in their context. This is part of what we called an 'intelligent accountability' approach, involving risk assessment and also reflected within a maturity model that can help organisations understand how to become more accountable.

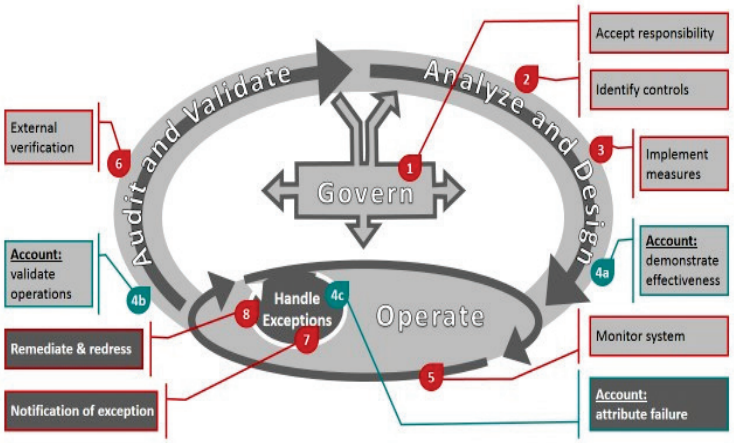

Fig. 4: Functional Elements of Accountability in an Organisational Lifecycle

Figure 4 shows how the functional elements of accountability are triggered at different phases of an organisation's operational security lifecycle, and how some of these (namely attribution of failure, notification and remediation) are triggered within exception loops corresponding in this case to non-satisfaction of obligations, for example by a data breach. It can be seen how there is involvement both of proactive elements (clarification and acceptance of responsibility, determination and implementation of appropriate measures and preparation of a demonstration that these meet the obligations involved for when it might be needed), as well as reactive elements

(corresponding to detection and handling of data breaches or other non-satisfaction of obligations).

5.3. Accountability Mechanisms and Tools

Accountability mechanisms are instances of tools and techniques supporting accountability practices. Organisations can adopt different available mechanisms as appropriate for their contexts. They will use what suits their particular processes best, demonstrating that the appropriate mechanisms have been selected. Accountability mechanisms focus on the core aspects of accountability (e.g. remediation, notification and risk assessment) and as discussed above are expected to be used in conjunction with separate privacy and security mechanisms.

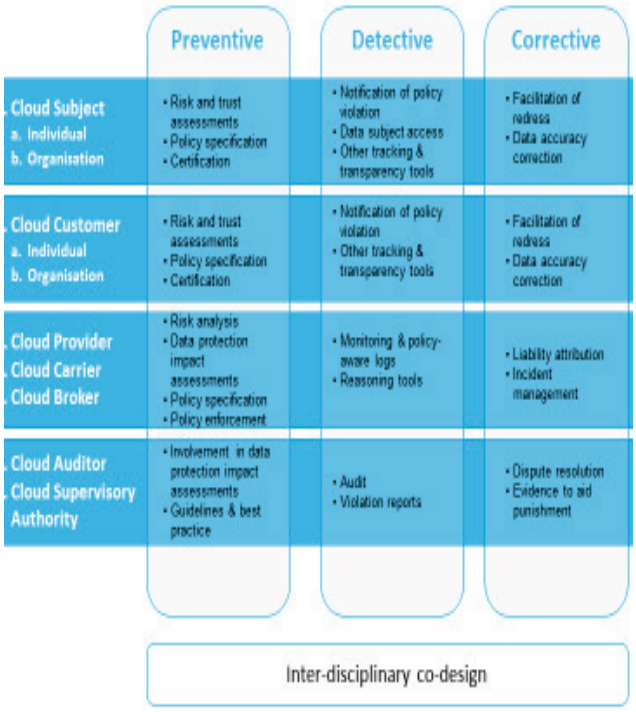

Fig. 5: Accountability Framework

A combination of legal requirements, governance mechanisms and technical measures can be used to enable chains of accountability to be built along cloud service provision chains. The aim in particular is to strengthen the accountability of organisations that use and provide cloud services to data subjects and regulators. Accountability promotes implementation of practical mechanisms whereby legal requirements and guidance are translated into effective protection for data. Legislation and policies tend to apply at the data level, but the mechanisms can exist at various levels, including the system and data level. Our approach is the provision of a hybrid accountability mechanism via a combination of policies, regulatory and technical means. It is a co-regulation strategy based on a corporate responsibility model underpinned primarily by contract. This approach places the onus upon the DC to take a more proactive approach to ensuring compliance, and encourages cloud service vendors and subcontractors to compete in providing services on the basis of evolving better privacy and security enhancing mechanisms and processes.

Figure 5 illustrates different functional aspects of accountability, with examples of corresponding mechanisms that can be used by different types of user (shown in the rows):

- **Preventive** – investigating and mitigating risk in order to form policies and determine appropriate mechanisms to put in place; putting in place appropriate policies, procedures and technical mechanisms
- **Detective** – monitoring and identifying policy violation; putting in place detection and traceability measures, and
- **Corrective** – managing incidents and providing notifications and redress.

These mechanisms might be procedural and human-based, or might encompass tools that organisations build, products and services that they use and tools that they extend and customise. In particular, technology has a role to play in enhancing the accountability of data controllers (although achieving meaningful accountability in practice is not an easy task and requires the right enforcement strategies).

The A4Cloud project has been developing a set of tools enabling an accountability based-approach [50]; these can work independently or together, but do not comprehensively cover the possible space. For example, at the enforcement level of the privacy policies lifecycle, A4Cloud has designed and developed an engine called the A-PPLE engine. This engine has been specifically designed to put in effect policies while also producing the evidence needed to assess the compliance of the actions performed. A-PPLE is able to process and enforce policies specified through the policy language denoted as A-PPL. Other tools include a data protection assessment tool, a cloud brokerage took focusing on the degree of accountability and privacy offered, a data track tool that facilitates transparency, continuous monitoring by system plug-ins that monitor changes in the system in relation to selected policies) and an incident response tools for reporting non-compliance and incidents to relevant stakeholders.

The project aims to support the current attempts to create a unified European data protection legal framework via technical and legal mechanisms, by enabling actors to operate effectively and to enable them to be accountable by a number of means, in the context of the GDPR. The aim is to ease accountability for cloud providers through technical support and automation, enable users to enforce and control vendors' accountability and improve best practice. Since accountability goes beyond technical tools, guidelines are also produced because Cloud customers (especially SMEs), end users and cloud service providers need to be educated what responsible stewardship of data means and how this can be accomplished.

We have also produced a reference architecture [49] that describes functional elements of accountability, accountability artifacts exchanged between actors and cloud-based accountability support services.

6. CONCLUSIONS

In this paper it has been explained how strong accountability can contribute to supporting the development of trustworthy information infrastructures, especially within cloud computing, and how this relates to other complementary data protection mechanisms.

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THE ROLE OF TRUST AND STANDARDIZATION IN THE ADOPTION OF INNOVATION

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ABSTRACT

In this presentation, we analyze the role of trust and standardization in the adoption of innovation. After recalling the importance of the adoption phase in the innovation management process, we make a detailed examination of three different categories of innovation adopters: the early adopters, the early majority of mainstream adopters and the late majority of mainstream adopters. Then we define the role of trust with three main components: integrity, credibility and benevolence; we contemplate the association of trust with the two main categories of risks, the internal risks and the transactional risks and we study the importance of trust in the different stages of the acceptance of innovation. Finally, we discuss the association between standardization and trust and their role in the adoption of innovation.

One originality of this presentation is a justification for the needs for dynamic standards along the innovation lifecycle from a user perspective instead of a technology viewpoint. A second original element is the discussion of the importance of the standardization of risks in order to foster trust in an innovation. There is a significant effort to standardize the risks associated with the lack of expertise from a supplier. But regarding the standardization of the risks associated to the lack of benevolence, there is still room for future development for both researchers and practitioners.

Keywords- adoption of innovation, truth, standardization, demand side innovation, innovation adopters.

1. INTRODUCTION

Innovation and standardization are two facets of economic vitality and industry competitiveness. In networked technologies and services, standards are essential for manufacturers and service providers. In other sectors, standards are needed for the protection of consumer interests, governing commercial activities in public and ethical domains (e.g. natural resources, communications, security, advertising, entertainment) but also the control of new technologies (and their impact on health, safety, environmental and social factors).

Innovation is about creativity, and standardization is about uniformity. Hence innovation has often been perceived to be at loggerheads with standardization. But they may complement each other as standardization is also a powerful way to enforce trust in a solution. And trust is an essential factor to drive the market acceptance of an innovation, more than ever.

Indeed, according to a recent survey more than half of the global informed public believe that the pace of development and change in business today is too fast, that business innovation is driven by greed and money rather than a desire to improve people's lives and that there is not enough government regulation in many industry sectors [1]. In the same survey, 69% of the people trust electronics and mobile payment and 59% have confidence in personal health trackers but only 55% trust cloud computing, while only 47% believe in Hydraulic fracturing and 32% rely on genetically modified foods.

In this perspective, I am going to discuss the relationship between Innovation, Standardization, and Trust, because trust plays a fundamental role in the acceptance of innovation, which is getting increasingly important in Innovation Management [2].

So, I will first comment on the recent focus on the adoption of innovation within the Innovation process. Secondly I will consider how trust is a decisive element to facilitate the adoption of innovation. In a third part, I will reflect on the role of standardization in the acceptation of innovation.

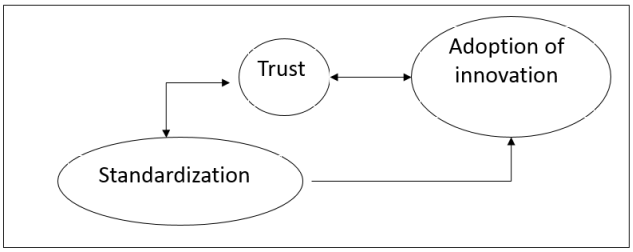

Figure 1. The relationship between Innovation, Standardization, and Trust

2. ADOPTION OF INNOVATION IS BECOMING A PRIORITY

For the last 5 years at least, innovation has been one of the top priorities for companies' executives and chief marketing officers [3] as well as an important topic in management research (see for instance [4]). However, the focus of both practitioners and academics has been mostly on how to connect with external stakeholders in order to find new sources of ideas, developing prototypes faster or more simply, and finding new business models.

Concepts such as "open innovation ", "networked innovation", "design innovation", or "lean innovation" for example have emerged and are now mainstream in the academic literature about innovation management. At the same time, some companies have shown an extraordinary ability to open their innovation process to external partners—suppliers, distributors, customers, even individual volunteers or members of social communities.

In other words, the emphasis was on the upstream activities of the innovation management process and specifically on how to obtain as well as to integrate new sources of innovation beyond the traditional and internal R&D function. One reason is that upfront creative idea generation processes are more fun and satisfying than the downstream commercialization processes which are hard work and discipline.

Conversely, the adoption of innovation by the market with the downstream activities of the innovation process, specifically marketing and commercialization, has attracted little research. For example, customers were considered mostly as an additional source of innovation among others, through the interaction process of co-creation, more than a key component of the commercialization of innovation.

But this situation is changing now. Indeed, companies and governments have realized that they have probably been focusing on the wrong priority as a large percentage of innovations are still failing to be successful in the market and to be profitable [5].

It is not enough to have good new ideas: first and foremost, an innovation must be adopted by the market. Without market success, it is just a useless invention whose failure will dent the profitability of the company which is selling it or may even lead it to bankruptcy. And at the same time, employees, suppliers, etc. must also be informed and convinced that the innovation is beneficial for them.

The importance of strengthening the adoption of innovation at the level of the consumers is illustrated by the recent emergence of the conceptual model of Quadruple Helix Innovation, where citizens are added as a fourth element to the more traditional combination of partnership for innovation between industry, government, and universities.

This conceptual evolution is strongly encouraged and put into practice by some very large companies including Intel and Rolls Royce. They have put the successful adoption of their innovations on the top of their priorities. Hence, there is now a renewed interest in the marketing of innovation and especially in the adoption of original products or services because one important function of marketing is to contribute to the adoption of innovative solutions by potential customers, which can be consumers or organizations.

Interestingly, trust plays an essential role to facilitate the adoption of innovation among other drivers.

3. A MARKET VIEW OF THE ADOPTION OF INNOVATION

The adoption of innovation follows the S curve defined by Bass and others when looking at a market over time. This curve measure the adoption of an innovation by considering the number of users adopting the innovation. The S curve is determined by the limited number of early users of an innovation which reaches a tipping point where there is an acceleration of the adoption of the innovation by a majority of adopters up to a tripping point where the innovation is now massively adopted and starts plateauing. This adoption curve mirrors the S curve used to describe the lifecycle of a technology along its five dimensions of emergence, improvement, maturity, substitution and obsolescence. This is because innovation acceptance depends on the innovation itself but also on the individual who adopts or rejects such an innovation [6].

The innovation adopters can be categorized into two different groups: the early adopters and the mainstream adopters; the latter group can be sub-categorized into early majority or late majority depending on the timing of their adoption of the innovation. Early adopters have a very different profile and have very different expectations about an innovation than mainstream adopters.

3.1 The early adopters

Early adopters, whether individuals or organizations, are buying an innovation for social, functional, hedonic and/or cognitive reasons [7]. One motivation for early adopters is the self-assertive social need for differentiation and status that comes with being the exclusive or one of the few owners of a novelty. Hedonic innovativeness focusses on positive feelings that accompany new product purchases. Cognitively motivated innovativeness relates to consumers who experience satisfaction when they encounter new and complicated information or products. Functional innovativeness focuses on the usefulness of new products and on the question of whether new products accomplish tasks better than existing ones.

Early adopters are also highly familiar with a specific product class of innovation. They may already have a good knowledge about the category of innovation they are going to purchase and they are often eager to look for more information.

Even if they are not immune to social interactions, early adopters are influenced mostly by personal and private assessment, as well as by trial in order to test the innovation. They are also comfortable with technology and they are not very averse to risk and ambiguity. They are tolerant with technical issues in an innovation as they know that the product or service is in its early phase. That does not mean that they will tolerate a failure but they will understand and accept that the innovation providers offer them a revised version or an adjustment of the product if it has a problem. Some of them, characterized in the literature as "lead users", are even ready to contribute to work with the provider to test the innovation and to improve it. Early adopters have also been shown to be not very sensitive to the price of an innovation. They are much more sensitive to delayed market introduction and may be less tolerant if the providers fails to deliver on time an innovation that has been announced.

3.2. Mainstream adopters: early and late majority

Mainstream innovation adopters are the ones who can break or make an innovation because they represent the biggest

number of potential customers. The significant failure rate of market acceptance of innovations reflects the difficulty that some companies have to convince the mainstream adopters to adopt an innovation because they behave very differently than the early adopters.

It is interesting to distinguish the early majority from the late majority of mainstream adopters. The former are usually described as pragmatic [8].When considering the innovation, they look for a measurable incremental benefit. Regarding social pressure, they will buy to act as the rest of the group and they will follow the advice of influent "opinion leaders", among their peer or external experts and influencers.

Early majority adopters are less tolerant with respect to technical failures in the innovation they have bought. One of the reason for delaying their purchasing decision is to make sure that the product is completely stabilized and works well. They are more focused on the price of the innovation or at least on its performance/price ratio. Consequently, they prefer to see various competitors offering the same kind of innovation because it allows for tougher negotiations on price and it also guarantees the development of supporting products and services around the innovation.

The price sensitivity tends to increase with the length of the adoption time and especially after the tripping point of the curve where price is the main determinant for adoption by the late majority of purchasers. Those late adopters are risk averse. They catch up with the rest of their reference group (the "bandwagon effect"). Late adopters are also less familiar with the product field. They are willing to spend a limited amount of effort and time to acquire the innovation, compared with early adopters, as conceptualized in the "lazy user model". They are not interested to spend too much time looking for information about the new product as they are using the experience of the early majority of adopters or opinion leaders to save them time in making their evaluation of the innovation.

4. THE ROLE OF TRUST IN THE ADOPTION PROCESS OF INNOVATION

In an online environment, the absence of trust has long been one of the most important obstacles to accepting online trade [9]. Online trade is now widely accepted and I mentioned in my introduction that electronic and mobile payments are now widely trusted by the general public. But other innovations in information technology still have a long way to go to be accepted, like cloud computing for the consumer market or "Big data" software for the business market.

I will start by providing a definition of trust; then I will discuss the relationship between trust and risk; next I will detail the role of trust in the adoption of an innovation.

4.1 The dimensions of trust

A widely accepted definition of trust in management research is: "The willingness to rely on an exchange partner in whom one has confidence" [10]. Individual trust can be related to personality characteristics. It is deeply rooted in the personality, with its origins in the individual early psychological development. It is also related to individual experiences. But besides individual trust there is also a societal trust. It is related to the relations between individuals and institutions or between organizations. Moreover trust can be built based on a social environment.

The role of the individual trust relationship to a specific exchange partner, such as a salesman or account manager, has been often investigated in the past while trust in the company is a topic that has only recently received increased attention from a management and research perspective.

In marketing, specific attention has been paid to the role of trust in the choice of brands. This is because consumer attitude to perceived risk is an important driver for selecting a brand, along quality and price. For instance, it has been shown that increasing trust in the quality of retail brands has a positive influence on their adoption among consumers. Similarly, the perceived benefits of detergent retail brands and products are positively related to the trust that consumers have in these brands and products. Also it has been demonstrated that the trust generated between a consumer and a brand contributes to enhance customer satisfaction and loyalty.

Three main characteristics are attached to trust in a business partner or vendor: integrity, credibility, and benevolence [11].

- Integrity - or reliability - indicates the characteristic of the partner to stand by its words and to fulfill given promises. Honesty is defined as the belief that the partner is open and always telling the truth and may be considered as an element defining the integrity of a partner. For instance, in the information service industry, perceived integrity is the confidence that merchants- will honour their commitment to protect the security of transactions and the confidentiality of information

-Credibility – or competence - is based on the customer's belief that the provider has the required expertise to perform the job effectively. The customer's confidence in the quality of outcome product or service is an essential component of trust. For example, in e-commerce, perceived credibility is the belief that the electronic supplier has the required knowledge and infrastructure to do his job effectively while in the service business, in general, credibility focuses on the expectancy that service personnel can be relied upon.

-Benevolence is based on the extent to which the customer believes that the partner is motivated to act in the interest of the customer's welfare and that the partner is motivated to seek joint gain and to establish a long-term relationship rather than by self-interest. Benevolence can be understood as part of the Hippocratic Oath taken by physicians which states that "I will apply, for the benefit of the sick, all measures which are required... and I will take care that they suffer no hurt or damage". Benevolence also includes a problem solving orientation, i.e. the intentions of the provider to act beneficially for the customer, e.g. when new conditions arise for which a commitment was not made. In e-business, benevolence is the belief that the electronic merchant takes user interests serious.

4.2 Risk and trust

Trust – in an individual or an organization - is always associated with risk, even if there are some cultural variations between regions (Hofstede, 1980). Trust reduces the perceived risk associated with a product or a service. The classical example is surgery whose results cannot be observed in advance and which often has an irreversible outcome with sometimes negative long-term consequences. Consequently, the customer has no other choice but to trust the surgeon.

Researchers in finance and economics tend to distinguish between the attitude of decision-makers to events with known probability, defined as risk, and an unknown probability defined as ambiguity [12]. Studies have shown strong evidence for ambiguity aversion, i.e. a preference for a clear bet over a vague bet.

Recent experimental results using functional magnetic resonance imaging techniques show that different parts of the brain are activated when individuals evaluate ambiguous or risky choices. People start considering the worst possible outcome associated with the emotional part of the brain, and screen through the various options with calculated risk associated with the computational part of the brain.

Risks can be categorized into universal risks and individual risks. Universal risks are related to natural disasters (storm, flood, hurricane...), macroeconomic shocks (recession, international crisis ...) and financial crisis (inflation, interest rate and, exchange rate fluctuations...), political risks (war, restriction or prohibition of use, taxes...), security risks (vandalism, crime, sabotage...).

Individual risks at the level of the buyer are internal and transactional. Internal risks are related to the financial risk and operational risks associated with the product and the service –including the risk of errors, the loss of control or the loss of availability - as well as the possible risk of unanticipated requirement for additional resources. For businesses, there is also the additional danger of a commercial risk, such as complaints or even the loss of customers who do not appreciate the new solution.

Transactional risks vis-à-vis an innovation provider are risks due to a lack of expertise and a lack of motivation. The internal risks combine with the transactional risk as for example in the case of the lack of motivation of a provider to effectively solve a technical issue.

Thus, individual risks are driving different kinds of trust. In the case risks due to a lack of expertise, trust is reflected in the confidence that an individual or an organization is reliable and trustworthy and whether it is capable of delivering good quality, and of being customer-oriented and consistent. It is a trust which is cerebral and analytical, based on facts. In the case of dealing with risks due to a lack of motivation of the partner, trust is reflected by faith in the integrity, benevolence, and honesty of the associate. This sort of trust is more emotional and less rational.

Addressing both internal risks and transactional risks is essential in order to establish a trusted relation with the customers. A company can be completely upright and benevolent in the sense of a customer's needs, but does not have the necessary capacities to deliver the right quality (e.g. a small bank may strive to advise a customer honestly but have a lack of competence regarding certain topics). On the other hand, a company can have the capability to deliver the required outcome in the right quality, but has selfish reasons or motivations for not acting optimally in the sense of the customer (e.g. a huge bank is capable of offering a wide range of financial products, but offers only the products with the biggest profit margins for the company).

This is equally valid for the adoption of innovation. If an innovative company fails to deal with one category of risk, either internal or transactional, it may jeopardize the relationship with the adopters and complicate the adoption of innovation.

4.3. Trust and innovation

There has been little research about the role of trust in the innovation process. The wide majority of it focuses on the upstream of the innovation process, mostly at the level of generating ideas and developing new projects. At the level of the firm, there is no doubt that the importance of trust within the different departments of a company increases during innovation due to high levels of uncertainty and need for collaboration of employees from different functions. Nowadays, with the development of open innovation or collaborative innovation where different partners are involved in the joint development of ideas, projects and prototypes, trust between partners is important and is positively associated with innovation [13].But, as we said earlier, there has been even less research about the role and place of trust in the downstream process of adoption, i.e. its commercialization for adoption.

Before we move to the role of trust in the adoption of innovation, let us first review briefly what the drivers of adoption of an innovation are. To do so, I will use the unified theory of acceptance and use of technology model (UTAUT) [14] which is highly relevant for this kind of analysis, especially in the case of technology driven innovation like the ones in the Information society.

The UTAUT model has been developed to study the acceptance of technology. It has four key constructs:

- performance expectancy is defined as the degree to which using an innovative technology will provide benefits to the users in performing certain activities
- effort expectancy describes the degree of ease associated with the use of the system
- social influence is the extent to which consumers perceive that important others (e.g., family and friends) believe they should use a particular technology;
- and facilitating conditions that define the degree to which an individual believes that an organizational and technical infrastructure exists to support use of the innovation

According to UTAUT, performance expectancy, effort expectancy, and social influence are theorized to influence behavioral intention to use a technology, while behavioral intention and facilitating conditions determine technology use. Individual difference variables, namely age, gender, and experience and voluntariness of use moderate various UTAUT relationships. It is worthwhile to consider the interplay of the three main characteristics of trust, i.e.

credibility, integrity, and benevolence, with this model of adoption (exhibit 2)

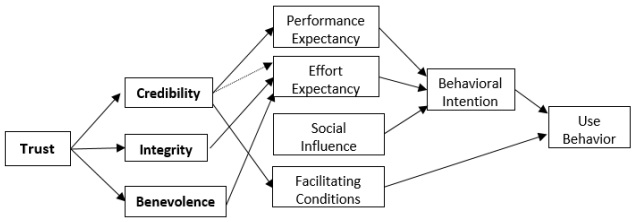

Figure 2. The impact of the component of trust on the adoption drivers defined by the UTAUT Model

We may assume that the level of credibility of the supplier, i.e. the belief that the provider has the required expertise to perform the job effectively, will have an influence on the performance of an innovation, especially if the supplier has already a reputation of technical excellence from earlier products. For example, in the case of Web-based shopping, where there are only electronic exchanges and where the user has to pay in advance, the consumer depends on the merchant for ensuring that the exchange is complete, including the delivery and the after sale service, and that the payment system is safe.

To a lesser extent, the credibility of a supplier is a determinant of the effort expectancy required for an innovation, especially with technology based products or services whose effective delivery requires some effort from the user. This will depend on the reputation and or a previous experience with the provider. Some innovation providers have a proven track record to deliver easy to use innovative product such as Apple or Amazon. Credibility of the partner can also be a determinant of the facilitating conditions from a material perspective. In case of web based services for instance, the consumer depends on the electronic system to conduct the transaction and on the safety of the payment system implemented by the Web merchant.

Integrity will play a role in the perception of the effort expectancy, especially in the case of an innovative solution where the customer has no experience and may require the support of the provider. In web based services, consumers must typically pay in advance a transaction and in a virtual environment; they are at risk should anything go wrong with the transaction. They must believe in the integrity of the Web merchant before engaging in any transaction.

Benevolence, based on the perceived generosity of the provider, will also be a factor in evaluating the effort expectancy to adopt an innovation. If something goes wrong, users may prefer to go with a supplier who can help them and who shows a problem solving orientation.

Early adopters and the majority of adopters have different expectations when it comes to trusting an innovation provider.

For the early adopters who are focusing on performance, the technical credibility of a provider and the quality of the innovation are obviously important and they will spend time to check the credentials of the innovation provider. But the integrity and the benevolence are probably more essential because at that phase early adopters know that they will probably experience some difficulties with an innovation which is not yet completely stabilized. It is actually one of the reason why they accept to enter in the acquisition process so early; they are excited by the novelty and are interested to contribute to the future of the innovation which has been launched. In turn, they expect from the vendor that it will be motivated to act in the customer´s interest (benevolence) and that they will keep their promise (reliability) should any problem arise.

The early and late majority of adopters are very sensitive first to the credibility of the innovation provider and the quality of the solution because they are looking more for safety than performance. Following the advice of peers and "opinion leaders", they prefer to go with innovation vendors which have already an established brand and a good reputation in order to minimize the risk of malfunction. They also pay a lot of attention to the reliability of the vendor as they don´t want to spend money or time with the repair of a potentially poor solution. It does not mean that benevolence is a factor that they do not consider but as they have been waiting quite a while before buying the innovation in comparison to early adopters they expect the product to be reliable enough so that the provider will not have to take additional actions.

It is important to conclude that integrity carries identical weight for early or late adopters as it is the basis of any commercial exchange. Any breech of rectitude by the provider, especially a trusted one, will negatively impact the attitude and the behavior of the users, as a German car maker has recently discovered. This is even truer for an innovative products as it implies a level of risk higher than a traditional product for a customer.

5. STANDARDIZATION AND TRUST IN THE ADOPTION OF INNOVATION

While the reciprocal relationship between standardization and innovation has been widely discussed in recent years, few researches have considered the importance of trust in the standardization process where it certainly plays a role. In this last part, I am going to analyze how standardization increase the trust of the different categories of adopters and thus facilitates the adoption of innovation. I will then discuss how trust can be standardized, at least in terms of risk management, in order to contribute to the acceptance of innovation.

5.1 Standardization supports trust to facilitate the acceptance of innovation

Firstly, at organizational level, cooperation and alliance between firms play an important role during standards settings, which are made on a voluntary basis. For instance, open collaboration with other partners such as suppliers or universities has been positively correlated with the proclivity to join standardization activities [15].

Secondly, and more interestingly for the audience of this conference, standards are also important for acceptance of innovation because they perform some fundamental functions such as interoperability, quality assurance, information and measurement. Thus, they contribute to

foment trust for the potential user or buyer of an innovation, as they contribute to the prevention of the occurrence of a risk and/or to the reduction of a potential loss should a risk materialize. In telecommunication for instance, standards reduce the managerial and financial risks in joint venture and mergers or in acquisitions of networks [16].

It is useful to distinguish how standards enforces trust depending on the level of adoption of an innovation. Standards are dynamic and need to be adapted to the different phases of the life cycle of a technology [17]. As the adoption curve of an innovation is just the market reflect of a technology acceptance, we will now discuss the importance of standards for fomenting trust of the early and the mainstream adopters, respectively.

Early in the adoption cycle, the risks are mostly technical at the level of the adopters. Especially in the case of a new technology the internal risks are important for the innovation adopters and most of them cannot be identified in advance. In order to mitigate those risks, specifications are built along with and in parallel to the production of prototypes, pilot services and beta tests in order to structure the available knowledge into a usable form for both the customers and the potential competitors. At that stage, early users may contribute to the design of those anticipatory standards to help the development of a promising innovation they are investing in. Anticipatory standards significantly contribute to setting up the trust between early adopters and innovation providers because they allow the various contributors to develop a common knowledge and language of communication that they can share in order to improve and stabilize the innovation.

When the innovation has passed the first initial acceptance of early users and is looking for the early majority of adopters, there is a risk of fragmentation of the offer because, with market growth and enhancement in the innovation, new competitors may enter the business and offer alternative solutions based on another technology. Such a fragmentation is reducing – or preventing the development of – the credibility of the innovation providers because different competing technologies or solutions are confusing the potential late adopters. As a consequence, they prefer to wait for a dominant model to emerge before considering a purchase. Furthermore, market fragmentation prevents the reduction of production costs associated with economy of scale. As late adopters are sensitive to price this is another deterrent to the adoption of an innovation.

So, at that stage of the adoption process, it is interesting to have "enabling standards" which support the offer around a common set of characteristics which will prevent the fragmentation of the market and will contribute to the emergence of a prevailing model of product or service.

Enabling standards also help diffuse technical knowledge and contribute to the education of the market and especially the opinion leaders who may have an influence on the late adopters, but do not yet have all the knowledge to be in a position to recommend the adoption of a given innovation.

Finally, at the end of the adoption phase there is always the risk that the late adopters do not buy the innovation or that they go with a less efficient one because of the bandwagon effect. At that stage "responsive standards" can contribute to the reinforcement of trust in the innovative solution as they codify the best characteristics of a stabilized dominant model. Such a systematization is exactly what the late users are expecting to base their decision upon as standards help them to gauge both the quality of the innovation and of the innovation providers on the market. Thus, standardization reinforces the trust into the innovation provider which is indispensable to facilitate the adoption of an innovation because it reduces the perceived risks associated to novelty for the various categories of adopters.

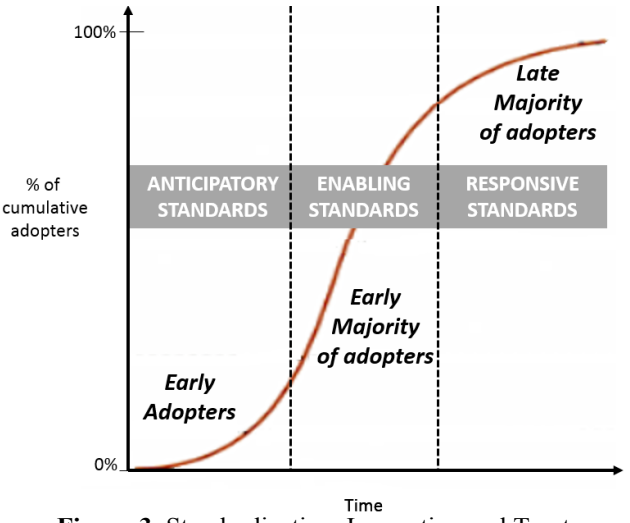

Figure 3. Standardization, Innovation and Trust

5.2. Standardization of trust to enable the adoption of innovation

While standards contribute effectively to trust, there has been a recent and interesting trend to standardize trust in order to make its management more effective. Actually, this standardization of trust has been initiated at the level of the management of the risks. Indeed, in view of the growing number and complexity of the risks in our global world, different risk management standards have emerged first in Australia in 1995, and then in other countries such as Canada, United Kingdom, Japan, and the United States, and ultimately internationally as the ISO 31 000 in 2009 [18].The latter focuses on the actions taken concerning identified risks in order to improve an organization´s performance. It is a universal standard, which can be adapted to the specific needs of an organization or a firm.

The ITU has also initiated various analyses of risk management, a cybersecurity risk indicator, or a risk analysis of next generation networks. From what I have seen all those effort to standardize risks and risk management have made a tremendous effort to identify, categorize and characterize risks. But they all tend to focus on the external risks and the potential technical or operational failures from a provider's point of view. In some cases they even define an indicator of technical reliability, accuracy or confidentiality.

This is extremely interesting and can contribute to enhance the trust in the organization in terms of credibility and integrity. But I have found almost nothing about managing the risks related to the lack of motivation of suppliers that can affect the dimension of benevolence. This is probably

due to the fact that those risks are more qualitative and less easy to identify than the mere technical risks. The risks related to the lack of expertise of a supplier can be more or less easily identified and they can be managed pro-actively. The risks arising from of lack of a supplier's benevolence are much more difficult to anticipate. They also need to be considered more from the customer's point of view than from the organization´s perspective alone.

6. CONCLUSION

In this presentation, we have analyzed the role of trust and standardization in the adoption of innovation, a stage which is considered as essential for achieving success in the market. We have examined the expectation and the behavior of the three main categories of innovation users: the early adopters, the early majority of mainstream adopters and the late adopters. Then we have analyzed how the three main components of trust - integrity, credibility and benevolence - can be related to the two main categories of risks for an innovation adopter: the internal risks and the transactional risks; and we have studied the importance and dynamics of trust along the different stages of the acceptance of innovation.

Finally, we have considered the association between standardization and trust and their role in the adoption of innovation. We have first detailed the needs and use of dynamic standards along the various stages of the innovation life cycle. I think this is an original discussion as we have done it from a customer/ user perspective while it has typically been done mostly from a technology/supply perspective. A second original element is my final reflection about the importance of the standardization of risks in order to facilitate their identification and mitigation. We have identified a significant effort to standardize the risks associated with the lack of expertise from a supplier. But regarding the standardization of the risks associated with the lack of benevolence, there is still room for future development for both researchers and practitioners.

Among the questions to consider are first the type of criteria which have to be used and their measurement. For example, in order to consider the degree of engagement of suppliers, one criteria could be the incentive policy for employees; but is this information easily accessible? Another important question is related to the cultural dimension of truth, as being benevolent does not have the same implications in different parts of the world. Finally, there are some limits to consider which are intrinsic to Standard Development Organizations (SDOs). The ultimate way to secure the commitment of an innovation supplier and to mitigate a possible lack of motivation is to have a legal control by regulators. But SDOs are defining voluntary standards and do not have the enforcement power of governmental administrations.

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SESSION 1

TRUST IN THE INFRASTRUCTURE

STRENGTHENING TRUST IN THE FUTURE ICT INFRASTRUCTURE

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ABSTRACT

Moving towards a hyperconnected society in the forthcoming "zettabyte" era requires a trusted ICT infrastructure for sharing information and creating knowledge. To advance the efforts to build converged ICT services and reliable information infrastructures, ITU-T has recently started a work item on future trusted ICT infrastructures. In this paper, we introduce the concept of a social-cyber-physical infrastructure from the social Internet of Things paradigm and present different meanings from various perspectives for a clear understanding of trust. Then, the paper identifies key challenges for a trustworthy ICT infrastructure. Finally, we propose a generic architectural framework for trust provisioning and presents strategies to stimulate activities for future standardization on trust with related standardization bodies.

Keywords— Trust, social-cyber-physical infrastructure, Internet of Things, ICT

1. INTRODUCTION

The widespread availability of feature-rich communications is the result of end-user devices, advanced networks and new services that exploit the developments in Information and Communication Technology (ICT). Key technologies are the Internet of Things (IoT), web services, cloud computing (including distributed and embedded computing), big data analytics, smart objects and sensing technologies.

The IoT is one of the hottest and most promising topics in ICT today. As more heterogeneous objects get connected to the Internet, novel mechanisms to manage, describe, discover and use these connected resources and the data they produce become necessary. A number of initiatives are available borrowing from the fields of autonomous systems, intelligent systems and semantic technologies, etc.. One of the main challenges of the IoT is to develop solutions that are readable, recognizable, locatable, addressable and/or controllable via the Internet. The convergence of technologies like IoT and cloud computing will enable innovative services. These involve technologies such as bio, nano- and content technologies going beyond traditional telecommunication services [1], [2].

From the perspective of connected devices, the introduction of sensors and devices in physical spaces poses particular challenges and increases the sensitivity of the data that are being collected. Connected devices are effectively allowing companies to digitally monitor our private activities. Moreover, the sheer volume of generated data allows those with access to the data to perform analyses and compile detailed profiles of consumer behaviour [3].

From the perspective of big data analytics, the processing and analysis of the large amount of data through cloud computing are becoming an important resource that can lead to increased knowledge, drive value creation, and foster new products, processes and markets. However, the large scale collection and analysis of data imposes difficult privacy, security and trust issues, ranging from the risks of unanticipated uses of consumer data to the potential discrimination enabled by data analytics and the insights offered into the movements, interests and activities of an individual [4].

Although recent advances in ICT have brought changes to our everyday lives [5],[6], various problems exist due to the lack of trust. Therefore, it is important to process and handle data in compliance with user needs and rights in various application domains. Based on the significant efforts made to build converged ICT services and a reliable information infrastructure, ITU-T has recently started new work on future trusted ICT infrastructures.

These infrastructures will be able to accommodate emerging trends in ICT, while taking into account social and economic considerations. Thus, this paper discusses an effort to find a good solution to these problems while developing advanced technologies for intelligent autonomous networking and services. The aim is to create a trusted environment for an ICT infrastructure in order to share information and create knowledge.

Firstly, in Section 2 this paper introduces the concept of an emerging social-cyber-physical infrastructure from the social IoT paradigm. Secondly, Section 3 presents different meanings of trust from various perspectives. In Section 4, the paper identifies key challenges for trustworthy ICT infrastructures. The paper proposes a generic architectural framework for trust provisioning in Section 5 and presents strategies to stimulate activities for future standardization on trust with other standardization bodies.

2. FUTURE ICT INFRASTRUCTURE FOR A HYPERCONNECTED SOCIETY

While traditional ICT infrastructures have focused on computer-centric approaches to data processing as well as network-centric approaches to information collection, the

emerging ICT infrastructures will use human-centric approaches. The transformation toward a hyperconnected society will contribute to our everyday lives with ICT problem-solving support, and will (hopefully) change to a more user-friendly, fun and enjoyable experience in terms of ICT provision.

The advent of applications such as content distribution, cloud computing and IoT requires the underlying network to be able to understand the context of various services. An emerging networking paradigm enables in-network knowledge generation and distribution in order to develop the necessary network control intelligence for handling complexity and uncertainty of future networked services and the multitude of users [7]. To support this paradigm, telecommunication infrastructures must be enhanced to make better use of the knowledge of networks, services, end users and their devices.

The evolving trend of telecommunication systems and ICTs has been to move from the living space of home appliances to large-scale communities in buildings, such as workspaces and digital infrastructures like smart cities. The IoT plays a major role in the rapid development of these technologies. The IoT initially focused on network connectivity for supporting heterogeneous communications interfaces but recently it has been developing to provide convergent services that integrate ICT in various industrial areas to offer a common service platform. These convergent services have been required to obtain reliable knowledge from raw data. As an aim of intelligent service provision is to make autonomous decisions without human intervention, trust has been highlighted as a key issue in the processing and handling of data, as well as the provisioning of services which comply with users' needs and rights.

The social IoT[1] [8] transforms smart objects into social entities which are capable of bridging human-to-object interactions. In this way, a social network of objects is created by intelligent reasoning/recommendation mechanisms. These mechanisms extract the social knowledge hidden in the rich profiles of humans and services maintained by various social network services [8]. The paradigm of Cyber-Physical-Social Systems (CPSS) [9],[10] has recently gained momentum as an environment that combines knowledge from various smart spaces to form an ecosystem, in which intelligence and reasoning about the social aspects that are embedded in human behaviour in smart spaces act as the glue for integrating physical, cyber and social worlds.

Based on the CPSS, Figure 1 depicts the concept of a social-cyber-physical (SCP) infrastructure as the future ICT infrastructure. This infrastructure consists of three regions – physical world, cyber world and social world. The main elements of ICT infrastructures rely mostly on 3C (i.e., Computation, Communication, Control) to extract knowledge from the information available in the data obtained from various systems, including sensors and actuators. The social world in relation to a trusted technology with an individual and communities is also important. The three different areas need an infrastructure that is more reliable and closely correlated through cross-tier trust management.

Most importantly, the transition to the SCP infrastructure depends upon how to acquire useful knowledge from data and information. Trust is essential in this knowledge acquisition process; also, for awareness and understanding of a specific context it is really important to have confidence in decision making. In other words, trust should be additionally considered in systems that behave intelligently and rationally to sense real-world behaviour, perceive the world using information models, adapt to different environments and changes, learn and build knowledge, and act to control their environments [11]. This is mainly related to the data, information, knowledge, wisdom (DIKW)[2] process in the cyber world, see Figure 1.

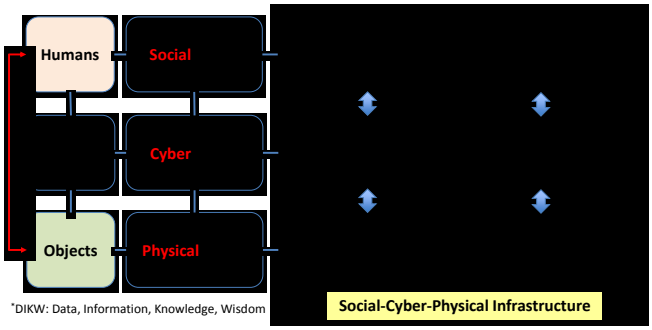

Figure 1. The concept of a social-cyber-physical infrastructure

To strengthen trust while building a hyperconnected society, a trustworthy SCP infrastructure will be a key work item for international standardization working on the development of technology and trust, while at the same time expanding the functions of the core technology components.

3. UNDERSTANDING OF TRUST

Because trust can be interpreted in different ways, we present its various meanings in the context of telecommunication systems and ICTs and highlight the relationship between knowledge and trust.

As a lexical-semantic, trust means reliance on the integrity, strength, ability, etc., of a person or object. Generally, trust is used as a measure of confidence that an entity will behave in an expected manner, despite the lack of ability to monitor or control the environment in which it operates [12].

[1] The Social Internet of Things is defined as an IoT where things are capable of establishing social relationships with other objects, autonomously with respect to humans [8].

[2] DIKW (Data, Information, Knowledge and Wisdom): This refers loosely to a class of models for representing purported structural and/or functional relationships between data, information, knowledge, and wisdom. "Typically information is defined in terms of data, knowledge in terms of information, and wisdom in terms of knowledge".
Source: https://en.wikipedia.org/wiki/DIKW_Pyramid

In computer science, trust hast two aspects "user trust" and "system trust". For a user, trust is based on psychological and sociological considerations because it is "a subjective expectation an entity has about another's future behaviour". System trust is "the expectation that a device or system will faithfully behave in a particular manner to fulfil its intended purpose" [12].

For the IoT, trust relies on the integrity, ability or character of an entity [13]. Trust can be further explained in terms of confidence in the truth or worth of an entity. For example, the EU uTRUSTit project defines trust as a user's confidence in an entity's reliability, including a user's acceptance of vulnerability in a potentially risky situation [12].

From a technical perspective, trust could be classified along three dimensions; technical trust (like data security), business/trading/community trust (or credits), and human trust (perceived by an individual human or group of members).

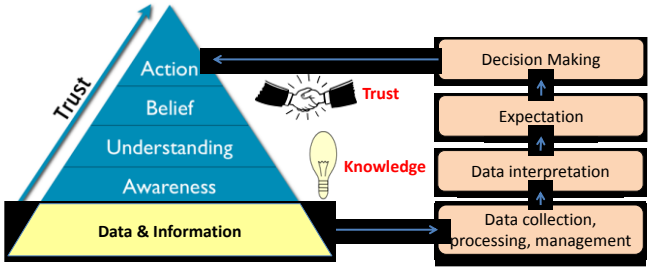

Figure 2. Knowledge and Trust (illustration compiled from trust pyramid [14])

The social and economic value of data is mainly reaped at two stages: firstly when data and information are transformed into knowledge (gaining insights) and secondly when they are used for decision making (taking action). The knowledge is accumulated over time by an individual or systems through data analytics. Data processing, management and interpretation for awareness and understanding have been considered as fundamental processes for obtaining knowledge. As shown in Figure 2, trust is strengthened from accumulated knowledge and it has a significant role as a link between knowledge (i.e., awareness and understanding) and action. It means that the expectation process for trust should be additionally considered before decision making.

4. CHALLENGES FOR THE TRUSTWORTHY ICT INFRASTRUCTURE

In a highly interconnected ICT world such as the SCP infrastructure, a number of independently developed, operated and managed systems network autonomously yielding a new kind of complex system that provides various services. Assuring continuous trustworthiness, taking into account such characteristics for future ICT infrastructures with highly interconnected systems, is becoming an essential issue. Therefore, this section identifies key challenges for the trustworthy ICT infrastructure.

4.1. Social-Cyber-Physical Trust Relationships

The SCP infrastructure comprise objects from the physical world (physical objects), the cyber world (virtual objects) and the social world (humans with attached devices), which can be identified and integrated into information and communication networks. All of these objects have their associated information, which can be static and dynamic [15]. Thus, social trust[3] between humans and objects is quite important. As shown in Figure 3, trust may be human to human, object to object (e.g., handshake protocols negotiated), human to object (e.g., when a consumer reviews a digital signature advisory notice) or object to human (e.g., when a system relies on user input and instructions without extensive verification). In addition to individual trust, community trust also needs to be considered. For social-cyber-physical relationships, trust as a cross-domain relationship is needed, taking into consideration coexistence, connectivity, interactivity and spatio-temporal situations between vertical layers.

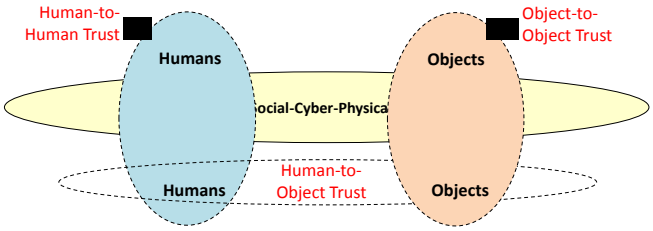

Figure 3. Trust relationships in a trustworthy social-cyber-physical infrastructure

4.2. Holistic Trust for Interconnected Systems

ICT services can be achieved through a chain of interconnected systems and components that share the responsibility for providing stable and robust services. Furthermore, many systems are based on open system architectures and their properties of interconnectivity and autonomics remove system boundaries. Such characteristics of interconnected systems lead to the introduction of security deficiencies that can be very hard to find and analyse. If this is not properly handled, the stability and safety of the overall system can be seriously threatened.

How can the stability and safety of such highly interconnected systems be achieved? Trust must be addressed and evaluated in all services and infrastructures, as well as in all system and component levels, in a holistic manner. Trust management is also required to apply between heterogeneous systems, service domains and

[3] Social trust implies that members of a community act according to the expectation that other members of the community are also trustworthy and expect trust from other community members.

stakeholders, while focusing on the relationships and dependencies between them [16].

4.3. Unified Approach to Trust-Security-Privacy

Scalability and complexity of the SCP infrastructure are due to the huge number of different links and interactions. Therefore, trust, security and privacy become tightly coupled because system features increasingly depend on networks, computation and processing. Trustworthiness requires cooperation and co-engineering of trust with security and privacy. It is not sufficient to address one of them in isolation, nor is it sufficient simply to combine components of trust, security and privacy. In order to address these issues, a unified approach is needed towards trust, security and privacy co-analysis, -design, -implementation and -verification [16].

4.4. Measurement and Formalization of Trust

For measurable trust, some mechanisms and solutions may be established by defining a trust metric or trust index. There are several attributes for trust provisioning such as reputation, strength, reliability, availability, ability, etc. Depending on the services and applications, the required attributes of trust may vary. The capability or attributes of trust can be also classified into application types, costs, technical complexity and human credibility/reputation.

Due to the diversity of applications and their inherent differences in nature, trust is hard to formalize in a general setting. However, it is important to quantify a level of trust in ICT. The level of trust can be measured and classified, similar to Quality of Service (QoS) used in an objective manner (e.g., measured quantitatively) or Quality of Experience (QoE) used in a subjective manner (e.g., counted qualitatively). A certain level of trust should be derived from the associated services and applications of trust. The level of trust should be well identified and measured objectively or subjectively. Depending on what levels of trust the users need to know, including those related to sensitivity of information and associated resources, there may be many Trust Level Agreements (TLA).

4.5. Trustworthy System Lifecycle

In order to achieve trustworthy systems, we need a systematic methodology to cover all relevant trust aspects of a design, development and operation life cycle. The trustworthy system lifecycle can be sub-divided into three stages: i) designing the definition and goal of trust, ii) developing trustworthy systems, and iii) maintaining trustworthy operations.

At the design phase, the definition, metrics and goals of trust for the target system should be determined and the system should be developed while trust measures are considered to meet the design goals in the development phase. Finally, the maintenance phase has to properly monitor the normal operation of the running of a trustworthy system and the dynamics of the execution environment to verify the trust provisions at runtime. Furthermore, certification and qualification are required to prove the system has been developed using a certification and testing process.

4.6. Dynamics of Trust

In the SCP infrastructure, the state of objects changes dynamically (e.g., sleeping and waking, connected/ disconnected, and node failure etc.), as does their context, including location and speed. Moreover, the number of entities also fluctuates. Basically, trust is situation-specific and changes over time. Due to the dynamics and complexity of trust, a single trust mechanism cannot perfectly solve all the issues; so it is necessary to combine different trust mechanisms.

4.7. Resource Constraints

For small-sized objects with limited computing power, their capabilities as communication objects are lower (sometimes much lower) than those of higher-end processing and computing devices. To cope with these constrained objects, trust solutions with lightweight mechanisms that remove unnecessary loads/messages and minimize energy consumption become a necessity.

5. ARCHITECTURAL FRAMEWORK FOR TRUST PROVISIONING

As mentioned in the introduction, ITU-T has recently started new work on future trusted ICT infrastructures to cope with emerging trends in ICT while also considering social and economic issues. As a result, ITU-T has established the Correspondence Group on Trust (CG-Trust). The CG-Trust is currently developing a technical report on trust provisioning of the ICT Infrastructure. Here we propose a generic ICT trust conceptual model and an architectural framework for trust provisioning which will be developed further in CG-Trust.

5.1. Generic ICT Trust Conceptual Model

From the concept of SCP infrastructure discussed in Section 2, the domain of ICT can be sub-divided into the physical, cyber and social spheres. The physical ICT sphere perceives the dynamic physical environment, collects and delivers data. The cyber ICT sphere analyses the data from the physical world and provides useful information or knowledge to users in the social world.

To clarify ICT capabilities for trust provisioning with social-cyber-physical relationships, a conceptual model is shown in Figure 4. The model comprises different horizontal layers (i.e., social, cyber and physical) and three

different vertical layers (i.e., object, networking and DIKW). There are multiple service domains for supporting a multiplicity of applications. The SCP infrastructure is logically sliced so that individual service domains share the infrastructure.

In the proposed model, trust is associated with all vertical and horizontal layers. Thus similar to security, trust management technology is necessary as a separate common layer which covers all vertical and horizontal layers. Using this model, we intend to illustrate the complex relationships and roles required for trust provisioning between and across layers which are associated with an individual entity of SCP infrastructure and services.

5.1.1. Physical Layer Trust

A physical layer contains a huge number of objects (i.e., H/W, device) including sensors, actuators and mobile terminals, which generate data by using sensing technologies to sense physical objects and their behaviours within their environments (e.g., temperature, pressure, etc.). Collecting secure and reliable data from physical objects is the first step to providing trustworthy ICT services and applications because the propagation and process of false data will cause service degradation and waste system resources.

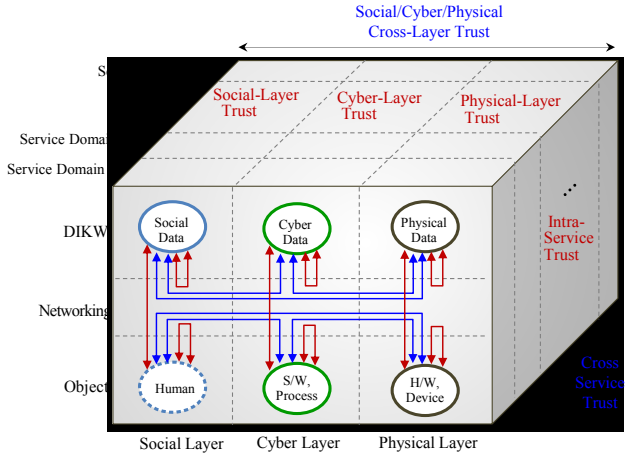

Figure 4. Generic ICT trust conceptual model

In order to detect trust problems in the physical layer such as injections of obstructive signals, malfunctions of systems, shutdowns or accidents, the operations of the physical objects and its data must be examined. Since many data are created from constrained devices, lightweight security and trust mechanisms are needed for data processing trust (e.g., efficiency, accuracy, reliability, etc.).

5.1.2. Cyber Layer Trust

A cyber layer includes virtual objects such as software agents, services and applications working over computing, storage and networking components. These virtual objects are seamlessly interconnected and cooperate for data coding, transmission, fusion, mining and analysing to provide information and knowledge to humans independent of location in fixed/mobile environments.

In order for virtual objects to safely cooperate, they have to distinguish malicious and non-malicious objects. One way to resolve this challenge is to evaluate the trust with their specific goal to decide which virtual objects to cooperate with. On the other hand, when huge amounts of data are collected in the cyber layer, they should be processed and analysed accurately and transparently.

Data, information and knowledge should be also transmitted and communicated in a reliable way via networking systems. Existing advances in networking and communications can be applied in order to achieve data transmission and communication trust. In particular, the trustworthy networking and communication protocols can support heterogeneous and specific networking contexts.

5.1.3. Social Layer Trust

Social networks are popular for sharing information and knowledge. Trust is an important feature in social networks because they rely on the level of trust that users have in each other, as well as in the service provider. Social layer trust actually depends on the behaviour and interactions of humans in the social networks. If trust is not gained by humans, they may not wish to share their experience and knowledge with others because of the fear that their knowledge and privacy will be misused.

5.1.4. Cross Layer Trust

In the SCP infrastructure, there are interactions between the social, virtual and physical objects, as well as data transmission between them. Actually, the objects in the physical and cyber world interoperate closely with each other and form a system organization around its (human) users in the social world. Human interactions with cyber/physical objects should be performed in a trustworthy way.

Furthermore, because most smart devices are human-related or human-carried devices, the social relationships between humans can spread between their devices. To define and manage trust between physical, cyber and social layers, appropriate trust models for the interactions between social, information and communication networks are required while taking into account the severe resource constraints and the dynamics. Trust evaluation and trust management are especially challenging issues in the social/cyber/physical cross layer trust.

5.1.5. Cross Service Trust

Trust management is service and domain specific, and it may be desirable to combine features from different trust management systems for developing a cross-service trust

management that is able to cover social/cyber/physical trust relationships between different service domains.

Trust dissemination means to distribute or broadcast trust information. To disseminate trust information from one service domain to another, a trust service brokering mechanism can be used for efficient, effective and suitable trust dissemination.

5.2. Trust Architectural Framework

Based on the generic ICT trust conceptual model, this subsection describes a trust architectural framework consisting of three parts as shown in Figure 5: i) Trust Agent (TA) to gather trust-related data from social, virtual or physical objects; ii) Trust Analysis and Management Platform (TAMP) to model and analyse trust-related data and the trust relationship; iii) Trust Service Broker (TSB) to apply and disseminate trust-based knowledge to various services.

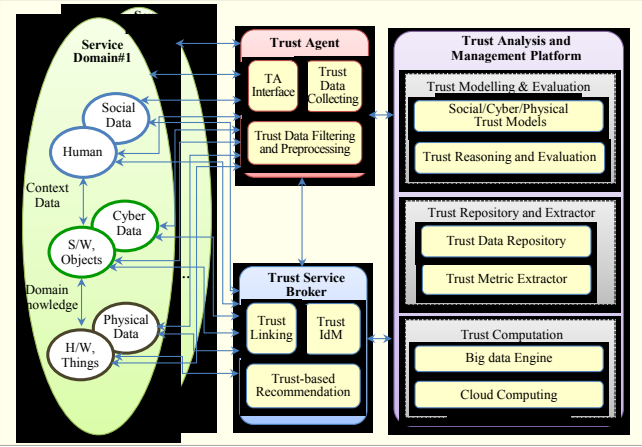

Figure 5. Trust architectural framework

5.2.1. Trust Agent (TA)

TA is used to collect trust-related data from the social, cyber and physical environments with the following modules.

- **TA Interface**: The TA provides lightweight interfaces to collect trust-related data from various types of objects in the social, cyber and physical layers. Furthermore, TA interfaces need to be easily connected to existing platforms and devices in order to extract the required data.
- **Trust Data Collection**: In order to evaluate a trust level of an object, the Trust Analysis and Management Platform (TAMP) identifies the required trust metrics for the object and informs TA's trust data collection module accordingly, as the trust data collection module is responsible for gathering the data required for the trust evaluation.
- **Trust Data Filtering and Preprocessing**: This module is used to refine trust data sets without including other data that can be repetitive, irrelevant or even sensitive for trust evaluation.

5.2.2. Trust Analysis and Management Platform (TAMP)

TAMP is used for modelling, reasoning and managing trust data collected from TAs to check whether the physical objects, virtual objects or humans satisfy certain trust criteria.

TAMP consists of several modules: trust modelling, trust reasoning and evaluation, trust data repository, trust metric extractor, trust computation, and so on.

- **Trust Modelling**: A trust model is used to specify, annotate and build trust relationships between objects for the purpose of reasoning trust data. Trust modelling is layer-specific and service domain-specific and there are social, cyber and physical trust models to define a trust model for each layer in the SCP infrastructure. According to its layer and a particular service domain, a suitable trust model is selected and applied for trust modelling. The trust-related data collected from trust agents can be transformed to structured and annotated formats by using semantic and ontology technologies through this trust modelling module.
- **Trust Reasoning and Evaluation**: Trust evaluation is used to analyse and assess trust levels based on the trust model. There are various types of reasoning methods which depend on the layer and service domain, and a proper reasoning method will be chosen for the specific object. For example, policy-based trust reasoning makes a binary decision according to which an object is trusted or not. Because trust status could change with time and circumstantial context, a trust reasoning method must handle such dynamics of trust.
- **Trust Data Repository**: The structured trust data including operations of objects and the history of interaction between objects can be maintained in the trust data repository. For trust evaluation, the necessary data will be loaded from this repository to the computation module.
- **Trust Metric Extractor**: A trust metric is used to judge or decide the trustworthiness of an object and it is separately defined in each service or each object. The trust metric extractor recognizes trust characteristics, accounts for factors influencing trust and determines proper trust metrics for the trust modelling and reasoning by analysing the metadata or semantic ontologies.
- **Trust Computation**: This module is used for data processing for trust evaluation. Trust computation happens when the state of an object has changed or an interaction occurs between objects. To process the large amount of data related to trust evaluation, it can adopt big data technologies, batch processing big data engines for calculation of the trust level of objects and real-time big data engines for examining the change of the trust state of objects based on direct observation.

5.2.3. Trust Service Broker (TSB)

TSB is used to provide trust knowledge of physical objects, virtual objects and humans for various types of services and applications in the ICT world. Furthermore, it can merge and disseminate trust knowledge across service domains or social/cyber/physical layers.

- **Trust Linking**: Trust linking is a module capable of creating a link between data/information/knowledge entities generated from a physical/cyber/social object based on trust criteria.
- **Trust IdM**: The identity management (IdM) can be used to manage digital identification/authentication of physical objects, virtual objects and humans. Trust IdM is able to involve trust knowledge to assure the identity of trustworthy objects and support trust-based services and applications.
- **Trust-based Recommendation**: This module provides recommendations to other objects. More specifically, a number of individual objects can be interconnected to construct a complex system for providing various services, and many objects with identical capabilities will exist on the Internet. This module aims at providing a recommendation for selecting a suitable object that meets the trust level.

6. CONCLUSION AND FUTURE STANDARDIZATION

This paper has looked at the future of converged ICT services and information infrastructures for a hyperconnected society and has provided the concept of an SCP infrastructure from emerging social IoT paradigms. From the understanding of trust, we have identified key challenges for trustworthy ICT infrastructures and proposed an architectural framework for trust provisioning as a key activity of the ITU-T CG-Trust. In conclusion, the future of ICT infrastructures is evolving towards a trustworthy SCP infrastructure with trust-enabled, knowledge-centric networking and services.

Until now, a number of standards focusing on network security and cybersecurity technologies have been developed in various standardization bodies including the IETF. The scope of these standards needs to be expanded to take into consideration trust issues in future ICT infrastructures. There are a few preliminary activities taking place, for instance in the Online Trust Alliance [17] and the Trusted Computing Group [18]. However, as existing research and standardization activities on trust are still limited to social trust between humans, trust relationships between humans and objects as well as across domains of social-cyber-physical worlds should also be taken into account for trustworthy autonomous networking and services.

Based on this, we first need to find various use cases considering user confidence, usability and reliability in ICT ecosystems for new business models which reflect a sharing economy. Then, a framework for trust provisioning including requirements and architectures should be specified in relation to the relevant standards. In addition, global collaborations with related standardization bodies are required to further stimulate trust standardization activities.

Acknowledgement

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WI-TRUST: IMPROVING WI-FI HOTSPOTS TRUSTWORTHINESS WITH COMPUTATIONAL TRUST MANAGEMENT

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ABSTRACT

In its list of top ten smartphone risks, the European Union Agency for Network and Information Security ranks Network Spoofing Attacks as number 6. In this paper, we present how we have validated different computational trust management techniques by means of implemented prototypes in real devices to mitigate malicious legacy Wi-Fi hotspots including spoofing attacks. Then we explain how some of these techniques could be more easily deployed on a large scale thanks to simply using the available extensions of Hotspot 2.0, which could potentially lead to a new standard to improve Wi-Fi networks trustworthiness.

***Keywords*—** Wi-Fi, public hotspot, computational trust

1. INTRODUCTION

The European Union Agency for Network and Information Security (ENISA) gives the following definition for Network Spoofing Attacks: "An attacker deploys a rogue network access point (Wi-Fi) and users connect to it. The attacker subsequently intercepts (or tampers with) the user communication to carry out further attacks such as phishing". This type of attack is ranked number 6 in its list of top ten smartphone risks [1]. In order to mitigate this risk, the Wi-Fi Alliance and Wireless Broadband Association have worked on a new standard called Hotspot 2.0 (HS 2.0) or Wi-Fi Certified Passpoint. Unfortunately, most hotspots currently deployed are legacy hotspots and it is going to take time and efforts to change them into Hotspot 2.0-enabled devices. In 2014, Ferreira et al. [2] underline regarding Hotspot 2.0 that "although technical security has improved in comparison with the previous hotspot version, many issues still need addressing before its full deployment and usage in parallel with that previous version (which will not quickly disappear)". In addition, even a Hotspot 2.0 may be compromised or controlled by an untrustworthy provider who can carry out different types of man-in-the-middle attacks if the user does not use a VPN. Therefore, authentication alone is not enough because the authenticated hotspot may be controlled by an untrustworthy owner/provider or attacker who has broken into the hotspot: another layer of trust is necessary on top of authentication trust to make the decision to use one or another available hotspot in user range.

Section 2 discusses what has been proposed so far to tackle remaining trust issues in hotspots, starting with computational trust management background and how it has been applied to hotspots by others and us. It also includes how we have validated it as part of different research projects [3]–[6] that we have carried out funded by the European Commission under the Seventh Framework Programme. In Section 3, based on this previous work that has shown the usefulness of computational trust for increased hotspot trustworthiness, we present our proposal for new standard for trustworthy hotspots selection and promotion called Wi-Trust that can be easily applied on top of Hotspot 2.0. Section 4 concludes with future work towards that standard.

2. COMPUTATIONAL TRUST TO MITIGATE REMAINING HOTSPOTS SECURITY HOLES

In this section, we first explain how computational trust based on the human notion of trust is different from the traditional concept of trust in computer security. Then, we detail the remaining security holes in Wi-Fi hotspots and the previous attempts to tackle these security holes both by others and us.

2.1. Computational Trust Management

In the human world, trust exists between two interacting entities and is very useful when there is uncertainty in result of the interaction. The requested entity uses the level of trust in the requesting entity as a mean to cope with uncertainty, to engage in an action in spite of the risk of a harmful outcome. There are many definitions of the human notion trust in a wide range of domains, with different approaches and methodologies: sociology, psychology, economics, pedagogy, etc. These definitions may even change when the application domain changes. However, it has been convincingly argued that these divergent trust definitions can fit together [7]. Romano's definition tries to encompass the previous work in all these domains: *"trust is a subjective assessment of another's influence in terms of the extent of one's perceptions about the quality and significance of another's impact over one's outcomes in a given situation, such that one's expectation of, openness to, and inclination toward such influence provide a sense of control over the potential outcomes of the situation"* [8].

Interactions with uncertain results between entities also happen in the online world. So, it would be useful to rely on trust in the online world as well. However, the terms trust, trusted, trustworthy and the like, which appear in the traditional computer security literature, have rarely been based on these comprehensive multi-disciplinary trust models and often correspond to an implicit element of trust – a limited view of the facetted human notion of trust. For

example, the trusted computing technology is assumed to be trusted once for all, full point.

To go beyond a fixed mandatory trust assumption, a computational model of trust based on social research was first proposed by Marsh [9]. In social research, there are three main types of trust: interpersonal trust, based on past interactions with the trustee; dispositional trust, provided by the trustor's general disposition towards trust, independently of the trustee; and system trust, provided by external means such as insurance or laws [7]. A trust metric consists of the different computations and communications, which are carried out by the trustor (and his/her network) to compute a trust value in the trustee. Trust evidence encompasses outcome observations, recommendations and reputation.

A very well-known attack, which is difficult to mitigate in open environments such as the Internet because allocating only one digital identity per person in the world is still difficult to achieve on a worldwide scale, is called the Sybil attack [10]. There is not yet a perfect trust metric that is Sybil attack resistant in all situations and without any constraints but for example we created the "*trust transfer*" [11] trust metric that is resistant to Sybil attacks if only positive recommendations are propagated.

The EU-funded SECURE project [11] represents a well-known example of a computational trust engine that uses evidence to compute trust values in entities and corresponds to dynamic evidence-based trust management systems. As depicted in Figure 1 below, the decision-making component can be called whenever a trusting decision has to be made. The Entity Recognition (ER) [11] module is used to recognize any entities and to deal with the requests from virtual identities. Relying on recognition rather than strong authentication, which means that the real-world identity of the user must be known, is also better from a privacy point of view because there is no mandatory required link to the real-world identity of the user if recognition is used rather than authentication.

It may happen that the trusting decision is not triggered by any requesting virtual identity, for example, if the user device would like to select the trustworthiest Wi-Fi hotspot in range in the list of nearby found hotspots. Usually, the decision-making of the trust engine uses two sub-components [11]:

- a trust module that can dynamically assess the trustworthiness of the requesting entity based on the trust evidence of any type stored in the evidence store;
- a risk module that can dynamically evaluate the risk involved in the interaction, again based on the available evidence in the evidence store.

A common decision-making policy is to choose (or suggest to the user) the action that would maintain the appropriate cost/benefit. In the background, the evidence manager component is in charge of gathering evidence (e.g., recommendations, comparisons between expected outcomes of the chosen actions and real outcomes, etc.) This evidence is used to update risk and trust evidence. Thus, trust and risk follow a managed life-cycle.

2.2. Hotspots Security and Remaining Threats

In a 2012 report [12], Cisco underlined the following remaining security holes in legacy Wi-Fi hotspots security that may lead to identity theft: legitimate hotspot spoofing, session hi-jacking or eavesdropping on unencrypted Wi-Fi. Common defense was to use 802.1X Port Access Control for robust mutual authentication. However, large-scale deployment was too tricky: "the most challenging part of deploying 802.1X involves installing and configuring client-side software and user credentials" [13]. Using a VPN on top of unencrypted communication solves eavesdropping, but most users do not have or know a VPN, and they even less want to spend time configuring it or pay for it since public Wi-Fi hotspot is more and more assumed to be free. The centralization of VPN servers is also not great from a privacy protection point of view. Private enterprise networks based on WPA2-Enterprise certification do not suffer from these attacks because they use IEEE 802.11i security and EAP authentication. Unfortunately, WPA2-Enterprise technology cannot be applied to legacy Wi-Fi hotspot networks because the access point's 802.1X port blocks all communications prior to authentication.

Due to the limitations of legacy Wi-Fi hotspots, the Wi-Fi Alliance started to work on Hotspot 2.0 and launched its first versions in 2012 in order to automate selecting Wi-Fi networks based on user preferences and network optimization, granting access to the network based upon credentials such as SIM cards, without user intervention, over-the-air encrypted transmissions with Certified WPA2-Enterprise.

Regarding worldwide user strong authentication that would ensure giving only one digital identity to any user, it is not realistic. So far, all initiatives to achieve it have not succeeded; a global PKI (Public Key Infrastructure) has been deemed not feasible. Social and federated logins [14],

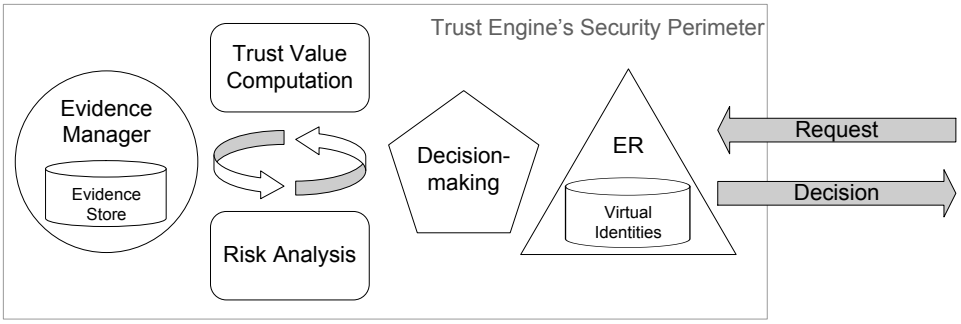

Figure 1. High-level View of a Computational Trust Engine

even though useful, cannot be tied properly to a real world identity because identities can be easily faked: for example, fake and zombie Facebook accounts are still a problem. Of course, if linking the user client with its real-world identity is done via strong authentication, the legal liability of the user client can be enforced but otherwise the hotspot sharer may be deemed liable in many countries. For example, in France, the Hadopi [15] law allows the French control service to use the IP address the Wi-Fi sharer to incriminate that Wi-Fi sharer if the user client cannot be strongly identified after having done illegal activities such as downloaded illegally shared copyrighted music.

On one hand, Hotspot 2.0 facilitates strong authentication of users linked to their real world identity because SIM-based authentication is possible. However, a SIM for a phone number may still not be linked to a real-world identity due to prepaid SIM whose owner real-world identity has not been verified yet. Filipinos services are known to provide fake Facebook accounts that have been validated with SIM. On the other hand, Hotspot 2.0 Release 2 is made to strongly authenticate the hotspot service provider. However, it does not mean that the owner of the authenticated hotspot is trustworthy. It may also happen that an attacker compromises a legitimate hotspot. Therefore even if user communication is encrypted between the user client and the hotspot or the hotspot service provider, the hotspot may have been compromised and man-in-the-middle attack is happening or the service provider itself may spy on unencrypted communication from the user. Another layer of trust is necessary on top of the authentication trust layer and computational trust is an appropriate means to compute that trust value in hotspots and service providers. With computational trust in the client user, even if the legal liability in the user is not enforced for sure, then the hotspot service provider can still allow access to trustworthy users and forbid access to untrustworthy ones.

2.3. Previous Attempts to Use Computational Trust in Hotspots

In this subsection, we first present the previous attempts to use computational trust in hotspots by others and then our own previous attempts.

Salem et al. [16] proposes a reputation system that enables the user to choose the best hotspot and discourages the Wireless Internet Service Providers (WISP) from providing a bad Quality of Service (QoS) to the mobile nodes. In their model, the behavior of each WISP is characterized by a reputation record, which is generated and signed by a trusted Central Authority (CA).

Momani et al. [17] introduce a new algorithm of trust formation in wireless sensor networks based on the QoS to be fulfilled by the network's nodes. They use three main sources to compute trust, namely direct observations (past experiences), recommendations from the surrounding nodes and fixed dispositional trust in nodes.

Trestian et al. [18] further examines network selection decision in wireless heterogeneous networks. They define a network reputation factor which reflects the network's previous behavior in assuring service guarantees to the user. Using the repeated Prisoner's Dilemma game, they model the user–network interaction as a cooperative game and show that by defining incentives for cooperation and disincentives against defecting on service guarantees, repeated interaction sustains cooperation. Their approach is very interesting because they focus on the user requirements or preferences although they do not prevent the user from connecting to malicious hotspots as we have done below.

As part of the FP7 EU-funded project called PERIMETER, we modeled and implemented a computational trust engine with a new trust metric called *TrustedHotspot* [3]. In our model, the behavior of each hotspot Access Point (AP) is characterized by a trust value in the range [0,1] computed based on the previous experiences of the users with that AP. Each AP owns its own private key and all messages are signed. We manage a central server hosting the cache of the trust values in each AP by each user. After using the AP, the user can rate it given different QoS rating possibilities. When possible, the QoS rating of the users are compared to automated technical measures such as average round-trips enforced by an additional application that must run on the user client. The user trust value decreases when it seems that the user has cheated when providing her/his rating. We have shown that it is more attack-resistant than Salem's one in [3].

We have also advanced computational trust management for hotspots in the other FP7 ULOOP project. First, we modeled and implemented an adaptive dispositional trust metric [19] where we don't use the dispositional trust level as a constant value as in Momani et al. [17] mentioned above, but as a value that can change over the time depending on the surrounding environment. Then, we have integrated trust management and cooperation incentives with our *"trust transfer"* trust metric [11], which has been proven to protect against Sybil attacks [10]. Our *"trust transfer"* trust metric implies that recommendations move some of the trustworthiness of the recommending entity to the trustworthiness of the trustee. Thus, in addition to assess trust, we can use the metric to reward in the form of trust points the agents that share their Wi-Fi connectivity [5]. To facilitate Wi-Fi sharing, we developed an Android app as part of the FP7 TEFIS smart ski resort project experimentation [20], which allowed locals to share their Wi-Fi network without taking the risk to be responsible of malicious activities done by the user client. Although it worked seamlessly for legacy personal hotspots and Android smartphones without having to jailbreak them, it is not yet possible to achieve the same level of automation with more controlled smartphones such as iPhones [6].

3. WI-TRUST: OUR NEW PROPOSAL TO PROMOTE TRUSTWORTHY HOTSPOTS

The above related work has shown the benefits of adding computational trust management to hotspots. It has also underlined that different authentication trust metrics as well as trust metrics in client users and hotspot owners exist. Unfortunately, previous work required too many changes in current Wi-Fi technologies to be easily deployable on a large scale. Therefore, our new proposal to reach wider

adoption should be able to easily plug different trust metrics. It is the reason we have based our proposal on the common high-level view of a computational trust engine as depicted in Figure 1.

In addition, to further facilitate worldwide adoption, it shouldn't require forcing too many changes in current hotspots standards. For example, Apple smartphones with iOS7 and Samsung S5, as well as Android M 6.0 and above, already supports some versions of Hotspot 2.0. Hence, we have investigated how to integrate our proposal with Hotspot 2.0.

Regarding the Entity Recognition (ER) component of a computational trust engine, fortunately, Hotspot 2.0 includes an Extensible Authentication Protocol (EAP) framework [21]. Therefore, we propose to map the ER module to this EAP part of Hotspot 2.0. Depending on the chosen authentication scheme selected between the client user and hotspot owner, then authentication trust can be computed. For example, SIM-based authentication is possible via EAP-SIM [22] and should get higher system trust than manual password-based only authentication. X509 certificates are also possible and the Wi-Fi Alliance has already allowed a few Certificate Authorities (CAs, e.g. Verizon, DigiCert and NetworkFX) to provide validated certificates for Wi-Fi hotspots providers to prove that their hotspot comes from a legitimate and trusted provider. In Hotspot 2.0 Release 2, a user client uses Online Sign-Up (OSU) to accomplish registration and credential provisioning to obtain secure network access. Each hotspot service provider has an OSU server, an Authentication Authorization and Accounting (AAA) server, and access to a CA, which is known by two attributes: its name and its public key. A user client trusts a hotspot if the OSU server has a certificate signed by a CA whose root certificate is issued by one of the CAs authorized by Wi-Fi Alliance, and that these trust root CA certificates are installed on the user client.

Since Release 1, Hotspot 2.0 has introduced new capabilities for automatic Wi-Fi network discovery, selection and 802.1X authentication based on the Access Network Query Protocol (ANQP), which forms the basis for 802.11u, an amendment to the IEEE 802.11 published in February 2011, and is a query and response protocol that defines services offered by an access point (AP), typically at a Wi-Fi hotspot. The ANQP communicates metadata useful for hotspot/AP selection process including the AP operator's domain name, the IP addresses available at the AP, and information about potential roaming partners accessible through the AP. When a subscriber queries an AP using the ANQP, that user receives a list of items that describe the services available, without having to commit to a network. In addition to the above-mentioned items, these elements can include geospatial and civic locations of the AP, capabilities of the network(s) being accessed, authentication types required by or available with the AP…

Thus, we propose to use those extra already available ANQP metadata fields called elements to exchange signed computational trust information in the hotspot at time of network selection by the user client. Different types of computational trust information are possible depending on the trust metric chosen but the main steps for exchanging computational trust information will follow the standard steps involved in the ANQP. Hence, our proposal to add computational trust management to hotspot is fully compatible with Hotspot 2.0 and can be seamlessly implemented in Hotspot 2.0 compatible hotspots by simply using the extra already available ANQP elements. For example, the OpenWrt [23] open source basis for hotspots, used by several hotspot providers such as FON, has already software components to be compatible with Hotspot 2.0. Figure 2 depicts the main sequence diagram of our proposal.

In Step 1, on the bottom left corner of the diagram, the user client, extended with our computational trust engine consisting of special hotspot selection policies and a potential additional installed app locally caching trust values, probes nearby hotspot to check whether or not they are compatible with Hotspot 2.0 and receives one from the nearby Hotspot 2.0 in the middle. In Step 2, the user client sends an ANPQ request including potentially Vendor Specific elements needed by the chosen and plugged computational trust metric used by the client. For example, our Sybil attack-resistant trust metric [11] or Salem's one [16]. In Step 3, the Hotspot 2.0 extended with our computational trust engine, initially implemented as an extension of OpenWrt Hotspot 2.0 implementation, checks the additional computational trust information sent in the ANPQ request elements and optionally gather during steps 4 and 5 other computational trust values in our new remote computational trust management (CTM) server. All trust values are signed by our CTM and can be passed back to the user client by the Hotspot 2.0 via ANPQ request answer Vendor Specific elements if needed. In Step 6, the user client receives the ANPQ request answer from the Hotspot 2.0 including optional Vendor Specific elements required by the trust metric. Locally cached and received computational trust values are used during step 7 by the user client to decide whether or not the Service Provider certified thanks to Hotspot 2.0 is trustworthy enough. Location coordinates of the Hotspot 2.0 may also be added in order to be able to trust not only the Service Provider owner of the Hotspot 2.0 but also the hotspot itself via the combination of location coordinates and Service Provider certification. If the user client decides to trust and select that Hotspot 2.0, the user client starts the normal Hotspot 2.0 authentication step with the Hotspot 2.0. In addition to carry out the normal authentication checks, the Hotspot 2.0 can optionally retrieve more trust information in the user client from the CTM server during steps 9 and 10 in order to decide during step 11 whether or not the user client is trustworthy enough to let it access the Internet through the Hotspot 2.0, for example, due to potential remaining legal liabilities of the hotspot owner when the user client accesses the Internet through the hotspot. If access is granted, then the user client accesses the Internet through the Hotspot 2.0 hotspot during Step 12 as usual. After its use, an optional step 13 is done by the user client to rate the QoS provided by the Hotspot 2.0 compared to what the Hotspot 2.0 proposed in the ANPQ answer. That new rating is turned into new trust evidence sent back to the CTM

server in step 14 and the CTM server updates the trust value in the Hotspot 2.0 during step 15. Based on the chosen and plugged trust metric, the new user client rating may be

In case of hotspots that are not easy to deploy according to Hotspot 2.0, such as personal hotspots shared by individuals because not everybody is able to manage extra

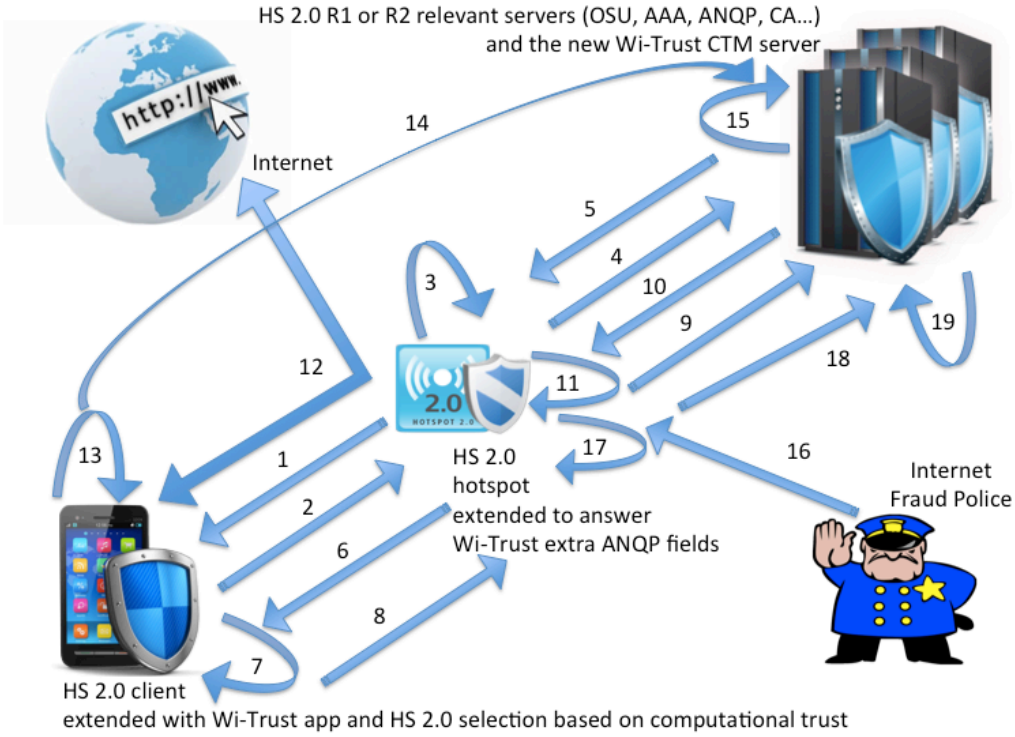

Figure 2. Wi-Trust Main Sequence Diagram

more or less trusted, for example, if the user client seems to consistently rate hotspots lower than others or other mechanisms are put in place to detect untrustworthy ratings as we demonstrated in [3]. Optionally, step 16 represents the case when an Internet fraud police institution, such as the French Hadopi institution created to monitor illegal Web activities by French users [15], contacts the Hotspot 2.0 owner due to illegal activity found at some stage from the Hotspot 2.0. In this case, the Hotspot 2.0 locally updates the trust value of the incriminated user client in step 17 and could inform the CTM server for further trust update on the server via steps 18 and 19.

Thus, thanks to our computational trust extension of Hotspot 2.0, 3 types of trust values can be computed:

1. Trust values in Wi-Fi service providers: these trust values will help selecting the most trustworthy service providers and encourage overall better Wi-Fi service quality because Wi-Fi providers will try to remain trustworthy in order to keep more users;
2. Trust values in Wi-Fi service providers hotspots: if location coordinates are used in addition to the certified service provider identity;
3. Trust values in user clients: user clients may be identified by various strong means depending on the EAP scheme used, for example, based on SIM number and trust values may concern their trustworthiness in rating service providers or not carrying out illegal activities such as downloading illegally shared copyrighted music.

servers such as Radius ones, although it may be possible to modify their software hotspot client and server to take into account trust values exchanged and stored in a similar way, worldwide adoption would be more difficult than with Hotspot 2.0, which is already backed up by major Wi-Fi stakeholders. The following table summarizes the available features.

Table 1. Available features

	Legacy Hotspot	Hotspot 2.0	Wi-Trust
Wi-Fi roaming authentication without initial manual intervention		*	*
Client/Hotspot encryption against eavesdropping		*	*
Strong authentication of the hotspot service provider and user client		*	*
Automated hotspot selection	*	*	*
Automated hotspot selection based on computational trust in hotspots and service providers			*
Hotspot owner legal liability mitigation by malicious user client exclusion based on computational trust			*

4. CONCLUSION

More and more users and devices want to use Wi-Fi to communicate and Wi-Fi may even be used to offload mobile data from telecom operator networks. Previous work has shown that computational trust management improves several security shortcomings of legacy hotspots but it was too difficult to deploy them on a large scale. We have presented how we could easily extend Hotspot 2.0 with computational trust management to even mitigate these shortcomings further. Legacy hotspots, which are likely to remain for a while, may also be extended with computational trust management, especially to secure collaborative Wi-Fi sharing with personal hotspots that cannot be achieved with Hotspot 2.0. However, there is much higher chance to achieve standardization of Wi-Trust based on Hotspot 2.0 because it doesn't require deep changes and can use open elements of Hotspot 2.0. We hope that our contribution published in the 2015 ITU Kaleidoscope conference will encourage standardizing Wi-Trust in a potential Hotspot 3.0 standard for increased trust in Wi-Fi.

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WIFIOTP: PERVASIVE TWO-FACTOR AUTHENTICATION USING WI-FI SSID BROADCASTS

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ABSTRACT

Two-factor authentication can significantly reduce risks of compromised accounts by protecting from weak passwords, online identity theft and other online fraud. This paper presents a new easy solution to implement two-factor authentication without affecting user experience by introducing minimum user interaction based on standard Wi-Fi. It has been validated with different software and hardware implementations in a real life environment to show it can easily be deployed in many cases.

Keywords— user-friendly security, multi-factor authentication

1. INTRODUCTION

Traditional two-factor authentication solutions use standalone hardware or software tokens (often isolated from the primary system, e.g. a mobile application running on a smartphone) that generate one-time passwords (OTP) for the second step of the login process [1]. Users need to transfer these OTPs to the primary system to complete the process. In most of the cases (with a few exceptions described in Section 2), users need to type the OTP manually. This introduces a certain level of inconvenience that leads to negative user experience and ultimately user resistance.

WifiOTP is a concept of simplifying user interaction with systems requiring two-factor authentication by eliminating the need of typing OTPs manually; instead, a special device (WifiOTP Token) will generate and broadcast OTP as a part of wireless network service set identifiers (SSID). This SSID will contain a system ID (a prefix to distinguish between other SSIDs) and an OTP part encrypted with a symmetric algorithm.

In this paper we present the concept on WifiOTP. In Section 2, we discuss related work. Section 3 presents the model of our solution and Section 4 shows how we have validated it with different software and hardware implementations to show it can easily be deployed in many cases. We conclude in Section 5.

2. RELATED WORK

We have reviewed a number of research and commercial products in the same or similar area. We believe the examples below have limited success in reaching the balance of strong security and minimal user interaction.

2.1. Google Authenticator

As our proof-of-concept will be a "drop-in" replacement of popular strong security systems, we review one of the most commonly used two-factor authentication systems, Google Authenticator, a mobile application concept used to secure services provided by Google, as well as many other services [2]. The application generates one-time passwords (OTP) by calculating a hash based on a secret shared key (known to mobile application and the authentication server) and the current timestamp with a 30 seconds modulo as defined in RFC 6238, Time-Based One-Time Password Algorithm (TOTP) [14].

As per described procedures, the authentication process assumes that user would manually type in the OTPs generated by mobile application. Obviously, this process is not very user friendly, and we will attempt to minimize user interaction by keeping the same security level.

2.2. Zero Interaction Authentication

Zero Interaction Authentication (ZIA) is one example of an effort for making security easy to use. A few academic papers include concepts of using existing wireless or wired network components for ZIA. However, the proposed systems are based on actually connecting to common wireless [3] or wired [4] networks which makes it impossible to use in systems that do not allow multiple wireless connections and presents additional risks of network based attacks. These papers also use constant characteristics of network components, such as BSSID of a WLAN network or a MAC address of network routers, which could make the systems vulnerable to replay attacks.

2.3. Context-aware application and Wi-Fi proximity

A system based on WIFI SSID is proposed by Namiot [5], [6] where SSID is used as a context-aware application concept. This paper describes using the information exchanged between access points and client devices to determine proximity data and using this proximity data to

send promotional information, similar to Apple's iBeacon technology but based on Wi-Fi rather than BLE (Bluetooth Low Energy). This paper uses similar concept of utilizing Wi-Fi SSID to relay information, but does not provide any security analysis as the system is not intended to be used as a security mechanism.

2.4. One-touch financial transaction authentication

SSID broadcasts based systems are researched by authors [7], where they propose to channel the authentication data via SSID, however their approach assumes two-way communication between the client and the SSID Access point. This approach is logical if the purpose is to be used in a typical online banking system where the user interacts with the second factor authentication system. In this approach, the client device sends a packet and receives a response from the system broadcasting SSID in both directions. The limitation of this method is that the client device will need to emit SSID broadcasts and not only scan for SSIDs; this method is a significant obstacle for systems using WLAN as their primary connection. This would not be required for TOTP based systems as only one-way data flow is needed for such systems.

2.5. Amigo: proximity-based authentication of mobile devices

Amigo [8] is another example of proximity authentication based on Wi-Fi proximity, which utilizes promiscuous mode for 802.11 frame packet scanning. This system requires at least three trusted devices in the close proximity (few meters), which can be considered a major drawback compared to WifiOTP which requires only one device providing Wi-Fi coverage with minimal signal strength (up to 100 meters).

2.6. BLE based OTP tokens

Another system with closer implementation is proposed [9], where TOTP broadcasts are emitted by a BLE based token beacon device. This concept may be further developed using Eddystone, an open beacon format recently announced by Google [10]. The drawbacks of these systems are: BLE is only supported on limited types of devices and also Bluetooth is usually not activated on devices as users often perceive it as a battery hog.

2.7. Authy Bluetooth

Authy Bluetooth is a TOTP based implementation of two factor authentication very similar to WifiOTP concept. As it is based on BLE protocol, the use of Authy Bluetooth [11] is limited to situations were both a client access system (e.g. a laptop) and the system running the token (e.g. a mobile phone with the Authy app) support the BLE protocol. For this reason, Authy Bluetooth is only supported on recent Mac devices as clients, iPhone 4s and above, plus Android devices running version 4.4.4 and above with BLE support as mobile device.

In addition, the current implementation can hardly be considered as a system with "minimal user interaction" as users need to: launch Authy application, select an account and after the current OTP is copied to clipboard, users are advised to paste it to the form requiring the OTP.

2.8. Yubico hardware tokens

Yubico offers a number of products appearing to be the achieving the real minimum of user's interaction required to submit second factor [12]. Yubico's Nano and Neo hardware tokens are designed to send generated OTPs via NFC or USB (emulating keyboard input). These devices are indeed making two-factor authentication much easier for end users, however there are still some disadvantages. The USB based token is impossible to use in the majority of mobile devices without additional equipment, and the activity range of NFC token is limited to 15 centimeters [13]. Furthermore, the number of accounts each token can use is limited to maximum 2 keys per device (up to 2 keys per device), whereas WifiOTP as a concept poses no such restriction.

3. OUR WIFIOTP SOLUTION

3.1. System model

The client part will be an application running on user's device that queries the WLAN network adapter for the list of currently available SSIDs and finds the one with required prefix (System ID) then decrypts the OTP part using shared key and sends as text to the relevant input fields either automatically or when requested by the user (e.g. by pressing a button or a keyboard shortcut). As a result, the final authentication credentials will contain three authentication components: the username (entered by user), password (entered by user) and OTP (automatically read from SSIDs and decrypted instantly upon activation).

The solution consists of two main components:

- WifiOTP client: a connector application or a service/daemon running on the client device that scans the broadcasted SSIDs periodically or when initiated by users

- WifiOTP token: a Wi-Fi access point running that broadcasts a periodically changing SSID that contains the encrypted one-time password together with other data (e.g. system ID etc.)

It is important to mention that WifiOTP concept does not require the clients to be connected to the detected WifiOTP network; in fact, it would be rather inconvenient as the SSID broadcasted by WifiOTP token changes periodically as mentioned above. The clients can be connected to any other network, wired or wireless, or via cellular data

connections. Therefore the type of the encryption used for WifiOTP wireless network does not matter, in our implementation we created secured WLAN with randomly changing pre-shared key value.

The system's principle is illustrated in Figure 1. The device used as an access point is using a locally stored secret hash to generate OTP values and broadcasts an SSID that includes the system identifier and the current OTP. OTP values change periodically (every 30 seconds as per TOTP specification [14]), therefore the broadcasted SSID equally changes.

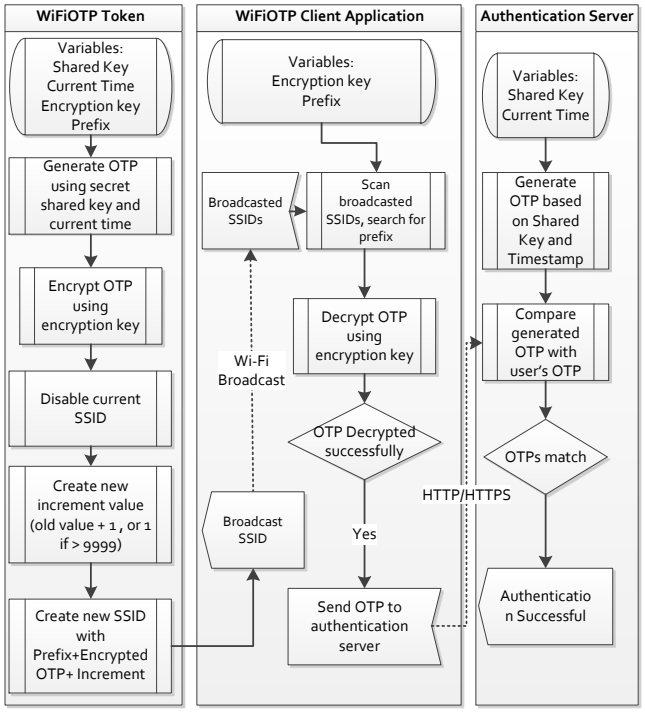

Figure 1. WifiOTP Logical diagram

The format of SSID broadcasted by WifiOTP token is shown on Figure 2.

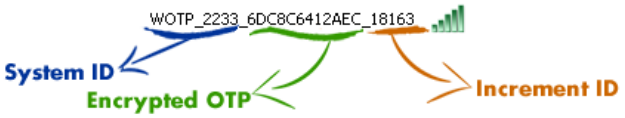

Figure 2. Format of SSIDs broadcasted by WifiOTP tokens

The connector application on the client device scans the broadcasted SSIDs periodically searching for SSIDs starting with predefined prefix (in the example above, "WOTP__") then parses the SSID name to extract the system ID and encrypted OTP. The system ID is used to distinguish between multiple WifiOTP accounts running in parallel on the same token device. The last portion of SSID, Increment ID, is required to overcome the SSID name "caching" on the client systems. The value of Increment ID will increment on every OTP change and the SSID with larger increment value will be used as the current OTP (if the increment reaches 99999, the SSID with increment equal to 1 will be considered the most current one). The client application may use a predefined API to pass the authentication data to the validating server, or just pass the parsed data to another application (i.e. a web browser) using keyboard shortcut or other methods. This data flow is illustrated in Figure3.

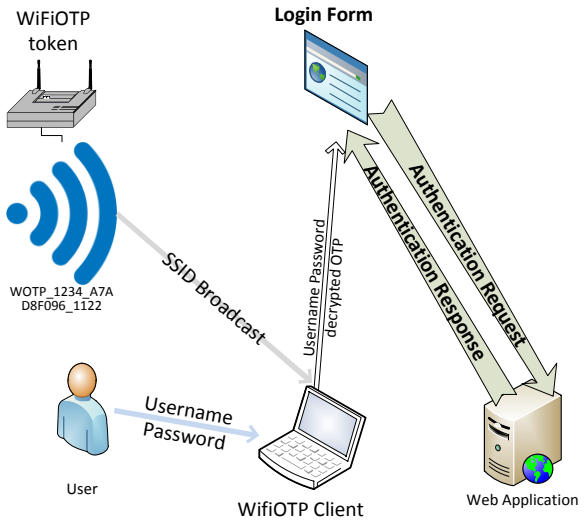

Figure 3. WifiOTP Data flow model

In this example, the current OTP (decrypted by the client application) is passed to the server together with the first authentication factor (username and password). At the final step, all submitted data is verified on the server: username and password checked for validity, and submitted OTP checked with the OTP generated on the server using the same secret hash.

3.2. One-Time password generation and encryption

As described above, we will be using TOTP as the standard for generating OTP. In principle, TOTP is a version of HOTP where current time is used as a part of secret key [14]. The value of OTP is calculated using function:

$$TOTP\ (K, T) = Truncate\ (Hash\ (K, T))$$

where:
T – The current timestamp's increment value,
K – The shared secret key (stored on the authentication server and the WifiOTP device),
Hash – a hash function (HMAC-SHA-256, HMAC-SHA-512 or other HMAC-based functions),
Truncate- a function to select a certain portion of the generated hash to be used as the OTP.
With WifiOTP, OTP is encrypted with a symmetric encryption algorithm in order to avoid transmitting current OTPs in plaintext. Due to the limitations of SSID name length (maximum 64 characters), the algorithms that can be

used for this step are also limited. The value transmitted using WifiOTP is calculated using the following function:

$$WifiOTPServer\ (K, T, E) = CiphEncr\ (TOTP\ (K, T), E)$$

where:
CiphEncr – a symmetric encryption function (e.g. RC4),
E - a key for encrypting the OTP (known to WifiOTP device and the client application).
The client application will scan the broadcasted networks and select one SSID matching the defined conditions (e.g. having a specific prefix and the highest increment number). Then, the OTP to be transferred to the authentication server will be calculated using the function:

$$WifiOTPClient\ (COTP,E) = CiphDecr\ (COTP,E)$$

where:
COTP- ciphered value of OTP broadcasted as a part of SSID,
CiphDecr - a decryption function utilizing the same key as in WifiOTPServer function.

4. VALIDATION OF OUR WIFIOTP SOLUTION

In order to validate WifiOTP in practice we have created the following system prototypes as a proof of concept:
- WifiOTP Token: a service running on a Windows 7 computer with a wireless network card,
- WifiOTP Client:
  a) an application on Windows 7
  b) an Android application
  c) an Android custom keyboard

4.1. WifiOTP token

WifiOTP Token is the central component of the system. It periodically generates the one-time passwords based on stored secret hash key and current time and broadcasts it as a part of a wireless network name (SSID) in encrypted format.
As building or configuring a standalone WifiOTP Token device might be rather complex, in order to ease the validation a Windows application has been created to be used as a WifiOTP Token. Windows application is based on creating computer-to-computer (ad hoc) wireless network using "***netsh hostednetwork***" command. An application has been created using Autoit [15] that generates and encrypts one-time passwords and passes SSID name as an argument to netsh command. This application can run on any computer equipped with a WLAN network card and a recent Windows operating system (tested on Windows XP, Windows 7, Windows 8.x and Windows 10 Preview). The parameters, such as SSID prefix, secret shared key and encryption key are stored in an ini file.

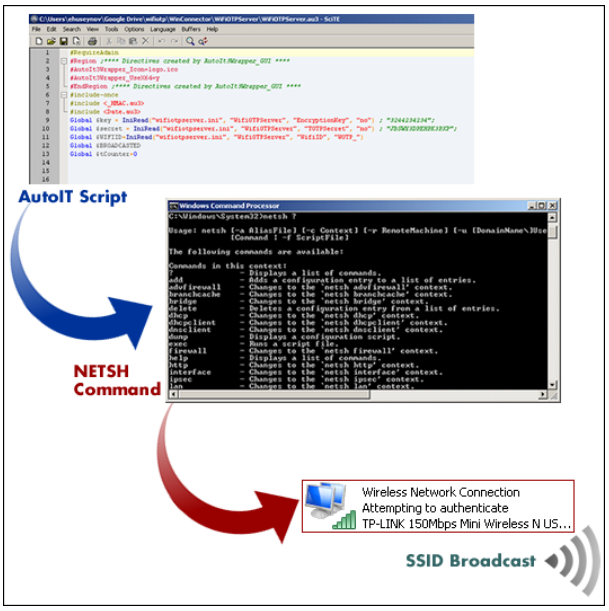

Figure 4. WifiOTP Token application for Windows

4.2. WifiOTP client applications

WifiOTP Client searches for the SSID with encrypted one-time passwords broadcasted by WifiOTP Tokens. For this proof of concept, we created a Windows client application and an Android app. The user interaction model of each application is explained within the use cases section of this paper.

4.2.1. Windows application

Standard Windows netsh command is capable of scanning the SSIDs broadcasted ("***netsh wlan show networks***") [16]. The parsed SSID data needs to be decrypted and sent to input field requesting OTP, which is then submitted the validation server together with other data. A simple system daemon has been developed using Autoit [15] monitors a specific keyboard shortcut (e.g. Ctrl+Alt+X) to send currently broadcasted OTP to active text input. Optionally, it can send return character together with OTP to minimize user's interaction: e.g. when user is prompted to enter OTP in a web application, pressing Ctrl+Alt+X will insert the required OTP and submit the current form immediately. A screenshot of a running WifiOTP Client application is shown on Figure 5. The window below shows the current OTP for demonstration purposes only; the client application should run silently in the background with only an icon displaying its activity in the tray area.

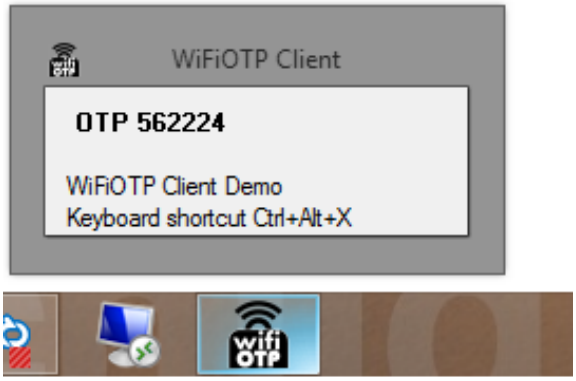

Figure 5. WifiOTP Client for Windows

4.2.2. Android mobile application

We decided to prototype an Android application for WifiOTP Client using PhoneGap [17] platform. A PhoneGap plugin scanning Wi-Fi networks currently in range was created for this prototype application. The broadcasted OTP is fetched by the application using the same methods as with the Windows application. The unencrypted OTP can subsequently be copied to the clipboard allowing pasting of the current OTP to a relevant field in any application (e.g. a web browser).

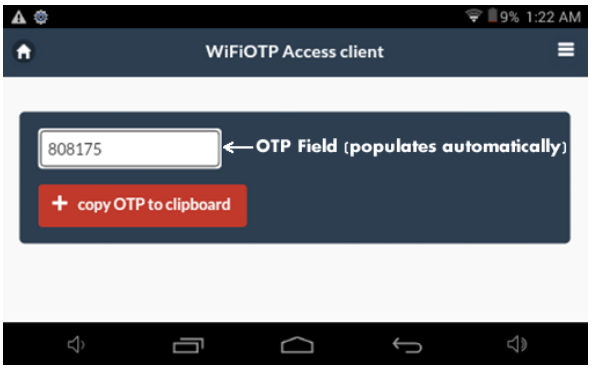

Figure 6. WifiOTP Android client. Clipboard mode

The application can also act as a web browser, and in this mode, the field requesting the OTP, is populated automatically.

Figure 7. WifiOTP Android client. Web browser mode

4.2.3. Android custom keyboard

Using a separate mobile application introduces a number of restrictions, the main one being the inability to use WifiOTP with any standard application, such as web browser. To resolve this, we need a resource containing WifiOTP Client code, which would be available to any application throughout the system. Android allows developers to create custom keyboards and run any type of code associated with its keys, including scanning for available Wi-Fi networks [18].

We have created a custom keyboard, based on a sample provided within the Android developer guide [19]. The keyboard consists of two keys: the first will execute Wi-Fi scanning, parse and decrypt OTPs broadcasted by WifiOTP Token and insert the OTP to current input field, the second will delete contents of current input field. User interaction required for our initial implementation of WifiOTP Android custom keyboard is shown in Figure 8. As can be seen from the image, the user interaction for entering second factor to authenticate can be reduced to two actions: selecting WifiOTP keyboard and hitting "Insert OTP" key. This process can be simplified further to reduce the number of actions to one: this will require the keyboard to automatically send an OTP upon activation.

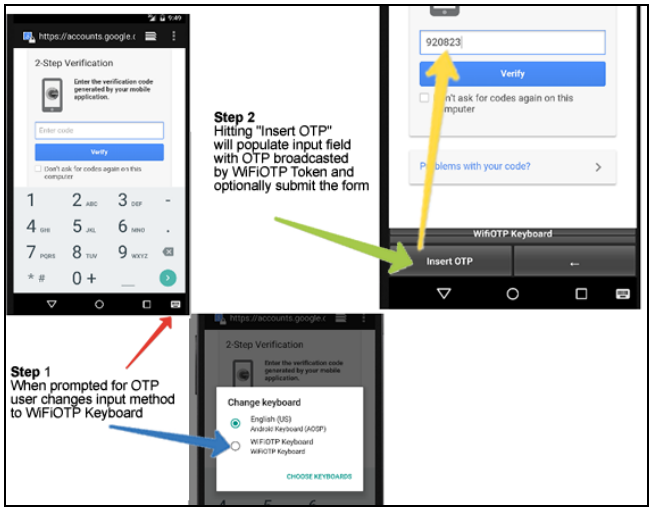

Figure 8. WifiOTP Android custom keyboard

Having an additional keyboard only for authentication purposes may introduce a certain level of inconvenience for users, especially for users frequently using more than one keyboard layout. To overcome this, a custom keyboard containing standard language layout and one additional key to insert OTP, can be created. With this keyboard set as default, user interaction to enter the OTP in the relevant field is reduced to pressing a key when prompted. See the example below (Figure 10) of such a keyboard based on English (US).

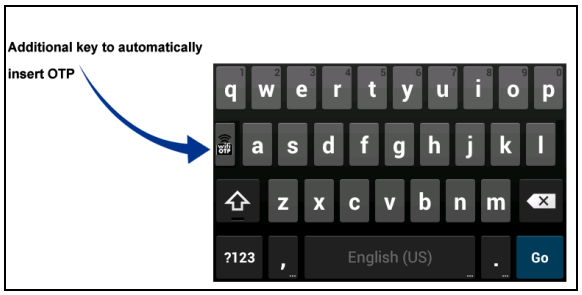

Figure 9. Custom WifiOTP keyboard based on English (US) layout

4.3. Use cases

In this section, we present two use cases to illustrate the usage of the WifiOTP in real-life scenarios. Both cases will consider logon to a web application with two-factor authentication enabled account. As a part of use case review, we will compare user experience with a classic two-factor logon process that has the following steps (assuming correct credentials are supplied):

1) User navigates to a login page
2) User enters first factor credentials (username and password)
3) User submits the logon form, either by clicking on a button or hitting Enter key on the keyboard
4) On the next window, the system asks for the second factor (one-time password), where the user manually enters the digits shown on the device or mobile application (OTP)
5) Login process completes

The flowchart of the classic process looks like shown on Figure 10.

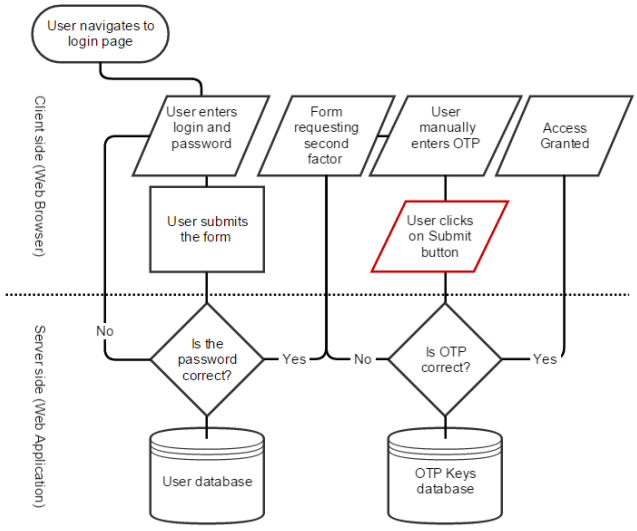

Figure 10. Classic two-factor authentication flowchart

4.3.1. Use case 1: minimal user interaction

Using WifiOTP Client for Windows is an example of this use case. Assuming a WifiOTP Token is correctly configured and active, the procedure of logging in to a standard system with two-factor authentication will consist of the following user interaction stages:

1) User navigates to login page
2) User enters first factor credentials (username and password)
3) On the next window, when the system asks for the second factor (one-time password), user presses Ctrl+Alt+X combination on the keyboard
4) Login process completes

As can be seen from the procedure, also illustrated on Figure 11, the second factor is entered automatically, with the only difference of using a specific keyboard shortcut (Ctrl+Alt+X) instead of hitting enter or clicking on Submit button.

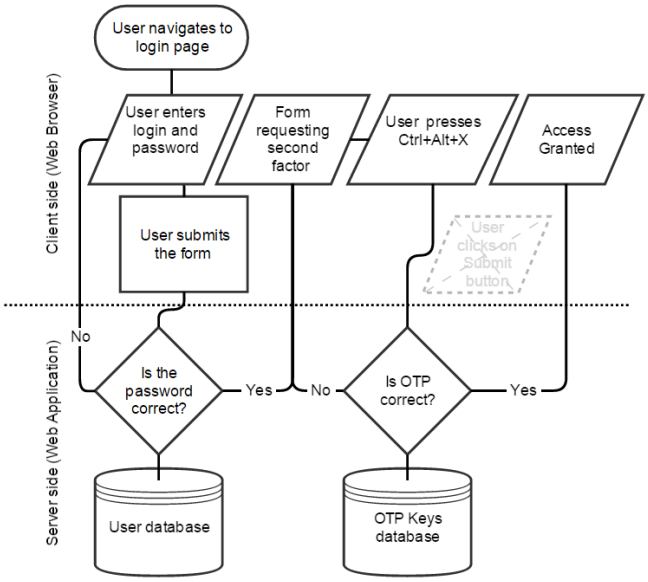

Figure 11. Two-factor authentication flowchart with WifiOTP Windows client

This use case requires no modification on the server side, thus can be used on existing systems with two-factor authentication implemented in one (where both factors are requested in the same time, e.g. on the same login form) or two steps using any standard software. This use case was successfully tested on a number of public services (including Gmail and Dropbox) using a standard web browser, as well as special applications (e.g. Google Drive). This use case is also valid for Android custom keyboard.

4.3.2. Use case 2: zero user interaction

To demonstrate this use case, we have developed an Android WifiOTP Client application that will allow zero user interaction for providing second factor during the authentication process. Procedure for this use case is as follows:

1) User launches the mobile application
2) User enters first factor credentials (username and password)
3) On the next window, when the system asks for the second factor (one-time password), the mobile application

automatically populates the relevant field with OTP and submits the form without any user interaction
4) Login process completes
The flowchart shown on Figure 12, illustrates that there are no additional actions required from the users to securely authenticate, which makes the user experience similar to one-factor authentication systems.

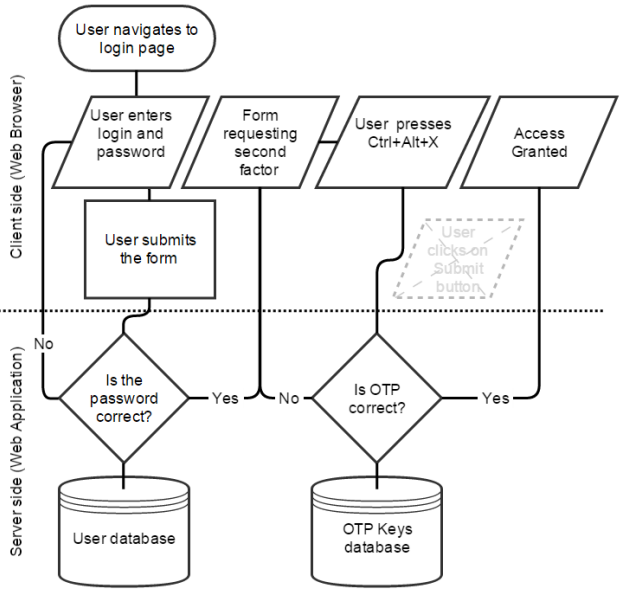

Figure 12. Zero user interaction two-factor authentication using Android mobile application

4.3.3. Summary of reviewed use cases

Both use cases demonstrated that using WifiOTP simplifies users' interaction compared to classic two-factor authentication systems. Although case 1 still requires additional user action, it has its advantages, as it can be used with existing client side applications without any modification of authentication systems. With Use case 2, user interaction is reduced to zero, but the method can only be used via a special mobile application. A detailed summary table of use cases is provided in Table 1 below.

Table 1. Use case comparison

Comparison aspect	**Classic two-factor authentication**	**Use Case 1**	**Use Case 2**
User interaction	User should manually type OTPs generated by token	Minimal (keyboard shortcut)	Zero
Software requirements	No additional application on client system.	Can be used with any application on Windows operating system	Access to systems can only be done via WifiOTP Android application
Server side web application	Any	Any	Any
WifiOTP Token	Any	Any	Any
Hardware requirements	Network access equipment (wireless, wired or cellular)	Wireless Network Card	Wireless Module

Additionally, we would like to clarify that the platforms chosen for both use cases are only examples chosen for our validation and not based on any technical restriction: i.e. Use Case 2 can be easily implemented as a Windows application and vice versa. Due to the fact that the interaction flows are similar for Windows Client and Android custom keyboard based solution, we have not reviewed it as a separate use case.
Both use cases demonstrated no interference or other negative effect to any of existing wireless or wired networks: we successfully tested the functionality on systems connected over different networks (such as Wi-Fi, wired network and cellular data network on mobile devices) as per current and proposed connectivity standards [20] [21] [22].

4.3.4. Security analysis and discussion

Generic security analysis of proposed two-factor mechanism is already done by many authors, and we will refer to existing work [23] as full analysis would be out of scope of this paper.
An additional security risk is introduced by transmitting OTPs via SSID name broadcast, which is publicly readable. This risk is still minimal even if OTPs are transmitted in plain text and equal to a situation when attackers gain access to the OTP device (e.g. a hardware token). However, even with this minimal risk, we attempted to eliminate it by introducing symmetric encryption of broadcasted OTPs using RC4 encryption algorithm. RC4 is rather weak compared to other modern cryptographic methods [24], however the limitation of the SSID length [22] does not allow many options to choose from.
Applications for other platforms (such as MacOSX, Linux and Windows Phone) could be also created. Only iOS devices can't have WifiOTP as long as API methods for scanning Wi-Fi networks are not publicly available. Future versions of iOS may allow it though.

5. CONCLUSION

User authentication is a balance of security and user experience. This paper presents the possibility of creating a simple and low-cost two-factor authentication system that simplifies user's interaction compared to existing solutions by minimizing or completely eliminating the actions required to add the second factor for authentication.
The solution proposed also presents a possibility of introducing an additional authentication factor – the physical location of the user, which we will investigate in future work.

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VULNERABILITY OF RADAR PROTOCOL AND PROPOSED MITIGATION

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ABSTRACT

The radar system is extremely important. Each government must ensure the safety of passengers and the efficiency of the system. This is why it has to be considered by suitable and high-performance professionals. In this paper, we have focused on the analysis of a protocol used to carry the information of the different flight parameters of an aircraft from the radar sensor to the operation center. This protocol has not developed any security mechanism which, itself, constitutes a major vulnerability. Every country in the world is going down this road, relying just on the security provided by other layer connections that could mean a step forward but definitely still not enough. Here we describe different parts of the protocol and the mitigation politics suggested to improve the security level for such an important system.

Keywords— Air traffic control, Radar, Transport protocol, Vulnerability, Mitigation

1. INTRODUCTION

ASTERIX is a standard protocol designed to exchange data between radar sensors and the control centers (ATC Systems) through means of a message structure. The protocol was designed by Eurocontrol and its acronym stands for "**A**ll Purpose **ST**ructured **E**urocontrol Su**R**veillance **I**nformation E**X**change".

ASTERIX has been developed bit by bit to provide and optimize surveillance information exchange inside and between countries (among other purposes) which makes the aerial traffic control centers (ATC) ASTERIX's main users.

Nowadays, almost every state of the ECAC (European Civil Aviation Conference) – are using it at their ATCs.

This protocol defines a standard information structure which is to be exchanged in a communication network, going from the codification of every single bit of data to the organization of the data in a data block.

These transactions can use any means of communication available like LAN networks, Internet Protocols (IP), and WAN. For this kind, data elements group up into Asterix categories. At present there exist 256 different types of categories.

The ASTERIX structure for the surveillance information exchange can be defined like this:

Data Categories

The data to be exchanged by a means of communication among different users must be standardized and classified into categories. These categories define the information that can be transmitted and encoded; in addition, its data will be standard for all of Asterix users. The purpose of this classification is to make easier the identification and the consignment of the data and also to establish a hierarchy based on their priority.

Data Item

It is the smallest unit of information in every category. For each one of them a Data Item group is determined, which constitutes the index of Data Items. Every Data Item has a unique reference that identifies it in an unmistakable way.

The symbolic reference is made up of eight characters and it is to be written in the following way: **Innn / AAA**

I stands for data item, **nnn** is a three-digit decimal number which indicates the data category it belongs to and **AAA** is a three-digit decimal number which indicates the data item number.

Data Block

It is a unit of information that contains one or more registers, each of which has the information about the same category. It is made up of:

A data octet called Category (CAT) which indicates what category the transmitted data belong to.

A 2 octet data field indicates the size of the data block (LEN).

One or more register which contain the data of the same category. Each register has a variable length but with a defined octet limit. The length will always be multiple of an octet.

The maximum size of a data block will be a mutual agreement between the data source and the users.

Field Specification (FSPEC)

The FSPEC is a content table in a bits sequence where each bit indicates the presence or absence of a determined Data Field.

There exists the possibility of using a non-standard Data Field. In order to do that, a bit is enabled and it indicates the presence of a special purpose (SP). On the other side and in this very field, another bit indicates the usage of a random organization (RFS).

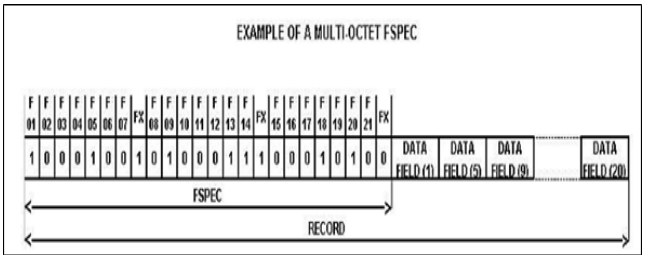

Figure 1: Example of a multi-octet FSPEC

We particularly focused on the Cat 48, a new version of the Cat 01 and Cat 16 SSR Mode-S since now is the most used for the civil aviation in our country.

Asterix CAT 48 is a category where the information about target radars goes from a header to a radar data-process system. In this category plot of tracks, messages can be transmitted by a combination of the two.

In the following table, you can see standard data items of the category.

Data Blocks containing radar target reports shall have the following layout.

CAT = 048	LEN	FSPEC	Items of the first record	FSPEC	Items of the last record

where:

- Data Category (CAT) = 048, is a one-octet field indicating that the Data Block contains radar target reports;
- Length Indicator (LEN) is a two-octet field indicating the total length in octets of the Data Block, including the CAT and LEN fields;
- FSPEC is the Field Specification.

Figure 2: Category 48 Data Block

As an example, in the following table it is shown the standard UAP (User Application Profile) for the information about tracks of category 48.

Table 1: example of standard UAP for the track information

FRN	Data Item	Data Item Description	Length in Octets
1	I048/010	Data Source Identifier	2
2	I048/140	Time-of-Day	3
3	I048/020	Target Report Descriptor	1+
4	I048/040	Measured Position in Slant Polar Coordinates	4
5	I048/070	Mode-3/A Code in Octal Representation	2
6	I048/090	Flight Level in Binary Representation	2
7	I048/130	Radar Plot Characteristics	1+1+
FX	n.a.	Field Extension Indicator	n.a.
8	I048/220	Aircraft Address	3
9	I048/240	Aircraft Identification	6

As shown in the table, each field has an integer amount of octets where the information is represented.

In order to conclude the ASTERIX matter, we will highlight one of the main protocol's issues: The lack of security.

The protocol does not include any security system in it, meaning that it does not have a corroboration of the information that is transmitted in the communication.

Since it is not able to assure the integrity or the authenticity of the information, ASTERIX turns out to be a protocol vulnerable to many different types of malicious attacks, as for instance, a Man in the Middle attack.

New Technologies

In these days, several countries are trying out a new technology surveillance in commercial aviation, know as ``ADS-B´´ (Automatic dependent surveillance-broadcast)

It is included in the US Next Generation Air Transportation System (NextGen) and the Single European Sky ATM Research (SESAR).

This cooperative technology is used in the aircraft setting its position through satellite navigation and transmitting it regularly so that it is possible to be tracked down. This information can be read not only by air-traffic control stations but also other aircrafts implementing such technology. The objective of ADS-B is to replace the secondary radars.

Even though this technology replaces the current system of transposition, its low level of communication remains in ASTERIX.

Using other ASTERIX categories like the Cat 21 will be the only difference. Therefore, the objective of this work will still be valid since all needed onwards is to encode / decode a new ASTERIX category for every program to work perfectly well.

3. MITM ATTACK

Man in the middle is a type of attack in which the attacker has the ability to read, insert and modify the messages that are being sent between the two hosts without either of them knowing that the link has been violated. Once the data link has been compromised, the attacker has the capacity of sniffing and intercepting the messages that are exchanged between the victims.

Below are some of the most common techniques to commit an MITM attack.

ARP Poisoning o ARP Spoofing: Is an MITM type of attack for Ethernet networks which allows the attacker to capture the network traffic exchanged over the LAN network, stopping it and also being able to deny it.

DNS Spoofing: This type, uses fake responses to the DNS resolution requests sent by a victim. There are two methods that the attacker may use: "ID Spoofing" and "Cache poisoning".

Port Stealing: here, the attacker sends a large amount of Ethernet frames (OSI Model Layer 2 packets), with the MAC address of the victim as source and with the attacker's own MAC address as the target. This switch makes the victim believe to be connected at the attacker's port.

DHCP Spoofing: The DCHP requirements are made up of broadcast frames due to the fact that these must be heard by all devices within the local network. If an attacker answers the request before the server does, the former may send the wrong information to the victim.

In this case, we use the **ARP Poisoning** method. This technique is used in local networks aimed to acquire network traffic destined for another host. Using this method allows us to redirect the data intended for the original host to our own network card and by doing this we are able to block, modify or even add new data.

This technique is not based on a particular vulnerability that may disappear over time, but on a TPC network design bug. That is why this kind of attack shall remain in force unless new specific security measures are taken.

4. SIMULATION

In order to do the testing in a controlled environment, there have been conducted simulations of a communication between a plane and an airport's control turret. To recreate each of the elements, custom software was coded. This software was located in different virtual machines which, as a unit, simulate the airport communication infrastructure. The communication method we have chosen to use was UDP sockets.

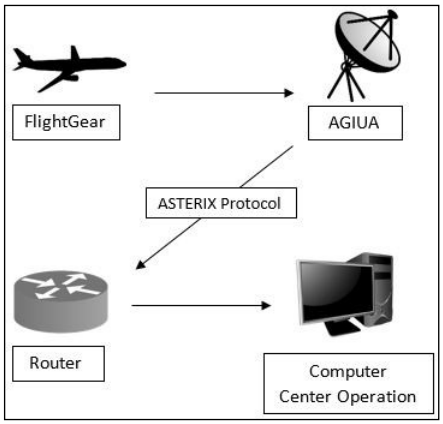

Figure 3: Network Simulation

The simulations are described in the following items:

Airplane Transponder

It is responsible for generating and sending the flight data used by the radar tower. Through Asterix packets, this information is transmitted to the operation center. In order to get more accurate data, we used the simulator called "FlightGear".

FlightGear

It is a multiplatform open-sourced flight simulator. We used this software getting after the objective of obtaining real-time plane data, generated virtually using the software's GUI (graphical user interface).

Radar

It is the responsible of receiving the raw data from the planes, using it for the creation of ASTERIX packets and sending them through a UDP socket to the network. So as to do this, we created a software called AGIUA (Asterix Generator IUA), fully developed in C++.

AGIUA

It takes the raw data from a predefined port, analyzes and makes the calculations to transform the information from the plane, into ``Data Items´´ of a category ASTERIX to be sent. After the length of the resulting fields is defined, they can be inserted in the corresponding ASTERIX´s headboard FSPEC in order to have the complete package that is going to be transmitted by another UPD socket to the next node. As for now, only AGIUA creates category 48 and category 34 ASTERIX packets most of which are the being used in commercial aircraft.

Router

This router/firewall is responsible for redirecting the ASTERIX´s packets to the operation center node, and drop another packet. We do this through a script made with iptables which have the following attributes:

DROP by default all the packets.

Redirect all the packets that are sent from the radar node IP, from a specified UDP port, and which protocol is ASTERIX to a specific port from the operation center node. In order to do that, we created NAT, PRE-FORWARDING and POST-FORWARDING rules.

We also took the security measures needed to achieve this simulation as close to the reality of the airport routers as possible, for instance: port blocks or an update of different services to avoid known vulnerabilities.

Operation Center

The operation center is the responsible of receiving the ASTERIX packets sent from the radar and at the same time, of decoding their data and distributing the packets to the different stakeholders. For example, send the location data to the control tower so the ATC can manage the air traffic. To simulate this system we made a C++ software, which is in charge of making those decoding. It also has a GUI (graphical user interface) in which is represented the location of the aircraft in order to visualize all the different tests that we made for the project.

To achieve this, it puts all the data in a queue where it will consider whether the ASTERIX and FSPEC headboard matches the rest of the saved package. If it is positive, it will take FSPEC byte by byte and shall be taking elements from the queue (which would come to form the ASTERIX DATA ITEMS package) and analyzing information sent for. At the same time, in another thread, the program will correctly be formed by plotting the packages taking its Aircraft Address and coordinates.

5. MITM APPLIED TO ASTERIX

In this section, we will explain how we applied this type of attack to manipulate the ASTERIX protocol according to our aims.

Basically, all the packets that are going to travel on this network have the same structure: header – packet body. In the header, we can find a different type of elements such as the source IP, target IP, packet length, checksum, etc. The packet body contains ASTERIX blocks (each one with its specific category) and own registers of each block specifying the flight data.

Having understood these concepts, we can approach the custom software coded for this section: MITMAST (Man in The Middle ASTerix). The main objective of this software is to capture all the packets between two nodes (in our case, the ASTERIX packet generator and the operation center) and manipulate them. It is a simple software, developed in C, that launches an MITM attack using the ARP Poison technique between two hosts. To do this, the software uses osdep, a tunnel creation library which is part of the air crack project. With this, we can create an interface (mitm0) in which the response packets will be written in order to be easier to sniff.

MITMAST will receive the following parameters:

mitmast -i interface **-t** ip1 ip2 **-o** option

- **-i**: It specifies the network interface to be used which will get in the promiscuous mode to sniff the network.
- **-t**: It specifies the victims' host IP network.
- **-o**: Using this option, we specify one of three options to determine the attack to make: BLOCK, MOD or ADD.
  - **BLOCK** – Delete an aircraft: Once the ASTERIX packets have been obtained, the software will recognize the packets that belong to a particular aircraft and will not forward them to the operation center, by doing so, the aircraft is deleted from the operation center data.
  - **MOD** – Modify the track of aircraft: Once the ASTERIX packets have been obtained, the software will recognize the packets belonging to a particular aircraft and by using an algorithm it will pretend a detour to make it look like the aircraft has changed its original route.
  - **ADD** – Insert a ghost aircraft: The software will generate new ASTERIX packets with reliable data and will send them to the operation center. This will make it look like the radar is receiving an aircraft that does not actually exist. This packet injection can be made with many aircrafts at the same time.

Once all the parameters are determined, it will request some information depending on the options we specified before:

- **BLOCK**: It will request the Aircraft Address. This is an element contained in each CAT 48 ASTERIX packet and it identifies unequivocally the aircraft.
- **MOD**: It will request the Aircraft Address and the modification TYPE. This last option can be: MANUAL or SIMULATED. If it is manual, it will ask the aircraft's final coordinates and the simulator will automatically make a parable until it arrives at the specified point and then, the aircraft will disappear from the radar, becoming blocked. If we choose the simulated option, within five seconds another instance of FlightGear will take over the flight coordinates, using them on a specified port.
- **ADD**: It will request the Aircraft Address, CANT and DIST. The aircraft address is asked in order to identify the aircraft, the CANT option is requested to specify the number of ghost planes to be added and the DIST option is requested to specify the distance between the aircrafts.

Having finished this stage, the software will make an ARP Poison attack to the specified hosts, misdirecting the packets to the attacker host. If this attack is successful we should be able to see in our screen confirmation message

and the software will begin to transform the packets. It is important to point out that before sending them, their header is modified, changing the source/target of the packet and making a new checksum leave no trace of our intrusion.

6. EXPAMPLES

In the following images, we will demonstrate how the attack works.

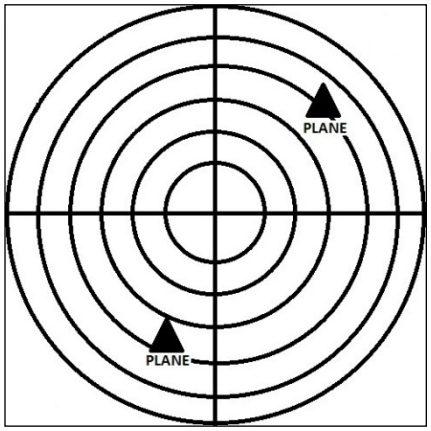

Figure 4: Normal Radar

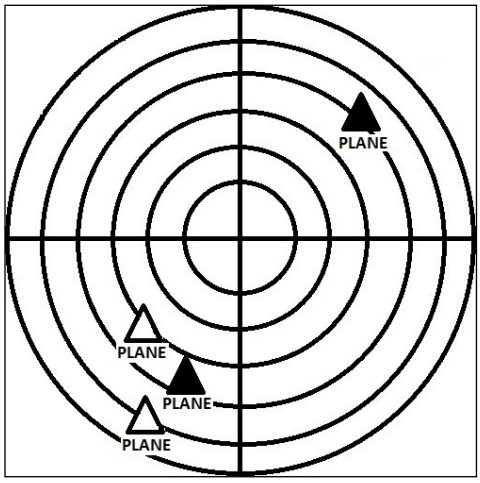

Figure 5: Radar in ADD Attack

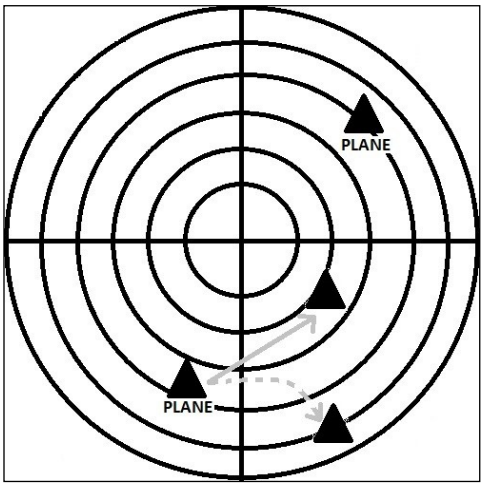

Figure 6: Radar in MOD Attack

7. MITIGATION

An action that can make the attacker to the network is to perform a listening on traffic established between radar and the operations center and save it. This will allow the attacker to subsequently perform a valid format inkjet packages and features but will not be valid in time. This indicates that within the mechanism proposed, we must remember that the attacker may be interested in making injection valid packets (Replay attack). Additionally, the attacker can select the stored traffic and perform a selective injection.

The main point is that Asterix packages have not implemented any security mechanism. This means that security mechanisms should be done outside Asterix. The problem is that if the attacker can pass through these security barriers, he will find all packages in plain text and can perform attacks Block, Mod Add.

Many electronic countermeasures are used in radar. They all seek to mitigate attacks that are made on the sensor, but once the signal is validated, this signal goes into a network protocol that has no additional security beyond the one that can be provided at network level.

As we all know, the security at the network level is continuously broken, you just see what happened with SSL-TLS during the last years, therefore, put our security in this protocol it is not enough.

Our first problem is to ensure the integrity of Asterix package. Although, in reality, we shall see that for the moment we will only guarantee the integrity of information of certain flight parameters. Listed in Table 1: standard UAP for the track information, we are going to focus on the FRN:

2	Day time,
8	Aircraft`s Address,
9	Aircraft`s identification,
11	Track number,
12	Position velocity calculate,
13	Track calculate,
14	Track`s status,

We will focus on these fields because it's on them that we have raised our attack. However, this does not mean that we cannot guarantee the integrity of any other field.

The mechanism to ensure the integrity of these fields is the use as a hash function. Because of the replay attack, we will add a field "time stamp". This field is added to the aforementioned and all of them will do the hash calculation.

Due to our network characteristics, we can say that among of different components of the network we can have a pre-shared secret, this is going to allow the use of other cryptographic functions such as the HMAC. The extra advantage in the use of such functions is that we can authenticate the sensor that is receiving the information.

Processing Time

A very important point in our analysis is if the processing time in the incorporation of these security measures compromises the normal flow of packet reception.

To verify this evidence, we apply this security method on flows with different types of frequency. Even in the worst situation, that is a scenario of maximum traffic, there can be processed more than 30 packets per second per sensor, and no bad effect appears, so no degradation in the flow of the packets was performed.

These measurements make us think about how to develop an additional security features.

Package encryption

While most importantly for this scheme is to ensure the integrity of the packages, an additional feature is to have confidentiality on the information we send. That is why we also propose additional security features as it is to perform encryption on the same fields on which it will ensure integrity.

To verify that it is possible to perform, we applied on the aforementioned fields, an encryption algorithm. Here we use AES-CBC. Other encryption mechanisms can be used, such as AEAD (Authenticated Encryption with Associated Data). This mechanism is very attractive because it provides confidentiality, integrity, and authenticity.

Once we complete the encryption process we replaced in the selected field, the plain text information with the cipher text.

And finally making a combination of both mechanisms, the HMAC function or just the typical hash function is applied. This allowed us to have guaranteed the integrity of the previously encrypted fields.

Final tests

With the two mechanisms (integrity and confidentiality) in place, we perform several tests in order to analyze the impact of the application of the two security features.

Here also taken into account the characteristics of the type of traffic we have between the sensor and the operation center.

Two different situations were studied. Low traffic operation can have 3 packets flow per second per sensor and in a high traffic operation we have approximately 10 packets per second per sensor.

During the complete operation, we can process 18 packets per second per sensor without any kind of delay in the normal flow. Therefore, the incorporation of the encryption method in the required fields can do without compromising the normal flow of traffic.

8. CONCLUSION

As a part of the critical infrastructure of a country, the radar system is fundamental in the air transport system. That is why we must make every effort to ensure the maximum availability and security. Asterix protocol designed by Eurocontrol is very efficient but lack of an adequate safety mechanism itself. That is why you should have to move to another link layer to obtain a security status, which seems insufficient, considering the criticality of the information handled.

The proposed mitigation presented in this paper covers possibilities described attacks but also provides an additional level of security thinking of an attack from inside of the organization.

Our proposed mitigation against vulnerability raised sharply covers actions that can be performed by an attacker who has enough information to be able to listen the communication channel between the radar sensor and the operation center, because it will not be able to manipulate any packages. Also, during a situation while implementing encryption of packages, the attacker cannot display the flight parameters that are being transmitted.

Last but not least, we highlight at this conclusion the importance of processing times involved in the cryptographic mechanism, to ensure the protocol`s integrity and confidentiality, saying we have been highly satisfied because there are no limits with the data flow required to be transmitted at all times.

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SESSION 2

TRUST THROUGH STANDARDIZATION

S2.1 Raising trust in security products and systems through standardisation and certification: the CRISP approach.*

S2.2 Drones. Current challenges and standardisation solutions in the field of privacy and data protection.

RAISING TRUST IN SECURITY PRODUCTS AND SYSTEMS THROUGH STANDARDISATION AND CERTIFICATION: THE CRISP APPROACH

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ABSTRACT

The need for security systems and related ICT solutions poses new challenges to the individuals in terms of fundamental rights such as the right to privacy. Those challenges generate mistrust at the same time to the end-users. Standardisation and certification can have a significant role in changing the picture and help reinstate the lost confidence. This paper examines the concept of "trust" to ICT employed for security purposes, identifies the needs of the stakeholders and concludes with recommendations for the potential role of standardisation and certification through the implementation of a pan-European seal based on robust standards.

Keywords—trust, security products and systems, standards, certification, harmonisation, European seal

1. INTRODUCTION

The need for security systems and related ICT solutions poses new challenges to the individuals in terms of fundamental rights such as the right to privacy, generating mistrust at the same time to the end-users [1]. These new challenges ask for upgraded tailored solutions to mitigate risks, such as data breaches and leakage, unauthorised access, automated profiling and differential, discriminatory treatment. Due to the actual risks to the freedoms and rights of the individuals, the levels of trust towards Information Communication Technologies (ICTs) have dropped. In a recent survey directed to European citizens of all European Member States on the protection of personal data, 67% of the respondents replied that they are concerned about not having complete control over the information they provide online [2]. At the same time, a large majority (71%) replied that providing personal information is an increasing part of modern life and they accept that there is no alternative other than to provide it if they want to obtain products or service. Furthermore, security breaches as events, which are communicated widely by the media, feed the above mistrust of ICTs.

At the same time, ICTs are widely employed for security purposes such as the combat against organised and local crime, border and infrastructure security, and security of citizens. Even though the actual contribution to the increase of quality of provided security might in most of the cases be high, the confidence of the citizens in such products, systems and services often does not align with the actual contribution. Respondents from the demand-side to interviews conducted for the FP7 research project CRISP, when asked about current standards and certification of video surveillance agreed that the current landscape is complex and may include national standards, ISO and IEC standards, CENELEC standards and various national codes of practice and other government policy documents. In addition, video surveillance is subject to national and regional specific laws and regulations, which cover their use as well as social implications such as privacy, data collection, storage, integration and analysis. Technological advancement in this sector is currently very fast, which complicates matters even further as changes to standardisation are too slow to keep up with technological change. Overall, there is a sense among stakeholders that the development of standards is too slow moving, which is seen as a detriment to standardisation and certification of security products, systems and services. Technology, perceptions of risk and threat change rapidly, and standards development is seen to be lagging behind [3]. Respondents pointed to the fact that different national security cultures conceptualised and understood video surveillance in different ways and this might be a reason for a slow uptake of European Standards. The example of the UK, where the use of video surveillance is highly regulated and other European states where it was less so, was mentioned to further explain this lack of uptake. Stakeholders also mentioned that added-value was not clear and that it might take longer to realise full uptake of the EN50132 standards series.

These findings demonstrate that the need for trustworthy security solutions and related ICTs is strong. Citizen's trust in ICTs, especially the security employed facilitates the acceptability of such security measures. But the question remains: What does "trust" mean in that context and by whom?

Technical standards play an important role not only to support innovation in the fields of security and ICTs, but also to develop trustworthy connections and infrastructures. Furthermore, the use of "trustmarks" and certificates, has been shown to enhance citizens' trust. Standards and certificates can be a synonym of reliability and assurance to the end user and citizen. What are the needs of the end users in that respect and what are the main challenges that existing security standards and certification schemes need to overcome in order to yield trust?

The current paper presents the findings of the FP7 research project CRISP on standardisation and certification of security products [4]. The project seeks to aide harmonisation efforts in certification across Europe with regard to security products, systems and services. It employs the STEFi methodology, which encompasses societal aspects such as Security (S), Trust (T), Efficiency (E) and Freedom infringements (Fi), in order to further urge and guide the security standardisation and certification stakeholders to consider such aspects in their standards and certification and evaluation schemes.[1] In the context of CRISP, trust encompasses the experience of the products, systems, services (PSS) users such as employees as well as those scrutinised by the PSS as for example passengers at an airport. Beside the experience, the subjective perception defines in which way a PSS reaches an appropriate acceptance level. Requirements for trust include transparency, openness, fairness and accountability or by using a more practical perspective, habitus (in the context of e.g. usability), emotions and cognition (e.g. the degree of discrimination regarding the use of technology as well as the potential physiological and psychological invasiveness such as body scanner and claustrophobia)."[2] In the paper we discuss the concept of "trust" in relation to security products and systems by presenting the results of the CRISP online surveys and the stakeholder workshop. Following that, we approach the role of standardisation and certification in building trust; what are the elements that enhance trust and should be incorporated/respected in security and related ICT standards and certification? The paper concludes with an overview of the forthcoming harmonised certification methodology of the CRISP project.

2. IDENTIFYING KEY STAKEHOLDER GROUPS AND THEIR NEEDS FOR TRUSTWORTHY SECURITY SOLUTIONS AND RELATED ICTs

The CRISP project carried out a stakeholder analysis and interviews as part of the research and analytical work in preparation for the new certification scheme [2]. Two web surveys were sent out to supply- and demand-side stakeholders across Europe in December 2014 and January 2015. The surveys were informed by literature reviews and interviews with stakeholders and were intended to examine the prominence of views on and needs from security standardisation and certification. 75 respondents from 23 European countries replied to the supply side survey and 50 respondents from 14 European countries replied to the demand-side survey. The objectives were to firstly identify the direct and indirect stakeholders in the security products, systems and services standardisation and certification sector and understand their motivations within and views on current system. Second, to gauge stakeholder views on a security certification challenges, whether they felt any changes were needed and if so, what their needs were with respect to those changes. Two web-surveys, for supply side (accreditation, certification and standardisation bodies, insurance companies and security industry stakeholders) and demand side (civil society organisations, consumer rights groups, procurers of security products, systems and services in private and public sectors, operators of security products and systems) were sent out to stakeholders across Europe.

2.1. Stakeholders views on security standardisation

Stakeholders identified advantages and disadvantages in the current system. Overall, both supply and demand-side stakeholders demonstrate considerable trust in the current system of certification as they selected as key benefits being that it drives better practice and assures quality of products and services. When asked to select three of its most important benefits (from a list of 7 and other) the notion of certification as a 'seal of quality' or assurance to end users' was rated highest by 82% of demand-side stakeholders. Furthermore, 43% of respondents agreed

[1] The STEFi approach was developed in the EU-funded FP7 SIAM project (Security Impact Assessment Measures). Read further: Hempel et al. , "Towards a multi-dimensional technology assessment. The introduction of security technologies at airports and public transport systems " in Fraunhofer Institute, *International Conference on the PRESCIENT project*, 27-28 November 2012

[2] When computer science and software engineering address security, Confidentiality, Integrity, Availability (CIA) and trust are relevant. In this context, trust can be defined as "a subjective probability that defines the expectation of an actor about profitable behaviour of another actor". Based on this, it is related with (system) dependability (i.e., availability, safety, reliability, maintainability and integrity). (Asnar, Y.; Giorgini, P.; Massacci, F.; Zannone, N., "From Trust to Dependability through Risk Analysis," in Availability, Reliability and Security, 2007. ARES 2007. The Second International Conference on , vol., no., pp.19-26, 10-13 April 2007). The CRISP approach is not exclusively focussed on ICT. It has a wider scope from a technological point of view but a narrow scope regarding the purpose of the PSS. It only includes security-related PSS. Based on this, our approach also considers for example security-related systems of systems, which can include hardware, software and services. Therefore a broader definition of "trust" is used. Nevertheless, the specific ICT related attributes can be added to our holistic concept.

that 'certification improves service and product standards.

In your experience, what are the disadvantages of the current certification system, for security products, systems and services, in Europe? (Please select the three most important disadvantages)	
Answer Options	Response Percent
The difference between certification schemes/seals is not clear	67.9%
National schemes differ in the quality they assure	67.9%
There are no disadvantages with current certification of security products, systems or services	10.7%
Certification schemes do not ensure quality of security	28.6%
It is unclear for what evaluation dimensions certification	64.3%
Other (please specify)	7.1%

Figure 1: Disadvantages of the current system of certification (number of responses = 28)

This points to the importance of certification as a brand, which signifies that a product or service has passed rigorous testing and quality assurance. The interviews also revealed that the certification seals are often considered as an addition to branding, and some well-established schemes are perceived to increase end-user trust in products and services.

When asked about the benefits of the prospective pan-European CRISP certification scheme, 53% of supply-side and 71% of demand-side stakeholders selected that its key benefit would be that it provided a recognisable European seal.
With regard to disadvantages of the current system most responses indicate frustration with an overly complex system and 68% of demand-side stakeholders selected that disadvantage is that difference between certification schemes/seals is not clear. There is also a perception, which was echoed in the interviews that national schemes differ in the quality they assure and due to lack of transparency it is difficult to compare and contrast different schemes. In order to be able to distinguish a strong scheme/seal and consequently high quality from lower quality products and services, it is imperative that standards, processes and evaluation criteria are clear to all stakeholders involved (see Figure 1).

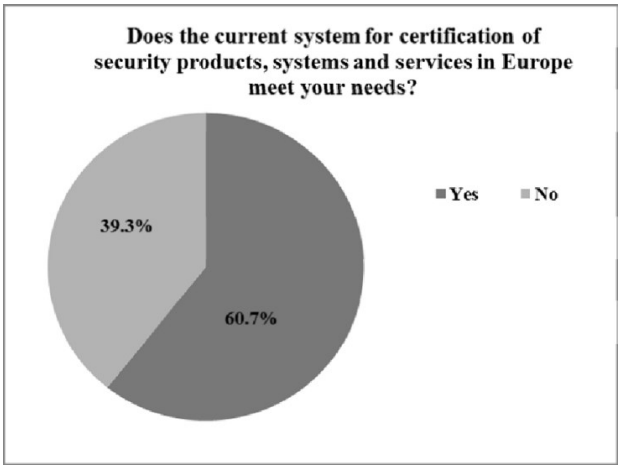

Figure 2: Does certification meet the needs of demand-side stakeholders? (number of responses, 28)

Furthermore, it is not always clear what certification seals stand for and what their foundations are in terms of standards, evaluation criteria and process. When asked whether the current certification landscape met the needs of demand side stakeholders, a majority states that it does not (see Figure 2).
When asked further about demand-side stakeholders' needs with regard to certification of security products and systems the following picture emerges (see Figure 3).

The preference for a robust foundation, in the form of a European or international standard was also selected as a key need by 69.6% of supply-side stakeholders and preferred over that of a national standard.

What are your needs regarding the certification of security products, systems and services? (Please select three most important needs)	
Answer Options	Re sponse Percent
That certification schemes are transparent in what they evaluate and certify	60.7%
That certification builds on robust national standards	28.6%
That certification builds on robust European/international standards	50.0%
That certification ensures quality and performance	75.0%
That certification ensure compliance with regulation and law	46.4%
Other (please specify)	3.6%

Figure 3: Demand side needs regarding certification of security products (number of responses, 28)

2.2. Implications and needs for security and related ICT standards

The interview and survey findings indicate that trust in security standards and certification is high among all stakeholder groups. Certification seals are perceived to guarantee quality and the process of certification and compliance is seen to enhance product and service standards to end-users. However, at the same time there is an overall lack of satisfaction with an overly complex current system in that the evaluation criteria of certification schemes, the certification process and how unclear the difference is between the various schemes. Also, national differences emerge as a challenge and there is a lack of trust between different national systems, where standards are perceived to be lower within specific national accreditation and certification systems. Stakeholder analysis revealed that within the diverse groups, there are common needs that pertain to transparency in both standardisation and certification. With regard to standards, there is a preference for robust European or International standard on which certification is built, that should also provide clear guidance to certifiers and testers on evaluation criteria. As for the certification scheme, the view of the potential benefits of the CRISP scheme is that it will provide a recognizable European seal. As can be seen (Figure 4), stakeholders see the key benefit of a new scheme being that it will provide a European seal and that it would provide added assurance to end-users and consumers.

In your view, what would be the key benefits of a European certification scheme, based on the evaluation of the above social dimensions, for security products, systems and services? (Please select the three most important benefits in your view)	
Answer Options	Response Percent
The scheme would provide a recognizable European seal	71.4%
The scheme addresses an important gap in the certification landscape	17.9%
The scheme would provide added assurance to end-users and consumers	53.6%
The scheme would guide the security industry to include social dimensions their designs and provisions	46.4%
The scheme would encourage further the inclusion of social dimensions in the writing of standards for security products	39.3%
The scheme would strengthen (the competitiveness of) the European security industry in international markets	32.1%
Other, (please specify)	3.6%

Figure 4: Key benefits of a European certification scheme (number of responses, 28)

The key lesson derived from the CRISP survey is that for the development of ICT standards, it is imperative that the standards, evaluation criteria and process are transparent and easily understood in order to instil trust in end-users. The current complex system of standardisation and certification is not meeting the needs of this stakeholder group, although they do see its end product - the seal – as ensuring quality. As it stands, standardisation and certification processes lack participation from end-users and citizens as stated by the European Commission [5] and most standards and certification schemes are unavailable to end-users without paying a fee. This system overall remains closed to citizens and a recommendation would be to seek ways in which it can be opened up to further instil and enhance trust.

3. ROLE OF STANDARDISATION AND CERTIFICATION IN BUILDING TRUST TO SECURITY SOLUTIONS AND RELATED ICTS

The CRISP project analysed existing multinational standards and evaluation/certification schemes of security products, systems and services. The analysis was based on the STEFi methodology, which encompasses four dimensions, security, trust, efficiency and freedom infringements, and specific interconnected attributes to each dimension [6]. Moreover, the SWOT model of analysis was used in order to highlight strong and weak aspects of existing schemes, as well as opportunities and threats for further development and enhancement of such schemes [7]. The analysis showed that the evaluation and certification schemes need to fulfil several conditions in order to be trustworthy [8] [9]. In parallel, the project conducted country studies in European (Germany, UK, Netherlands, Belgium, France and others) and non-European countries (U.S., Brazil, Canada and others) which led to recommendations [10]. The following sections outline some of the recommendations and conditions.

3.1. Content of evaluation in the framework of standardisation and certification

This section outlines recommendations for the content of evaluation of the certification schemes, i.e. what a certification scheme should demand in the evaluation of the security product or system process. The following recommendations are also applicable for technical standards, as they refer to requirements the security product or system needs to fulfil in order to generate trustworthiness and acceptability from the end-users (operators and scrutinised).

Actual safety and technical reliability. The main factor enhancing trust in security products and systems is the actual safety it provides, the extent to which the security products and systems keep individuals free from harm and danger. An evaluation or certification scheme must look into the actual safety requirements of the security measure under evaluation and ensure that the security measure complies with the relevant safety of equipment legislation and the technical standards.

Evaluation that takes into account freedoms and rights. Users and those scrutinised need to rely on evaluation that has specific requirements for protection of fundamental rights and freedoms. The perception of respect for human rights and freedoms by the security measure brings confidence to the affected persons. A certification scheme that takes into account the societal aspects of STEFi and in particular the freedoms and rights re-instates trust to the certified products.
End users and scrutinised should be made aware what the certificate or the evaluation stands for; this entails that the scheme needs to have an appropriate reach to the market and a broadly recognised mark (trust-mark). In the same context, privacy and personal data protection have a significant role in affecting the trust to the security measure. This is partly due to the potential intrusive nature and impact that some of the security technologies might have to these two fundamental rights. In particular therefore, the need for protection of the two rights needs to be enshrined in the evaluation of the security measure. Privacy by Design requires the adoption and implementation of principles such as proactive instead of reactive protection of privacy, full lifecycle protection, visibility and transparency, privacy embedded into the design of the product or system [11]. Data Protection by Design suggests taking into account protection of personal data in the whole lifecycle of the product, starting from the design process by building data protection safeguards in the product itself [12].

Another safeguard for the rights is the Privacy Impact Assessment (or Data Protection Impact Assessment) [13]. The European Union Agency for Network and Information Security (ENISA) in a recent study recommended that standardisation bodies need to include privacy considerations in the standardisation process [14]. According to the study, also privacy certification or privacy seals provide also a framework for privacy assessment. Finally, there is a growing development of privacy and data protection related standards and technical specification, which are technology-related and could serve as normative basis for the evaluation [15].
Accountability and transparency. According to the CRISP report on security standards and certification in Europe, which discussed the concept of accountability in European Standardisation, accountability in European standardisation entails "that the system is open and transparent, that the standard meets the consensus of all major interested parties and that it is applied in a uniform way throughout the territory of the Member States" [16]. The EU privacy Seals project identified accountability as one of the added values of correctly implemented privacy seal schemes [17]. An evaluation and certification scheme that requires clear distribution of responsibilities and liability issues, compliance with norms and regulations and capability of demonstration of the compliance offers a degree of confidence to the end user and scrutinised [18][19][20].
If not compliant with the accountability requirements, the certification should be subject to revocation. Transparency is crucial for the end user of the security product. Transparency should be met at least at two levels: in relation to the security measure and in relation to the evaluation or certification scheme itself. The scheme should impose transparency obligations to the security product under evaluation, such as open and accessible security and information policies, auditable processes and documentation. The transparency of the results of a certification should be made publicly available. The evaluation or certification scheme should also be clear on the scope of the evaluation, its procedures, the validity period of its evaluation, its rules, criteria and methodology.

Reliable normative references. A very important aspect for every scheme in the field is the normative basis; the rules and regulations that form the basis for the scheme requirements and the framework and scope of testing and auditing. Both the CRISP Legal Analysis of existing schemes and the CRISP Stakeholder Analysis Report highlighted the importance of building a certification scheme on reliable norms, such as legal acts and robust international and European standards [7][2].

3.2 Factors pertaining to organisation of the certification system

Trustworthiness towards security systems and related ICT solutions starts from a trustworthy evaluation system itself. The following recommendations concern certification and aim at increasing the trustworthiness of certification as evaluation system.
Role of accreditation. The added value of certification is well recognised by stakeholders so it would be appropriate to invest efforts in the requirement of certification by accredited entities (not voluntary but mandatory). The role of the government (public administration) is very important in this area (introducing standards in legislation and supporting the accreditation as a tool for the implementation of its policies). A good point to reach transparency and fair competitiveness among certification entities is the harmonisation for accrediting auditors. Cross trainings of accreditation auditors, mutual assistance between them and the reduction of differences among accreditation programs are needed in order to avoid substantial differences in the same accreditation scheme.
Independence of certification bodies. Inextricably related to transparency, the independence of the Certification or Evaluation body in relation to the manufacturer or service provider is also an element substantial to increase the trust of the end users and the scrutinised. EDRi, the European Digital Rights organisation, points out that "commercial trustmark schemes suffer from a tradeoff between being sufficiently thorough (which requires an often off-putting level of investment in terms of time and oversight) and being sufficiently lenient for companies to be willing to join (which can undermine the credibility of the system)

[21]. A third party evaluation therefore should provide increased warranties of impartiality and integrity; Certification bodies that are themselves accredited according to the ISO/IEC 17021 for management systems and relevant standards prove to be independent and to comply with internationally accepted requirements.

Involvement of stakeholders. As the CRISP Stakeholder report highlighted, the involvement of the stakeholders in standardisation and certification is of paramount importance for the quality, acceptability and trust in the end result. An evaluation or certification scheme that consults the needs of different stakeholder groups, especially the consumers, will be heard. Participation in such procedures that have an impact, boosts trust of the result, i.e. the scheme or the standard.

Regular review of the compliance and updating auditing procedures. Post-evaluation is very important for the certification procedure. Recent cases of certification providers failing to meet their obligations emphasised the importance of monitoring not only the certified product after the first evaluation, but also the certification body itself for the obligations they undertake (e.g. the settlement of privacy certification provider TRUSTe with the Federal Trade Commission, over failure of the former to conduct annual re-certifications) [22]. The certification body needs to regularly review that the product, system or service continues to be compliant. Outdated certifications and control methods work in the opposite direction; they foster general public mistrust on certification and consequently to the certified security products and systems.

Faster certification processes and a shorter developmental period for standards. As the CRISP research efforts have shown, the security market is growing and demanding new secure, efficient, trustworthy products and systems, which also take into consideration the freedom and rights of citizens. In this regard, faster certification processes and a shorter developmental period for standards are needed. It is necessary to establish a more flexible and rapid standardisation process to allow the conformity assessment to adapt to the development of new technologies and markets. There is also a need for certification organisations and institutions for better solutions in order to continuously improve and speed up their proposed services on certification for security products, systems and services.

4. FINAL REMARKS

This paper briefly presented the key findings of the CRISP project in the field of security standardisation and certification with an emphasis on the trust aspect, identifying stakeholder needs and recommendations for security standards and certification schemes.

The research is ongoing. CRISP is currently working towards a harmonised approach and a certification methodology for security products and systems in Europe. The ongoing research aims to develop and outline policy and certification procedures for security certification, and test drive the proposed certification model, evaluate its actual working and accordingly, revise and refine the certification scheme. A CEN Workshop Agreement (CWA) and a certification roadmap are among the forthcoming CRISP deliverables.

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DRONES. CURRENT CHALLENGES AND STANDARDISATION SOLUTIONS IN THE FIELD OF PRIVACY AND DATA PROTECTION

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ABSTRACT

The issue of drones has burst onto the public agenda due to the rapid expansion from their military and enforcement use to the domestic market where seemingly endless uses appear. This paper is focused on the analysis of the risks to privacy and data protection that arise from these devices and the efforts in Europe to establish a framework to address the problems. The paper's thesis is double: first, the current data protection rules in the European Union (EU) do not adequately cover the implications for civil liberties of the potential use of pervasive aerial surveillance systems and second, the idea that privacy standards have a supportive role to the regulations as they can have added value by mitigating some privacy risks and promoting compliance of the drone operators and data controllers with data protection principles.

Keywords— drones, RPAS, standardisation, GDPR, privacy, personal data protection, certification.

1. INTRODUCTION

The protection of personal data is an important concern for EU citizens who want to better control their personal data [1]. Simplifying the regulatory environment for businesses is also important in order to increase legal certainty. Thus, data protection rules must be fitted for the purpose of addressing the risks of the new products and services in the digital age. A new European privacy framework is currently being designed to update and replace the Directive 95/46/EC (Data Protection Directive) by a new General Data Protection Regulation (GDPR). In this study, we are focusing on drones because they face many technological challenges and their relevance in current and future data protection regulation must be defined.

According to the International Civil Aviation Organisation (ICAO), a drone – also known as Remotely Piloted Aircraft System (RPAS), Unmanned Aerial Vehicle (UAV) or Unmanned Aerial System (UAS) – is a set of configurable elements consisting of a remotely piloted aircraft, its associated remote pilot station(s), the required command and control links and any other system elements as may be required, at any point during flight operation [2]. They are no longer used solely by the military but a wide range of applications such as; traffic monitoring, tracking and surveillance, wilderness search and rescue, commercial drones, disaster recovery, hazardous material recovery, wildfire monitoring and many others are being implemented [3]. As a consequence, manufacturers are now making a variety of them of different designs, sizes and functionalities to meet the specific needs of companies and customers. They are increasingly cheaper, and at times more capable of sustained flight. Because of that, large as well as small and medium-sized companies (SMEs) are starting to make use of drones to provide a range of services.[1]

Until now, developments and challenges in analogous products and services such as close-circuit television (CCTV) had been analysed at a national level.[2] However, RPAS is a revolutionary product the implications of which are not yet fully understood and their use is posing a threat to privacy and personal data protection.

EU legislation is not covering all issues regarding to it due to the following aspects: a lack of a common and consistent framework, gaps in existing EU legislation, the lack of mutual recognition for national certificates due to substantial differences in national rules on drones.[3] In this sense, self-regulation through

[1] A complete list of non-military use of RPAS can be checked on European RPAS Steering Group, 2013, p. 5.

[2] This is the case of UK where codes of practice were implemented to provide guidance on the appropriate and effective use of surveillance camera services. See Home Office Surveillance Camera Code of Practice, presented to Parliament Pursuant to Section 30 (1) (a) of the Protection of Freedoms Act 2012, June 2013.

[3] The following EU legislation regarding to RPAS will be analysed in this paper: Treaty on the functioning of the European Union (TFEU) in particular, Article 16 (The right to the protection of personal data), Charter of Fundamental Rights of the European Union (CFREU) in particular, Articles 8 (Protection of personal data) and 52 (Scope of guaranteed rights), European Convention of Human Rights (ECHR), in particular, Article 8 (Right to respect for private and family life), Directive 95/46/EC of the European Parliament and of the Council of 24 October 1995 on the protection of individuals with regard to the processing of personal data and

certification may be an alternative to detailed legislation, but not to all legislation. This may work best within a consistent legislative framework although both complement each other in order to produce a result which neither could achieve on its own. Apart from legislation *stricto sensu* and private sector voluntary initiatives, EU institutions are generating great interest in adopting an effective implementation of privacy and data protection. Given the importance of drones, the European Commission (EC) initiated in September 2012 its first discussions on RPAS followed by a planning in April 2014 and the adoption of the EC strategy on the future regulation of RPAS in the EU, in order to respond to the call of the European manufacturing and service industry to remove barriers to the development of RPAS for civil use while safeguarding the public interest [4][5][6]. Moreover, the European aviation community adopted the Riga Declaration establishing the general principles to guide the regulatory framework in Europe regarding to RPAS [7]. Finally, the recent opinion 01/2015 of the Article 29 Data Protection Working Party (WP29) on Privacy and Data Protection Issues relating to the Utilisation of RPAS must be noted. WP29 notes the lack of an adequate regulatory framework in most Member States. In this context, the harmonisation and the modernisation of Member States' aviation policies in relation to RPAS should be encouraged. In addition, it considers equally important to highlight all the threats and risks to data protection and privacy resulting from a large-scale deployment of RPAS technology [2].

2. CHALLENGES POSED BY DRONES TO THE FUNDAMENTAL RIGHTS TO PRIVACY AND DATA PROTECTION

In the analysis below, attention is drawn to the risks that drones, as a new surveillance technology which processes personal data, present to privacy and data protection rights, both not properly protected under the current regulatory framework.

In the UK, the Information Commissioner's Office has included the use of drones within its 2014 CCTV Code [8]. It points that operators shall perform robust privacy impact assessments (PIAs) before operating drones for surveillance purposes in order to prevent privacy breaches.

on the free movement of such data (Data Protection Directive) in particular, Articles 6, 7, 10, 15 and 17, and the European Parliament legislative resolution of 12 March 2014 on the proposal for a regulation of the European Parliament and of the Council on the protection of individuals with regard to the processing of personal data and on the free movement of such data (Proposal for a General Data Protection Regulation, GDPR) in particular, Articles 20, 78 and 79.

Since they are able to carry out any type of surveillance, it can be distinguished between 1. Mass or undirected surveillance which is not targeted on any particular but gathers images and information for possible future use (CCTV and data bases are examples of mass surveillance) and 2. Targeted or direct surveillance which is addressed at particular individuals. It can involve the use of specific powers by authorised public agencies and can be carried out overtly or covertly (interception of communications, visual surveillance devices, sensors of movement, "traffic" data are examples of targeting methods) [9].

In this sense, efforts are evolving to complete the law enforcement and many initiatives address the issues of privacy and data protection from ethical, social and juridical perspectives [10][2]. We defend the idea that privacy standards have a supportive role to the regulations. Standards can have added value by mitigating some privacy risks and promoting compliance of the drone operators and data controllers with data protection principles. The aim is "finding a balance between the advantages inherent in the civilian use of drones and possible harm to the right to privacy and data protection (as well as other fundamental rights such as freedom of expression)" [11].

Before introducing our reflections, clarification is needed with regard to the categories of RPAS. These devices can be equipped with a large and heterogeneous variety of pieces, technologies and capabilities – from simple devices such as on-board cameras or sensors to extreme complex technologies such as high-power zoom lenses, night vision, infrared, ultraviolet, thermal imaging, radar technologies, video analytics technology, distributed video or facial and other soft biometric recognition [12] –. Due to this broad range of equipment's, RPAS are being used for very diverse civil applications (and, undoubtedly, they will be used for still more applications).

As it has been stressed by Article 29 WP, "The most basic type of RPAS consisting only of vital components may not be processing personal data but can still cause annoyance and social disturbance to others. Adding other sensors for other purposes such as to record audio or video data raise obvious data protection and privacy concerns"[2].

2.1. The impact of drones on the right to privacy

Although the concept of privacy is constantly evolving as it depends on social and technological factors, the right to privacy is recognized as a fundamental right and an element of human dignity according to European legislation and case law. But legitimate concerns about the potential damages that drones may cause to privacy have been side- lined because the combination of technologies mounted on drones allow a totally new type of surveillance in ways never possible before: it is

a form of surveillance that is likely covert or hidden, may be highly intrusive and potentially permanent on persons and objects.

Threats to privacy may be grouped in a few categories affecting physical privacy (which is concerned with the integrity of the individual's body), information privacy (which is related to the content of communications: data, images or voice, for example) privacy of communications (which affects to any kind of transmissions by email, sms, telephone communications, etc.) and location privacy (which protect people from being detected, identified or tracked) [13]. But, certainly, an aspect is repeated in an almost unanimous way: drone surveillance may affect behavioural privacy "that is concerned with freedom of the individual to behave as they wish, without undue observation and interference from others" [14] and, consequently, may have a "chilling effect" on citizens who must change their behaviour in order to comply with social or political conventions [15]. Liberties such as freedom of expression or right to association might be seriously affected by this effect.

2.2. The impact of drones on the right to data protection

It is difficult to identify all the risks drones can pose on the right to data protection because this depends on the technologies with which they are fitted. But, in an attempt to summarise, we can emphasize the following ones.

First, lack of transparency in the collection, storage, and even further transmission and data processing due to the difficulty of perceiving their presence. This principle of transparency demands to inform the data subject of the processing carried out and it is an obligation that drone operators are engaged to perform. In specific cases regarding drones, lack of transparency may also affect to the absence of data subject's consent which must be freely given, specific and informed (also "explicit" in words of the GDPR) whenever the collection/processing of personal data affects to private areas or events of third parties and is not based on legitimate criteria.[4] Furthermore, when individuals have no external sensory perception of the devices, it may have a negative impact on the exercise of their rights and on accountability. But even in the case of drones are visible, a personal data breach may result in substantial harm to the individual affected if the controller does not notify the breach to the supervisory authority in order to allow the individual to take the necessary precautions against adverse effects (such as identity theft or fraud, physical harm, significant humiliation or damage to reputation).

A second principle relating to data quality at stake is purpose specification. Personal data must be collected for specified, explicit and legitimate purposes and not further processed in a way incompatible with those purposes. Compared with other surveillance systems such as CCTV, the characteristics of drone (mobility, advance technologies, covert observance and potential permanent surveillance) facilitate the capacity to process and store vast amounts of data in an indiscriminate manner. This indiscriminate nature of the capture of data by drones is contrary not only to the purpose limitation principle but also to the data minimisation and proportionality principles and may lead to the possibility of function creep. According to Directive 95/46/EC data must be adequate, relevant and not excessive ("limited to the minimum necessary", as stated in the GDPR) in relation to the purposes for which they are collected and/or further processed. Drones aimed at monitoring the safety of hazardous installations can gather massive and unnecessary personal data from workers which go further than needed to fulfil the legitimate aim being pursued causing serious injury to the rights to privacy of individuals in breach of Article 52.1 CFREU and Article 8 ECHR.

A third critical point in relation to data quality principles is data security. Illegal disclosure and unauthorised access of data captured by drones are the risks associated to the breach of this principle. Data security basically means that it is necessary to implement the required security measures and remove or anonymise those personal data which are not strictly needed. Integrity and confidentiality of the data stored by drones must be assured as well as checked any potential transfer of data to third countries. In fact, when data are collected and processed via drones they have to be removed or anonymised after the period to achieve its purpose is expired. If storage of data is for a long period of time there is a significant risk from loss or theft.[5]

The fourth challenge that drones pose is profiling which can be defined as the process of assembling bulk data, creating disproportionately large datasets that can be used for anticipatory action.[6] Profiling is considered by WP29 a risky processing operation as far as the rights and freedoms of data subjects are concerned and Article 20 GDPR stipulates the data subject's right not to be subject to a measure based on profiling.

Profile techniques have been used in the public sector to predict a variety of risks patterns in the population and taking, consequently, appropriately focused actions and services by law enforcement agencies. But, on the other hand, profiling may lead to discrimination by

[4] Criteria for making data processing legitimate in Article 7 of Data Protection Directive.

[5] Article 30 GDPR based on Art.17 (1) of Data Protection Directive.

[6] Currently, Art. 15.1 of Data Protection Directive only grants individuals the right not to be subject to a decision which is based solely on automated processing of data intended to evaluate personal aspects of the data subject.

identifying individuals or social groups for adverse treatment based upon flawed assumptions. Furthermore, drones may engage in discriminations ticking off race, ethnicity, gender, national origin, religion, sexual orientation and gender identity. These categories of data are considered sensitive data and they are out of bounds for drone targeting as their collection and processing is severely restricted.

The GDPR aims to tackle most of the problems that new technological products and services face in the field of privacy and data protection. However, this is not enough. Other public and private initiatives such as standardisation and certification schemes shall be implemented. It will be better suited to technological changes preventing damages and helping to create a harmonized and consistent framework for rapid and effective response to new threats.

3. STANDARDISATION OF DRONES: A DEVELOPING FIELD

The majority of stakeholders highlights the need for robust standards for civilian drones: from policy regulators to civil protection organisations and individuals. The EC, in the Roadmap for the integration of civil Remotely-Piloted Aircraft Systems into the European Aviation System published in 2013 [5], stressed the need for new standards to regulate the operation of RPAS particularly in relation to safety, security, insurance, liability, data protection and privacy. By the end of 2015, the draft regulatory framework will be public. Nonetheless, as seen in the previous section, the privacy and data protection risks at stake go beyond the existing legal provisions, due to the sophistication and complexity of the drone technologies. As to the current standardisation activities and guidance for drones at European level, the EASA has a new regulatory approach, the "Concept of operations", developed with input from manufacturers and users [16]. The approach is "risk based", which entails that safety requirements depend on the risk an activity poses to the operator and 3rd parties, such as the general public. EASA acknowledges the significance of the privacy, data protection and security implications of drones. EUROCAE, has already established two working groups related to drones, the WG-73 on UAV systems and the WG-93 on Light Remotely Piloted Aircraft. Moreover, JARUS has published a certification specification for Light Unmanned Rotorcraft Systems consisting of an airworthiness code and the acceptable means of compliance [17].

At an international level, ISO established last year the ISO/TC20/SC 16 on UAS. There are eight countries participating in the TC and four observing. Currently, there is no project in progress announced for the TC. ISO is also in favour of the risk based approach and has announced as priorities for standardisation, standards for "detect and avoid" and for "command and control" [18].

IEC has not developed specific standards on drones; standards developed by several TCs are applicable for components of drones, such as batteries and sensors. The IEEE has published the "IEEE Draft Standard for Discovery, Authentication, and Authorization in Host Attachments of Storage Devices" [19], which defines discovery, authentication, and authorization protocols between hosts and storage devices over multiple transports. The activity of the standardisation bodies and civil aviation organisations shows a tendency to consider drones as an area where standards are in need and can have an added value, in terms of safety but also security. Until now, there is no initiative on standardisation addressing the specific privacy and data protection risks posed by drones.

3.1. Overview of existing privacy and data protection standards: core issues and risks addressed.

The challenges and risks of the emerging technologies to the protection of personal data and privacy have urged for action, not only at a regulatory framework level with the modernisation of the personal data protection legislation in the EU, but also at self-regulation and co-regulation level. Technical standards, guidelines, codes of conduct and certification schemes have been developed internationally and in Europe, in order to complement the legislation and promote compliance and awareness. In support of this activity, the forthcoming GDPR endorses the standardisation and certification activity in the field of data protection. Standards are seen as a means to warrant security, interoperability, transparency and trust among data subjects.

The existing privacy-related standards vary as to the scope, objectives and target audience. ISO is active in developing privacy-related standards via the ISO/IEC JTC1/SC27 and the ISO 29100 series. The ISO/IEC 29100:2011 "Information technology - Security techniques - Privacy framework" is a free standard which provides a high-level framework for the protection of personally identifiable information (PII) within ICT systems. Such a standard, specifying terminology and describing privacy principles and high level requirements can be beneficial for any technology with a potential privacy risk, including drones. A "common principles" framework is needed to ensure that every privacy-related technical specification builds on the same foundations. The ISO/IEC JTC1/SC27 has also developed the ISO/IEC 29101:2013 Information Technology–Security Techniques–Privacy Architecture Framework, a technical standard which concerns ICT systems in general processing PII [20]. The standard defines the different actors of a PII processing ICT system and the different processing operations (called

"Phases of the PII processing life cycle") such as collection, use transfer, use, storage, and disposal. When it comes to drones as an ICT system, many of the controls and management operations of the standard can be applicable; the question however remains whether the specificities of the drone as the vast collection of big data through the flying capability for a long time over large areas, the function creep and the security of all the collected and transmitted data (including PII), are addressed. The ISO/IEC 29101:2013 is developed for any ICT system processing PII, independently of its capabilities, functions and level of sophistication, which when applied to the case of drones entails the risk of not covering some of the specific risks that are described in the second section of this paper. This was the case with cloud computing, another challenging area in terms of privacy and data protection; ISO and IEC developed the ISO/IEC27018 standard, which builds on existing standards related to information technology and security techniques, but includes additional requirements and controls to address the specific risks posed by cloud computing [21][22].

At the level of the European Standardisation Organisations, CEN and CENELEC, have not published privacy-related European standards. The EC mandate from CEN (M/530) [23] to develop European standards that will address privacy and data protection issues during the design, development, production and service provision processes of security technologies and services, has the dynamics to cover data protection risks of drones as security technology [24]. However, the function of drones for recreational, marketing or journalistic purposes creates a whole new spectrum of data protection risks, in particular relating to the accountability and distribution of responsibilities of the data controller and data processor. An operator of a civil drone for domestic individual purposes on the one hand might be beyond the applicability of the current European data protection legislation (due to the "household exemption" or data processing for journalistic purposes exemption) and on the other hand might even be unaware of any data protection restrictions and risks. In such cases, a specific standard that already takes into account the potential lack of awareness of data protection regulations and restrictions and incorporates core principles specifically at risk by drones would be of great significance for the protection of the two fundamental rights and for enhancing trust to drones.

OASIS has developed two significant privacy related standards: 1. The OASIS Privacy Management Reference Model (PMRM) [25] and the 2. Privacy by Design Documentation for Software Engineers [26]. PMRM provides guidance on how to develop operational solutions to privacy issues and touches upon the broader topics of privacy management functionality and compliance controls. The Privacy by Design Documentation (PbD-SE) standard provides a specification to operationalise Privacy by Design (PbD) in the context of software engineering. The PbD-SE specification "translates the PbD principles to conformance requirements within software engineering tasks, and helps software development teams to produce artifacts as evidence of PbD-principle adherence".

3.2. Final remarks in identifying the gaps

The above discussion demonstrated that despite the significant emerging standardisation activity in the area of ICTs and privacy/data protection related issues, the existing standards are not sufficient to cover the data protection risks that are inherent in drones (collection of data without a direct line of sight, covert surveillance, wide constellation of stakeholders, linkability of collected data to other pieces of information). The development therefore of new standards specific for drones and privacy and data protection is imperative. The new standards would need to be either codes of practice or technical specifications covering the following high level principle issues:

- Notification of processing to data subjects
- Provision of information on the identity of the operator and the purpose of the collection and processing of data
- Provision of information on the rights to access, rectification, objection and erasure of the personal data
- Accountability models for drone operators
- Minimisation of collected data
- Data security, integrity and confidentiality of the processed data, including unauthorised access and data flows.

As several authorities, experts and institutions stress, standards are complementary to legislation. As voluntary means of self-regulation, it is crucial that the protection of the fundamental rights of the privacy and protection of personal data, is not left solely to the industry players, but there is a comprehensive regulatory framework and oversight that promotes and enforces the rights. Technical standards are substantial in addressing the specificities of the technologies that pose additional risks to the protection of the rights and raising awareness on the need for compliance with the rights. Their role in that respect is urgent and an added value.

4. RECOMMENDATIONS

Ensuring privacy and effective data protection of EU citizens is one of the main purposes for EU institutions since loopholes exist in the field of implementing privacy, balancing privacy against security and introducing governance schemes in the area of surveillance regarding to RPAS.

Current EU legislation does not cover new threats on privacy and data protection. GDPR is intended to replace Data Protection Directive to strengthen the existing legal framework. However, specific and future challenges shall be addressed in the following forms of governance:

a. EU data protection legislation must remain technology neutral if it is to be flexible enough to apply to the unique characteristics of RPAS and other mechanisms such as guidance and recommendations developed by Data Protection Agencies and delegated acts by the Commission should be implemented to be adapted better to changes of these products increasing legal certainty.

b. Standardisation activity in the area of drones with the aim to mitigate the specific data protection and privacy risks should be initiated at international and European level.

c. Certification schemes based on the forthcoming GDPR, delegated acts, guidance and recommendations that meet high standards in privacy and data protection will be a key component of the risk management framework that will need to be developed for the systems to operate safely and with due regard for third party interests.

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SESSION 3

TRUST IN THE CLOUD

S3.1 Regulation and Standardization of Data Protection in Cloud Computing.*

S3.2 Autonomic Trust Management in Cloud-based and Highly Dynamic IoT Applications.

S3.3 The Impact of Cloud Computing on the Transformation of Healthcare System in South Africa.

REGULATION AND STANDARDIZATION OF DATA PROTECTION IN CLOUD COMPUTING

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ABSTRACT

Standards are often considered as an alternative form of regulation to legislative rule setting. However, standards also complement legislative acts, supporting their effective implementation and providing precise definitions for sometimes vague legal concepts. As we demonstrate, standards are not mere technical regulations but relate to sensitive political issues. The genesis and contents of ISO/IEC 27018 illustrate the interaction between both forms of regulation in the case of data protection in cloud computing. While the standard has been written with intensive consideration of the legal framework, we argue that the standard could reciprocally influence legal rule-making in the same domain.

Keywords— Regulation, Standards, Cloud Computing, Data Protection, Privacy, ISO/IEC 27018

1. INTRODUCTION

Todays' most advanced economies increasingly depend on knowledge and information [1]. If data and information are the oil that keeps our economies running, as it is often argued, then the pipelines for this oil undoubtedly are computing concepts. A fundamental concept for efficient computing is *cloud computing*, a label for networking and distributed computing solutions. For current and future innovations in information and communication technology (ICT), cloud computing is a key enabler and basic innovation. Its regulation might thus be a limiting or enabling factor for the adoption of important information and communication technology innovations. However, like the greenhouse gases associated with traditional oil, the use of this new oil may have negative implications. In this case, the challenges are in the realms of data protection and privacy. Therefore, the regulation of information systems regarding these issues gains economic and political importance.

How much power do standards have in this field? Potentially a lot, as we argue. To demonstrate this, we first explain the significance of data protection. This reveals that the subject touches on core regulative matters and is not "merely technical". Second, we explain how legal rule setting and standardization intertwine in order to better understand the peculiarity of the standardization process of ISO/IEC 27018. We thus locate this standard on the map of regulative approaches. Fourth, we show the comprehensiveness of the standard, arguing that it captures most of the important phases of a data life cycle in the light of data protection. Finally we discuss potential effects of this standard in the regulative landscape. In conclusion, we find that this standard may regulate very effectively and influence activities in other forms of regulation.

2. DATA PROTECTION AND CLOUD COMPUTING

Regulations of computing technologies regarding data have to consider the issue of privacy. Though it is unclear how much customers actually change their behavior ("privacy paradox", cp. [2]), the media coverage proves that by citizens' perceptions, privacy and data protection are of utmost importance and the privacy concept appears in legal systems around the globe. The common idea of these legal entitlements and moral claims is that privacy is "the claim of individuals, groups, or institutions to determine for themselves when, how and to what extent information about them is communicated to others" [3], or simply a state in which one is not observed or disturbed by other people. The rationale for privacy can be to ensure preconditions of other fundamental rights (e.g. the freedom of speech); to protect individuals against discrimination (e.g. based on religious beliefs, sexual orientation, union membership); to prevent identity theft or simply to respect personal integrity.

Privacy is lacking when people or their behavior are under observation, i.e. the collection of data about a person. Seen from the opposite perspective, data that allows conclusions about the behavior of people is personal data ("personally identifiable information (PII)", or "personal information", including information from which identities are reasonably ascertainable). In this context, the function of data protection is to control the distribution (or diffusion) of personal data or to prevent the emergence of personal data from "ordinary" data which might be possible by linking data. Any measure towards that goal can therefore be designated as "data protection". Finally, the regulation of data protection is (a set of) rule(s) that governs the conditions of data protection. Thus, rules banning the

collection of data, rules about the processing of collected data, and rules ordering a certain degree of data transparency would all be some kind of data protection regulation.

Moreover, privacy by itself also has a specific economic dimension. On the one hand, referring to perfect markets as markets with complete information, privacy could be considered "fraud in 'selling' oneself" [4]. On the other hand, privacy can be part of commercial confidentiality.

Earlier work in this field has studied the costs and benefits of privacy in general but without regarding specific regulation regimes. Amongst others, this research has shown that producers have an interest in using knowledge about their customers for pricing (e.g. the price of health insurances for smokers), that Internet sellers use adverse selection instruments for revealing identities [5], that organizations which lose personal data experience negative economic effects [6] but not in the long term [7]. Also, external effects have been studied (individuals that disclose personal information also reveal information about others [8]), as well as bounded rationality issues (false understanding of Facebook's privacy settings even by "digital natives" [9]).

In sum, data protection regulation appears as a pivotal issue for the diffusion of innovations in ICT. While data protection can be an obstacle to diffusion, it ensures a democracy-conform market, safeguards open societies and protects the economic interests of consumers.

Several important developments in ICT have been labeled as cloud computing. While the definition of this term has proven "remarkably elusive" [10], it can be characterized by the core concept that IT services are not provided by one computer, but instead virtualized by a network. Cloud computing can be used by private or professional customers alike. For example, data can be stored in a cloud or the cloud can provide computing capacity. One of the service or delivery models of cloud computing ("Software as a Service") allows using application software as a service (provided by a server) instead of an installation on a single computer.

On the one hand, cloud computing offers miscellaneous benefits depending on how the concept is realized. For instance, users may need less powerful hardware, application software may always be up to date, and cloud computing services are potentially available from everywhere ("ubiquity"). On the other hand, cloud computing requires access to the network that provides the services, i.e. cloud computing via the Internet needs sufficient bandwidth and resilience. Because the cloud is independent from a single computer, data is not lost when a computer is stolen. At the same time, the user relinquishes some control over his or her data.

From an economic perspective, cloud computing allows several advantages like cost reduction but also increased reliability of services. Costs are cut by economies of scale and outsourcing, because resources can be pooled (in the cloud). These pools can be run be specialized experts in the respective domain. Particularly the innovative and fast-scaling enterprises require agile and flexible IT services. Nevertheless, all corporations are subject to a plethora of legal requirements that often come with liability and compliance implications. Data protection issues are among them.

Therefore, an effective and efficient regulation of data protection in cloud computing is the foundation for the adoption of clouds and cloud-based innovative ICT. Regulation, however, is exacerbated as cloud computing makes the physical control of data more difficult than traditional forms of computing. From the perspective of the data owner, there are more entities involved. In contrast, cloud computing may also provide the opportunity to professionalize data protection measures (services are run by specialized experts).

As the economy of the 21st century will be built on the processing of data, users want maximum benefits from using the new ICT services without surrendering their privacy rights. Strict privacy rules may "dumb down smart devices" [11]. In short, what all these stakeholders want is an efficient data market. The regulation of data protection in cloud computing is thus the issue of key market regulation.

3. RULES AND STANDARDS: THE GENESIS OF ISO/IEC 27018

Shaping policies can be achieved by different forms of regulation. The first form that may come to one's mind is to write down a normative proposition as a legal rule in a law (statutory law). Legally binding texts can also be decrees, ordinances or court decisions, all of which are acts of the state. However, there are also forms of non-state regulation and hybrid forms, like self-regulation (objects of regulation impose the rules themselves), multi-stakeholder regulation (involvement of different stakeholders in the process) and co-regulation (state and non-state actors collaborate, cp. [12]). Standards can be imposed by using any of these rule setting approaches. Standardization by standardization organizations is first an issue of (industry) self-regulation.

Nevertheless, the linkage between an industry standard and state regulation can convey a legally-binding status. The link can be realized by a direct reference in a law ("the standard x applies") or by an indirect reference (e.g. "the current state of the scientific and technical knowledge has to be applied"). Moreover, standardization organizations can be explicitly commissioned by official decision-making authorities. For example, with the concept of the *New Approach,* the EU institutions mandate CEN, CENELEC or ETSI to compile a standard in order to harmonize essential product requirements. In this case, the EU issues a mandate with the relevant policy objectives and the standardization organizations set up detailed regulations. The legal effect is that compliance with this standard leads

to the presumption of conformity with the respective (legal) EU regulation – a directive (cp. [13]).

ISO/IEC 27018 addresses the issues of data protection in cloud computing. Its full title is "Information technology – Security techniques – Code of practice for protection of personally identifiable information (PII) in public clouds acting as PII processors". The aims of this standard – as stated within – are, first, to support providers of cloud computing in meeting their legal obligations. Legally, cloud providers act as processors of personal identifiable information. The corresponding obligations might be statutory or contractual. Second, the standard intends to make the procedures of providers more transparent. Third, it should ease the conclusion of contracts between cloud providers and their clients. Finally, the standard should facilitate compliance verification by allowing for audits through professional auditors, as an individual review by a client would not only be technically difficult but could also introduce risks to the security of the cloud system as a whole.

ISO/IEC 27018 aims at fostering legal compliance. The genesis of the standard, though, has not been mandated by the *New Approach*. Still, an important goal of this particular standardization effort was to evoke a presumption of conformity and this goal steered the standardization process. The linchpin for ISO/IEC 27018 and its relation to the legal system is a provision from the EU data protection regulation (95/46/EC) which is implemented by national legislation in each EU member state. Article 17 of this regulation stipulates that anyone who is responsible for the processing of data has to take appropriate measures to "protect personal data against accidental or unlawful destruction or accidental loss, alteration, unauthorized disclosure or access, in particular where the processing involves the transmission of data over a network, and against all other unlawful forms of processing." If the responsible party (the "data controller") is using a contractor for the data processing (a "data processor"), it has to select a provider that applies appropriate technical and organizational measures and it has to verify that these measures will be observed. Violations of data protection principles as laid down in the relevant regulations can be sanctioned. Therefore, enterprises that outsource data processing to others face liability risks. ISO/IEC 27018 is designed to solve this compliance problem. In order to meet the requirements of the EU legal systems, the standard defines a number of *controls*.

For the definition of the controls, the authors of the standard have first identified the laws that govern cloud-based data processing in the EU (Each member state has at least one law implementing the EU directive. Germany, for example, regulates with one federal law on data protection and 16 state laws on the same issue). Based on the requirements set out in the laws across the EU, the standard establishes about 70 new controls, i.e. measures for data processing. Moreover, the standard's authors also considered the statements of the "Article 29 Working Party". This body consists of representatives of the member states' data protection authorities, the EU commission and the EU data protection supervisor. The group supervises the implementation of the EU data protection regulation in order to contribute to a consistent application in all member states. The group also analyses the level of protection in third countries and writes opinions and reports to different issues arising around data protection. Among these statements is also the opinion 05/2012 on data protection in cloud computing [14].

While ISO/IEC 27018 is the first international standard for privacy in cloud computing, it is embedded in the system of information security standards of the ISO/IEC 27000-series, the core of this framework being information security management systems according to ISO/IEC 27001. The guidelines for organizational information security standards and information security management practices including the selection, implementation and management of controls are set up in ISO/IEC 27002:2013. This standard contains controls on information security but it is neither cloud specific nor addresses the protection of private identifiable information.

Therefore, the drafting process of ISO/IEC 27018 compared the requirements of the EU legal system with the contents of ISO/IEC 27002:2013. As a result, the former provides guidelines on how to implement the latter's controls in the light of PII protection needs. Moreover, it offers additional controls that are specific to cloud computing and privacy issues, also being complemented by guidelines on their implementation.

As mentioned above, ISO/IEC 27018 specifically focuses on the legal regulations for data processors or – speaking in the terminology of cloud computing – for providers of cloud computing. Whether or not cloud providers comply with the standard and thus indirectly with the legal requirements can be assessed through an audit by certification providers. Therefore, clients of these cloud providers do not have to perform their own investigations and receive an independent confirmation that cloud providers fulfill the standard's requirements. This may also indicate a presumption of conformity with the EU data protection regulation, its implementing national laws and possibly also the Safe Harbor framework (a process by which US companies can comply with EU data protection regulation). Apart from these effects regarding existing EU regulations, the implications of adherence to this standard could extend to other jurisdictions. The level of protection of private identifiable information in the EU is considered to be high by international standards. Therefore, companies that select ISO/IEC 27018 certified cloud providers may also have fewer problems with data protection compliance outside the EU.

4. ISO/IEC 27018 AND THE DATA LIFE CYCLE

To understand the requirements of data protection, it is useful to study the life cycle of data (cp. figure 1). First, data is generated or collected (e.g. by sensors, questionnaires, a user filing out a form or merely clicking on an item at a website). Then, data is transferred from one information system to another (or within a system) to allow for its use. A particular but very important aspect of data use can be sharing. Here, third parties acquire access to the data. If the data is not only processed in real time it necessarily has to be stored at some point. For future use, data may also have to be archived. If it the data is no longer needed it may finally have to be destroyed (destruction phase). Each of these phases of the data life cycle can pose specific challenges from the perspective of data protection. Therefore, a comprehensive system of data protection would have to deal with all these phases. ISO/IEC 27018 addresses most of them (cp. figure 1).

As mentioned above, ISO/IEC 27018 consists of two parts. First, it references controls from ISO/IEC 27002 and provides guidelines for their implementation regarding processing PII in cloud computing. Second, ISO/IEC 27018 lists additional controls. These additional controls are specific to the nature of processed data (relevancy of privacy) and of commissioned data processing. While the aim of ISO/IEC 27001 – and most of the 27000-series – is the security of one's own data, ISO/IEC 27018 addresses the protection of the data of others (the cloud computing client and third parties, e.g. clients of the service that the cloud computing client provides). The idea behind ISO/IEC 27018 is to take the protection of PII data into account in the design phase of the cloud computing service ("privacy by design"; cp. [15]).

For example, this standard intends to explicitly define the tasks and responsibilities of cloud providers, cloud clients and possible suppliers. Furthermore, the cloud provider shall appoint a contact person for the issues of PII data. Employees of the cloud provider should be trained in possible consequences of privacy breeches for the cloud provider, its staff and its customers. From a technical perspective, providers of cloud computing should offer secure log-in procedures and inform users about encryption. When in doubt, storage media should be treated as if it contained PII. Each access to data should be logged. Cloud providers may also consider making these log files accessible to clients, such that they can access logs for their own data only.

Examples of the more cloud specific controls of ISO/IEC 27018 are that PII data may not be processed differently as allowed for by the client. Particularly, this data may not be used for marketing and advertising. Access to data by third parties may only be allowed if the cloud provider is legally obligated to do so. The provider also has to inform the client about such access (unless conveying this information is itself prohibited). The client should be notified about the use of subcontractors by the cloud provider. If any unauthorized access to data happens, the client should be informed about it immediately. Temporary data should be deleted regularly, print outs of data avoided and the transfer of data through networks encrypted. Another control suggests documenting the location (country) of stored data.

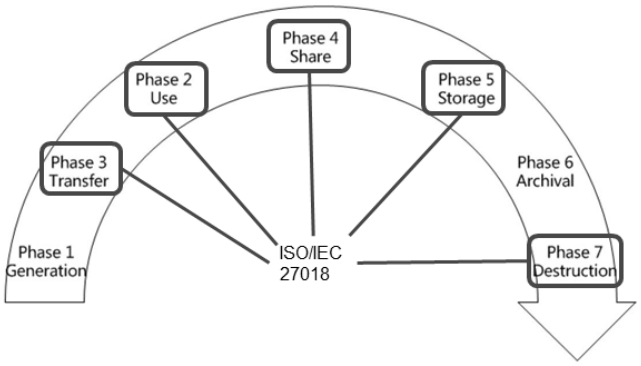

Figure 1: Data life cycle and ISO/IEC 27018, cp. [16].

All of the above are examples for possible measures for implementing the standard. For compliance with ISO/IEC 27018, cloud providers have to assess their particular situation (nature of data, legal situation, etc.) and choose the appropriate measures from the catalogue of controls provided by the standard. The controls selected may vary according to different types of clouds (e.g. SaaS- or PaaS-clouds) or the roles of cloud providers and users (cp. ISO/IEC 17789 on cloud computing reference architectures). ISO/IEC 27018 does not specifically address the data life cycle phase of archival (which could also be seen as a particular form of the storage phase) and does not address the issues of data generation. Although data generation is an important phase of the data life cycle and poses numerous risks to data protection, ISO/IEC 27018 cannot cover this phase, as the standard focuses on the protection of data that is processed by another. The data generation phase would thus have to be addressed by other pieces of regulation. Therefore, it appears that ISO/IEC 27018 is a very comprehensive approach to its selected scope.

5. POTENTIAL EFFECTS AND THE REGULATIVE LANDSCAPE

In general, standards have a strong influence on economies. For example, standards contribute to economic growth (at least as much as patents) and provide macroeconomic benefits – not only profits to companies [17]. However, this paper wants to study the function of a standard in a particular domain from a regulative perspective, concentrating on ICT. While ISO/IEC 27001 focuses on the protection of an organization's *own* information assets, the new ISO/IEC 27018 provides guidance for the protection of *customers' assets*, specifically the protection of PII in cloud computing. The analysis of the genesis of ISO/IEC 27018 revealed the

strong influence of legal regulation on the drafting process. The standard has been written in order to relate cloud computing to the vague legal concept of Article 17 of 95/46/EC: If the cloud customer is a corporation and exerts legal control of the stored PII of a third party (the end customer), the cloud customer is subject to the regulation and needs to take appropriate measures for data protection. Adhering to ISO/IEC 27018 eases compliance with these data protection obligations and thus facilitates the use of cloud computing services.

But what (reciprocal) effect does the standard have on legal regulation? First, the standard provides assistance for the implementation of the EU regulation and the member states' laws. The EU regulation was created twenty years ago, in a time where the need for data protection had already been recognized, but the concept of cloud computing not yet known. Therefore, the EU regulation could not take the specifics of cloud computing into account. In this regard, ISO/IEC 27018 fills a gap in the regulative system.

Second, the standard could extent the geographical applicability of the material provisions of the EU regulation. As demonstrated, the standard has been created with the explicit goal of conformance with EU regulation. The legal situations of the EU and its member states have been thoroughly assessed. Thus, European ideas of data protection receive greater recognition worldwide via their incorporation into an international standard. The more international market participants implement the standard, the higher the de-facto level of data protection, regardless of the legal situation in a given country. The standard does not allow circumventing of legal rules. However, it provides incentives to multinational corporations – be they providers or clients of cloud computing services – to align their product or requirements on the comparatively high level of data protection of the EU system. In effect, a higher level of protection in the standard may also result in countries adjusting their legal situation and aligning with the European Union (cp. figure 2).

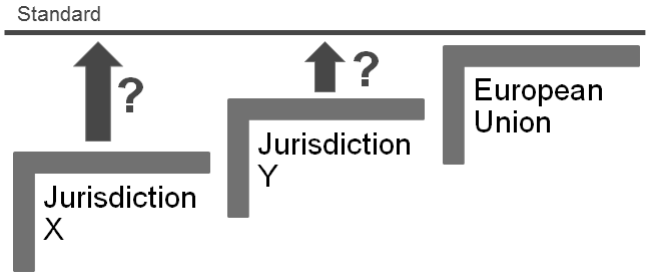

Figure 2: Potential effects of a standard.

ISO/IEC 27018 has been published in 2014. By now, it would be too early to expect significant effects. Nevertheless, there are certain indications suggesting that this is the case. Regarding the market situation, key providers of cloud computing solutions have adopted the standard (e.g. Microsoft for the products Azure and Office 365, Dropbox for Business). Moreover, national regulative authorities refer to this standard [18]: The Office of the Australian Information Commissioner (OAIC) referred to it in its guide to securing personal information, the Belgian privacy commission referred to it in its Guidance on Security & Privacy in the Cloud, the Canadian Office of the Information and Privacy Commissioner (OIPC) mentioned it in a blog post, the Slovenian Information Commissioner indicated the consistency of ISO/IEC 27018 with its requirements and Singapore's Personal Data Protection Commission (PDPC) is considering its use. Korea recently passed a law on cloud computing [19]. Though it does not reference any standards explicitly, the law is considered to be the first cloud-specific law and contains provisions on data protection. This indicates that legislative regulators have identified cloud computing as a field of regulation.

6. CONCLUSION

If data is the oil of the 21st century, the regulation of data protection and privacy becomes paramount. Cloud computing is a key enabler for the use of this new oil. When it comes to data protection, legal regulation has thus far neglected the specifics of cloud computing. With ISO/IEC 27018 these issues have now been addressed by a non-legal form of regulation, linking it to the EU system of data protection through Article 17 of 95/46/EC. This reveals how standards can complement legal regulations and fill in their gaps. A broad use of the standard will harmonize the practice of handling PII in a globalized economy and will advance PII-protection in jurisdictions with low protection levels. Current developments indicate that the standard might have a reciprocal influence on legal rule setting.

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AUTONOMIC TRUST MANAGEMENT IN CLOUD-BASED AND HIGHLY DYNAMIC IOT APPLICATIONS

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ABSTRACT

In this paper, we propose an autonomic trust management framework for cloud based and highly dynamic Internet of Things (IoT) applications and services. IoT is creating a world where physical objects are seamlessly integrated in order to provide advanced and intelligent services for human-beings in their day-to-day life style. Therefore, trust on IoT devices plays an important role in IoT based services and applications. Cloud computing has been changing the way how provides are looking into these issues. Many studies have proposed different techniques to address trust management although non of them addresses autonomic trust management in cloud based highly dynamic IoT systems. To our understanding, IoT cloud ecosystems help to solve many of these issues while enhancing robustness and scalability. On this basis, we came up with an autonomic trust management framework based on MAPE-K feedback control loop to evaluate the level of trust. Finally, we presents the results that verify the effectiveness of this framework.

Index Terms— Trust, Internet of Things, Cloud Networks, IoT cloud ecosystem, smart homes, MAPE-K

1. INTRODUCTION

One of the preliminary objectives of Internet of Things (IoT) is to deliver personalised or even autonomic services to individuals, building on a pervasive digital ecosystem that collects information and offers control over devices that are embedded in every one of ours' everyday lives [1]. The extraordinary power of this vision is expected to lead to fundamental social change: it will affect the way in which we interact with our environment and each other, and will result in the creation of new business opportunities and innovative business models [2]. However, the embedded nature of this technology and a lack of awareness of its potential level of trust and, social and personal consequences, as balanced against the more clearly articulated benefits, makes specific issues correspond to trust, security and privacy [3]. On the other hand, cloud computing has virtually unlimited capabilities in terms of storage and processing power, is a much more mature technology, and has most of the IoT issues at least partially solved.

The IoT integrates a large amount of everyday life devices from heterogeneous network environments, bringing a great challenge into trust, security, and reliability management. In doing that, smart objects with heterogeneous characteristics should cooperatively work together [4]. It is a known fact that the Devices in IoT very often expose to public areas and communicate through wireless, hence vulnerable to malicious attacks [5, 6, 7]. Migrating IoT application specific data into the Cloud offers great convenience, such as reduction of cost and complexity related to direct hardware management [8, 9, 10]. However, to evaluate the trustworthiness of their systems cannot use only the past experiences, since the novel autonomic systems nowadays are highly dynamic and the behaviors are unpredictable. These restrictions are detrimental to the adaptation of Trust Management Systems (TMSs) to today's emerging IoT architectures, which are characterized with autonomic and heterogeneous nodes and services.

Clouds or cloud computing has picked up many researchers' attention, as such it is being a part of IoT. Undoubtedly, trust management is the most challenging issues in emerging cloud systems where millions of services, applications and nodes deployed together under a single umbrella to serve each other [11]. Together with the current dynamism of the systems and the autonomous users' behavior, the latter task has been too complicated [12]. In reality, autonomic trust management is hard to be realized because the cloud of things is hard to control due to the scale of deployment, their mobility and often their relatively low computation capacity [13, 14]. As a result, the trust manager itself should be adaptive to the autonomic conditions posed by the system.

In this paper, we propose a framework for autonomic trust

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management based on Monitor, Analyse, Plan, Execute, Knowledge (MAPE-K) feedback loop to evaluate the level of trust in a IoT cloud ecosystem. Even though many research activities were carried-out in the scope of autonomic trust management, non of them have addressed how an integration between IoT and cloud would work. We utilize MAPE-K feedback control loops to enhance consistency of the system while improving robustness and scalability with the introduction of cloud concepts.

The rest of the paper is organized as follows; Section 2 describes the related work. Section 3 describes challenges of TMSs in IoT, next Section 4 describes cloud integration in IoT, Section 5 presents the system model and Section 7 describes simulation and results. Finally, in Section 8, we conclude the paper.

2. RELATED WORK

Yan et al. [15] have done a survey on trust management for IoT where they discuss the current state of art while elaborating open issues and key challenges in IoT trust management. They have categorized trust properties into five categories and proposed ten objectives for trust management in IoT. Manuel [16] introduces a trust model for a cloud resource provider where they use four parameters namely availability, reliability, turnaround efficiency and data integrity for the evaluation of trust. Their model is based on the present value as well as the history of the parameters.

Chen et al. [17] have created a trust model for IoT that uses fuzzy sets. They focus mainly on different security challenges such as detecting malicious attacks. Firdhous et al. [18] have done a critical review of trust management in Cloud Computing. They discuss existing TMSs for the cloud and compare them based on a set of parameters. Noor et al. [19] have introduced a framework for trust management in cloud environments called Trust as a Service. Their work helps to differentiate credible trust feedbacks from malicious feedbacks where feedbacks originate from consumers of the cloud service.

3. CHALLENGES OF TRUST MANAGEMENT IN IOT

The current IoT systems challenge TMSs in following different aspects. First, the behavioral features of an IoT system is expected to have huge amount of entities. The problem with that is the existing trust management protocols do not scale well to accommodate this requirement because of the limited storage and computation power. Second, an IoT system evolves with new applications, services, and nodes frequently joining and leaving the systems. Therefore, a trust management protocol must address this issue at the same time in order to allow newly joining elements to build up trust quickly with a acceptable level of accuracy.

Third, the building blocks or entities of IoT systems are mostly human carried or human operated devices, which implies that a TMS must be capable of compensating the human errors at some level. At this point that IoT may take into account the social relationships among entity owners in order to maximize protocol performance. Lastly and arguably most importantly, like other Internet systems, an IoT system is frequently the target of many cyber attackers, since many IoT entities are accessible through wireless networks, the network itself is a point of failure in terms of the level of trust offered. Therefore evaluating the level of trust in such autonomic and hostile environments has been a critical challenge.

4. CLOUD INTEGRATION IN INTERNET OF THINGS

Even though the worlds of cloud computing and IoT seem to evolve independently on their own paths, an integration of Clouds with IoT will lead to the production of large amounts of data, which needs to be securely stored, processed and accessed. Cloud computing as a paradigm for big data storage and analytic needs the trustworthiness. Cloud can benefit from IoT by extending its scope to deal with real world things in a more distributed and dynamic manner, and for delivering new services in a large number of real life scenarios. Essentially, the Cloud acts as intermediate layer between the things and the applications, where it hides all the complexity and the functionalities necessary to implement the latter.

Trust is one of the most concerned obstacles for the adoption and growth of cloud computing. Although couple of solutions have been proposed, determination of credibility of trust feedbacks is neglected in most of the cases which lead to many security failures. TMSs usually experience malicious behaviors from its users. In addition, managing trust feedbacks in cloud environments is a difficult problem due to unpredictable number of cloud service consumers and highly dynamic nature of cloud environments. On the integration of clouds with IoT, there are many advantages. Adoption of clouds enables new scenarios for smart services and applications. New scenarios for smart services and applications based on the extension of Cloud through the things delivers extensions in IoTs.

IoT is characterized by a very high heterogeneity of devices, technologies, and protocols. Therefore, scalability, interoperability, reliability, efficiency, availability, and security can be very difficult to obtain. Sensing as a service, sensing and actuation as a service, sensor events as a service, sensor as a service, database as a service, data as a service, and Ethernet as a service are all different potential extensions to IoT based clouds. IoT makes IP-enabled devices communicate through dedicated hardware, where the support for such communication can be expensive.

The applications of such systems could be extended to healthcare, smart cities, smart homes and smart metering, smart grids, etc. However, so far non of the research activities has been carried out in the scope of trust management in cloud integrated IoT. Automation of management is one of the essential characteristics of the cloud networks today.

Autonomic computing is an approach to equip computer systems with capabilities to autonomously adapt their behavior and/or structure according to dynamic operating conditions. For effective self management, a system needs context awareness, self-configuration, self-optimization, self-protecting, self-management, self-healing, anticipatory, and openness.

5. DECOMPOSITION OF THE SOLUTION

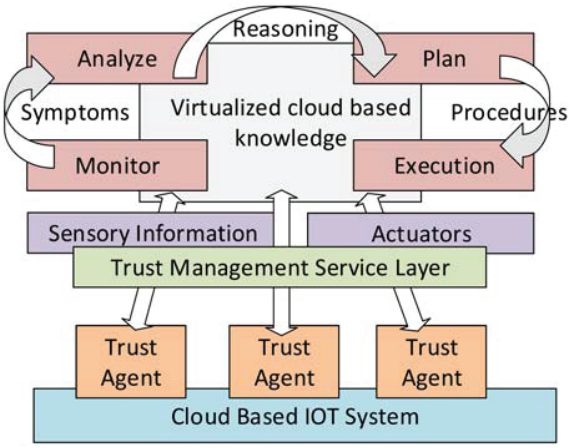

Figure 1. MAPE-K feedback loops for adaptive trust agents.

The system we are interested is highly dynamic which implies the need for adaptive decision making and autonomic agents with control loops to manage resources. A promising approach to handle such dynamics is self-adaptation that can be realized by a MAPE-K feedback loop. To provide an evidence that the system goals are satisfied, regarding the changing conditions, state of the art advocates the use of formal methods. However, it is important to remark that the trust agents in Fig. 1 do not replace the monitoring phase of the MAPE-K, but instead it filters out the trust information from other information while holding the required knowledge to support the autonomic decision-making process.

The distributed nature of the trust agents assure quick responses and scalability of the solution. In Fig. 1, the monitor function aggregates, correlates and further filters the information until it determines a symptom that needs to be analyzed. Analyze function performs complex data analysis and reasoning on the symptoms provided by the monitor function. Analyze function would be influenced by stored knowledge data which, in fact, virtually centralized but physically exists within the trust agents. If changes are required, a change request is logically passed to the plan function. The plan function structures the actions needed to achieve goals and objectives and creates or selects a procedure to enact a desired alteration in the managed resource. At the same time it can take on many forms, ranging from a single command to a complex work-flow. Execution phase changes the behavior of the managed resource using effectors, based on the actions recommended by the plan function. In fact, the executors are open APIs to the trust managers' feedback system. The knowledge in Fig. 1 is the standard data associated with the monitor, analyze, plan and execute functions. The knowledge here is shared among the trust agents and could be virtually centralized using cloud techniques to facilitate decision making. This would include data such as all trust related information, context information, topology information, historical logs, metrics, symptoms, policies, etc. This system now becomes self-adaptive based on MAPE-K feedback loops that deal with dynamic trust issues arising due to openness. It is important to notice that our particular focus is on adaptations that require elevating or downgrading the level of trust in a system.

5.1. Trust as a Service (TaaS)

Cloud is a flexible framework to effectively implement services. Among many other services "Trust" can be thought of as a service offered by the cloud system to its users. In an IoT system, multiple devices would associate with each other as well with users. Internet and IoT play a significant role in service deployment, especially in facilitating and automating the human needs and requirements. An effective trust management system helps cloud service providers and consumers reap the benefits brought about by cloud computing technologies.

Despite the benefits of trust management, several issues related to general trust assessment mechanisms, distrusted feedbacks, poor identification of feedbacks, privacy of participants and the lack of feedbacks integration still need to be addressed. Traditional trust management approaches such as the use of Service Level Agreements (SLA) are inadequate for complex IoT based cloud environments. Sometimes, the vague clauses and unclear technical specifications of SLAs can lead cloud service consumers to be unable to identify trustworthy cloud services. For example, a smart home environment could be one of the possible applications of cloud based IoT system that implements services. Fig. 2 presents a smart home environment in which the proposed TMS could be applied. Nowadays, modern homes are equipped with many IoT devices that are automated and controlled remotely through Internet. For example, an owner may access the electrical devices at his home through his mobile device.

It could be like switching the security system on or monitoring through the surveillance cameras when he is away from his home. However, the risk behind such a solution is about producing the wrongful information that mislead the owner. For example, at the time the owner remotely switch on the home security system, a criminal may produce a faulty acknowledgment and send it to the owner to misguide him and burglarize. Because of that, the trust on IoT devices and their applications in real-world is critical. There have been many different approaches to enhance the trust over information and devices. These solutions address several trust related issues in common. They are;

- Trust plays a critical role in risky and uncertain environments that are not under control.

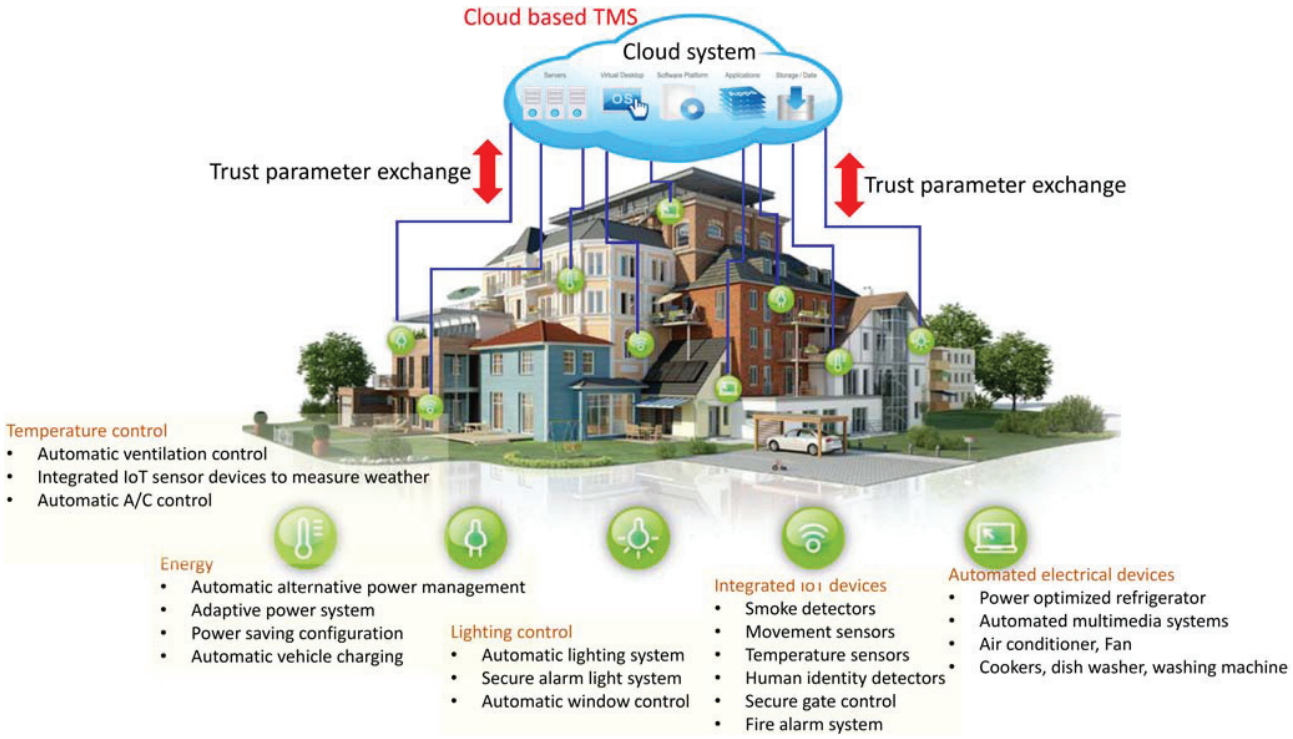

Figure 2. Smart home environment with the trust management system. The IoT devices sense the trust parameters and exchange information to the trust agents virtualized in the cloud network.

- Trust is the basis on which certain decisions are made in our day-to-day life style.
- The decisions are taken mostly on the prior experience and knowledge where wrongful history produces incorrect results.
- Trust is subjective and it is based on the personal opinion and their preferences.
- Dynamic environmental and contextual information modifies level of trust. Possible changes with time and new knowledge may override influence over the old ones.
- Trust is context-dependent which may produce incorrect information in extreme contextual conditions.

5.2. Cloudifying TaaS

The TMS proposed in this paper acquires the contextual and environmental information through the IoT sensor devices and deliver it to the trust agents which filter information and send it to the MAPE-K control loop implemented on the cloud. Therefore, trust now operates as a service on top of the cloud, which we call "TaaS". Behind cloudfying the application, many advantages would be delivered to the end users.

- Availability: availability of the "TaaS" service could be thought as the reachability between the target environment and the cloud system. "TaaS" will communicate with the IoT devices and sense the information.

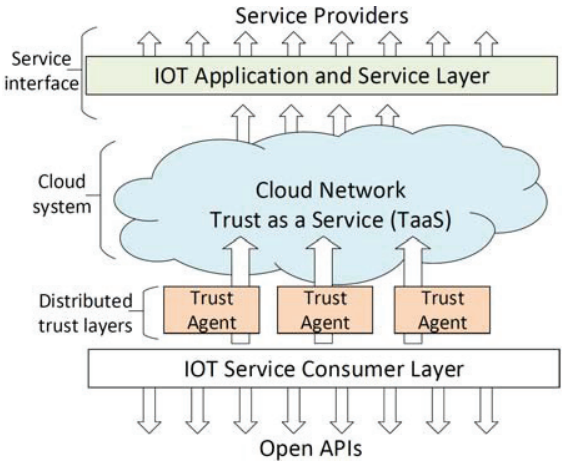

Figure 3. Overview of the solution architecture.

As far as the devices are connected to Internet, service will always be available to its users.

- Scalability: scalability defines the ability of "TaaS" to handle the growing number of IoT devices. Over the time, many houses hold smart devices would be added to the Internet. In order to cater them, "TaaS" defines distributed trust agents that filter raw data.
- Accessibility: in relation with our example of smart home environment, the user may need to switch on his home security system. As far as "TaaS" is imple-

mented on a cloud network, the user may access the service through Internet from wherever he is.

- Flexibility: MAPE-K control loop in the cloud aggregates trust parameters through the trust agents. The cloud system enables the trust agents to be deployed in a flexible and distributed manner. By doing so, the system allows the IoT devices to communicate trust related information.

Fig. 3 describes the solution architecture of the proposed trust management system that consists of distributed trust agents. They produce the trust parameters and filters them to the adaptive trust parameter pool which is on the cloud. The service consumer layer integrates the clients to the TMS. This layer consists of several distributed TMS nodes that expose interfaces to the clients. Cloud deploys trust as a service together with the MAPE-K control loop. The feedback system produces results based on the past history. In doing that, we normalize the impact of favorable abnormalities to reduce the expected dynamism. This is because the context has a significant affect on the level of trust. The raw information as it is will happen to produce incorrect decisions which we overcome with MAPE-K control loops.

6. SYSTEM MODEL

The systems model consists of three layers, service consumer layer, cloud network layer, and applications and service layer. Furthermore, the service consumer layer consists of open Application Programmable Interfaces (APIs) on which clients access the services and trust agents that locally filters trust related information to the trust data pool. In second layer - cloud network is implemented with the service ("TaaS") which utilizes cloud based computing intelligence to obtain the corresponding parameters. These parameters are then fed to the MAPE-K feedback control loop that produces the set of trust parameters on which the final decision is made. However, the process runs over many iterations to modify a final result based on the past history. Fig. 4 demonstrates this control loop which modifies the current level of trust and make decisions. In fact, we consider four trust related parameters; availability, reliability, response time and capacity.

- Availability is about making the resources available for users. The trustworthiness of a system lies on whether the resources are available when it is required.
- Reliability defines the level of trust among two entities. A reliable system always produces correct information.
- Irregularities in response time predicts possible intrusions in the system. That helps to identify changes from normal.
- Finally, capacity contributes to the model by assuring accessibility in one hand and scalability on the other hand.

"TaaS" measures the level of trust in terms of these parameters and finally aggregate them to make the decisions or to continue into a feedback loop that modifies current value based on past values. It is done by the analyzer which runs multiple computing methods for reasoning based on the provided set of parameters. "Planner" transforms reasoning to procedures which could be directly forwarded to the executors or adapters through which they are converted to decisions. If the decision does not fit in the context to be executed that can be modified with the past history and return it to another feedback loop for modifying. At last, all the parameters are stored in the adaptive parameter pool on the cloud and accessible by the service providers through application and service layer.

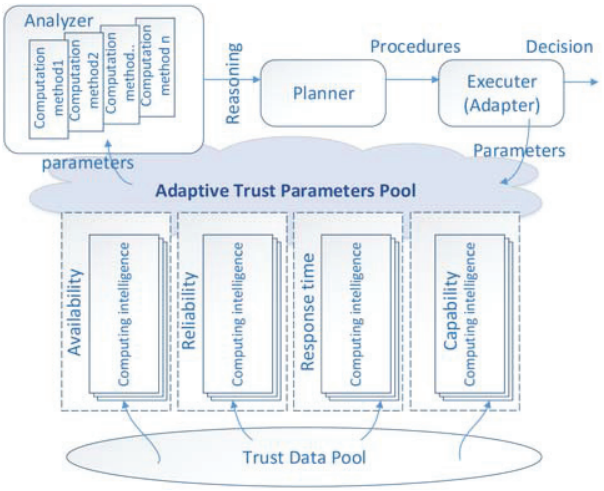

Figure 4. State of art of trust agent.

This framework thus provides the flexibility on both clients and operators and adjust the trust level according to the context. The IoT sensor devices send raw data that they collect where their representation would differ with respect to which trust parameter they are contributing to. For example, a sensor that senses the availability would sense the number of successful ping requests made in a unit time interval while a sensor that senses reliability would measure the Bit Error Rate (BER) in the target environment.

As a result, the raw data must be first normalized and transformed appropriately to generate the trust value that depicts the current state with respective to the trust parameter. Since this value only describes the present status, we made an extension to that to integrate it with the previous history appropriately. In a nutshell, this complete process, where we represent the state as a combination of both history and the current state can be thought of as a feedback loop. Thereby, the MAPE-K control feedback loop comes into the model. Herein, a trust parameter for a IoT device d at a time t can be evaluated using Eq. (1).

$$P_{d,t} = (\alpha P_{d,t-1} + (1-\alpha) C_{d,t})^{\frac{1}{b}} \quad (1)$$

$$C_{d,t} = \left[\frac{-s(V_0 - V_{d,t})}{V_0 - V_{min}} r_1 + \frac{s(V_{d,t} - V_0)}{V_{max} - V_0} r_2 \right] \quad (2)$$

Thus, the same parameter at time $t-1$ is represented as $P_{d,t-1}$. $C_{d,t}$ represents the current value for the trust obtained via transformation of the sensor raw data using Eq. (2). In Eq. (1), α is the weight given on the history which should be a value between 0 and 1. The value b is a parameter that defines by how much the calculated trust values are to be augmented or diminished. A value slightly greater than 1 would result in an augmented trust level while a value slightly less than 1 would result in a diminished trust value. This parameter could be set based on the dynamic nature of the system such that the effect on the trust due to the high variations are compensated. In Eq. (2) parameters of the format V_k are with respect to the raw data that is received from IoT sensor. The maximum raw data value that can be generated by the sensor is given by V_{max} while the minimum is given by V_{min}. The raw data value update sent by a sensor about the device d at a time t is given by $V_{d,t}$.

The $P_{d,t}$ value evaluated by Eq. (1) always falls between -1 and 1. It reaches 1 at the highest level of trust while the value will remain around 0 when there is no trust on the device (the fact that device is neutral with respect to others). At the same time, it remains at 0 when there is no data to evaluate the trust, for example when a device is just added to the system. In case, if the device is untrustworthy and may cause a damage on others, then the value would reach -1. V_0 determines the value coming from the sensor that would result a zero value when normalized and transformed. A value $V_{d,t}$ which is less than V_0 can lead to a negative value for the trust parameter. The value for r_1 and r_2 in Eq. (2) must be selected as follows:

- if $V_{d,t} < V_0$ then $r_1 = 1$ and $r_2 = 0$
- if $V_{d,t} >= V_0$ then $r_1 = 0$ and $r_2 = 1$

The value for s must be selected based on the fact whether the raw data values received from the sensor is directly proportional or inversely proportional to the trust. When the parameter is directly proportional with trust, for example the number of successful ping request, s should be positive, i.e. 1. When it is inversely proportional to trust, for example the BER, then s should be negative, i.e. -1.

The formula we discussed so far only calculates a single trust parameter. The total trust of a system actually depends on multiple such parameters. Therefore, finally all the different parameters evaluated using Eq. (1) must be integrated to evaluate the effective trust level. Total trust can be evaluated by using weighted sum as given in Eq. (3). Here the effective total trust for a device d at time t denoted by $T_{d,t}$. A trust parameter calculated using Eq. (1) is depicted as $(P_{d,t})_i$ and there are n number of such different parameters. The respective weights assigned to each of those trust parameters are denoted by β_i.

$$T_{d,t} = \sum_{i=1}^{n} \beta_i (P_{d,t})_i \quad (3)$$

7. SIMULATION AND RESULTS

We simulate the proposed model for a smart home environment by using Matlab. We evaluate four parameters, namely availability, reliability, response time and capacity. First, for evaluating availability, we checked whether the devices are alive and reachable by sending out a fix number of ping requests. The number of responses thus, depends up on the route to the target device. Furthermore, any hardware failure will also happen not to receive any response. Then, evaluation of reliability was measured by simulating the possible BER on the target environment. Next, the response time was evaluated based on the round trip time whereas finally, the capacity was evaluated based on the number of current sessions on a device and the maximum number of connections to an IoT device.

The calculations are based on Eq. (1) and Eq. (2) discussed in previous section. The value for α for the trust parameters availability, reliability, response time and capacity was set to 0.8, 0.8, 0.8 and 0.9 respectively. The value for b was set to 1.16. Fig. 5 describes level of trust against availability, reliability, response time and capacity. The graphs with feedback demonstrate the level of trust when the trust protocol is applied. Without feedback demonstrates when it is not applied, where huge variation of level of trust can be seen over time. The significance here is the adaptation of MAPE-K control loop to improve the consistence of level of trust. That is because dynamic systems are highly vulnerable and may change their behavior/level of trust quite fast. To comply these needs, the framework applies history across the MAPE-K control loop in order to reduce impulses that misguide the TMS.

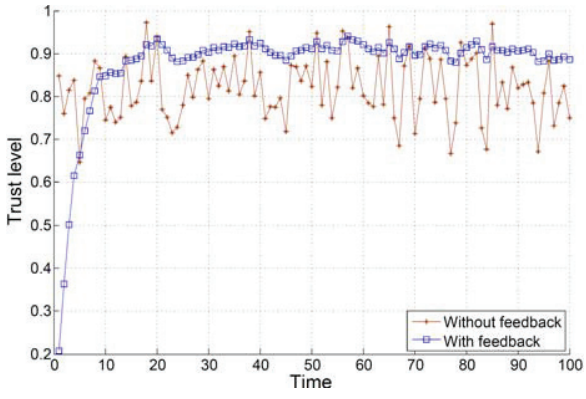

Figure 6. Effective level of trust. (Aggregated availability, reliability, response time and capacity)

In doing so, we make sure the framework will not produce incorrect decisions at last. Finally, we integrate these trust parameters to obtain the effective level of trust. Fig. 6 presents the effective level of trust on which the decisions would be

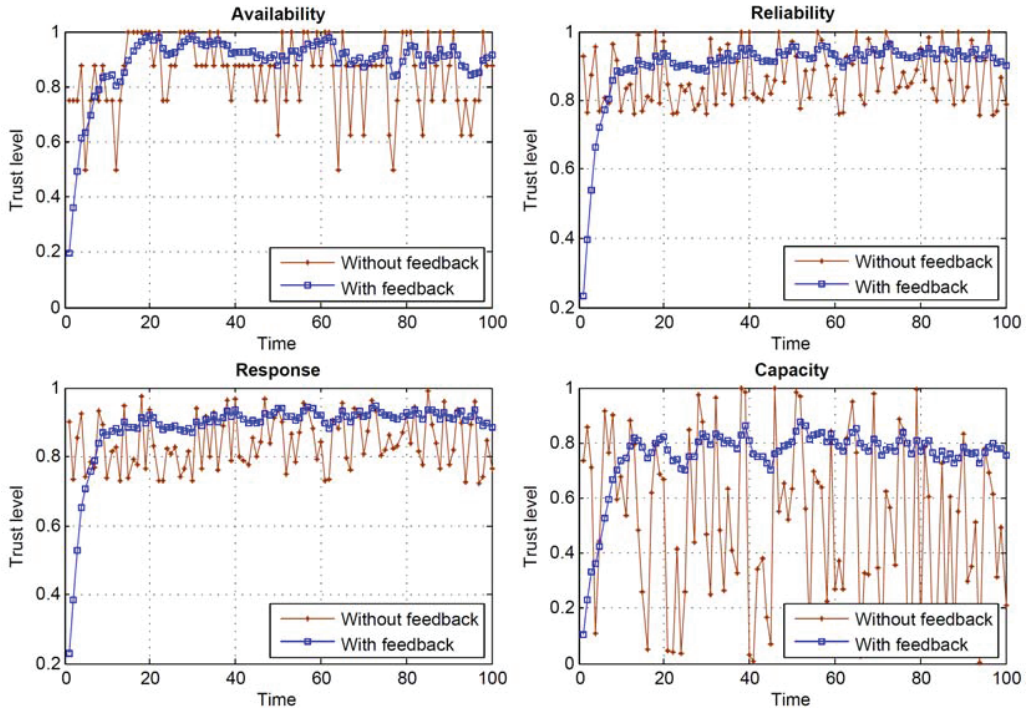

Figure 5. The subplot describes level of trust against availability, reliability, response time and capacity.

made. Once, the results are integrated, the target environment still produces highly varying set of information which is not usable to make decisions. With our framework, we managed to normalize the results and let them fall within a short range which may alter based on the current state. Therefore, applied the framework the decisions made becomes trustworthy over the time. However, having a long history more accurate decisions could be made while reducing the seen dynamism when no feedback is applied.

8. CONCLUSION

Based on in-depth understanding of trust establishment process and quantitative comparison among trust establishment parameters, this paper presents an autonomic trust management framework for cloud based and highly dynamic IoT applications and services. We are increasingly aware of the necessity of eliminating the influence upon the evaluation results affected by malicious recommendation and defamation behaviors of a third party. In this framework, we adopt MAPE-K feedback control loop to evaluate the level of trust in an IoT cloud ecosystem. To evaluate the framework, we have developed a simulation framework. Thereby, we demonstrate consistency of the level of trust which is important with many IoT based dynamic applications and services. Apart from that, referring to the history of the records we enhance the level of trust at the same time. However, deployed the system, we expect it to improve further as history will accumulate over time. The trust management framework proposed for cloud based IoT system have been extensively studied with respect to their capability, availability, reliability and response time in practical heterogeneous cloud environment and their implementabilty. In the evaluation, it is evident that contributions from different parameters could be customized to fit into a specific context as it would be needed by a client. This enhances the flexibility of the system and let users to customize on their own need.

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THE IMPACT OF CLOUD COMPUTING ON THE TRANSFORMATION OF HEALTHCARE SYSTEM IN SOUTH AFRICA

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ABSTRACT

An increasing number of organisations around the world are making use of information and communications technology (ICT) for health (eHealth) to address healthcare challenges. This includes aggregating vast amounts of data from various sources to create evidence for policy and decision making. However, the eHealth initiative in South Africa is hindered by unreliable ICT platforms. This research study is designed to leverage eHealth and propose a conceptual cloud computing model to improve healthcare service delivery. The aim of this research study is to instigate new collaborative efforts for the creation of evidence value-based healthcare system. The findings attest that the sensitive nature of clinical data remains a challenge. Similarly, the South African government should resolve concerns on regulatory frameworks for proper governance of eHealth standards implementation, whilst accelerating healthcare improvements within the public health sector in particular.

Keywords— Information and communications technology, Cloud computing, Healthcare

1. INTRODUCTION

The following citation from the Department of Health (DoH) puts matters into perspective concerning healthcare system effectiveness in South Africa [6]: *"Although large sums of money have been used to procure health Information and Communications Technology (ICT) and Health Information Systems (HIS) in South Africa in the past, the ICT and HIS within the public health system is not meeting the requirements to support the business processes of the health system thus rendering the healthcare system incapable of adequately producing data and information for proactive management and for monitoring and evaluating the performance of the national health system. This results from the lack of an overarching technology policy framework and supporting regulations to inform ICT procurement and management processes"*.

Porter and Guth [18] also make similar observations in relation to the efforts to reform the German healthcare system by contending that, *"the future demographic shifts and innovations in medical technology threaten to further accelerate spending and destabilise the system"*. According to [18], nearly every government is now asking *"how can we design a healthcare system that produces better value for the money we spend"*.

Based on these observations by [18] in relation to the healthcare system reform in Germany, it could be argued that the healthcare system challenges are not confined only within the boundaries of the developing world. These interpretations of evidence also hold true as reiterated by [16] relative to the healthcare system reform in the United States (U.S.) in that: "*Despite many waves of debate and piecemeal reforms, the U.S. health care system remains largely the same as it was decades ago. We have seen no convincing approach to changing the unsustainable trajectory of the system, much less to offsetting the rising costs of an aging population and new medical advances"*.

As noted by [12], an inability to communicate and the lack of information technology (IT) standards undermine the ability of IT to enable value measurement and to restructure care delivery around the integrated care for medical conditions. These revelations conform to Porter's [17] strong belief that the fundamental issue in healthcare is not necessarily access, volume, convenience or cost estimation; but the value for patients.

2. NATIONAL E-HEALTH STRATEGY

The World Health Organisation defines eHealth as the use of ICT for health to treat patients, conduct research, and educate the health workforce, track diseases and monitor public health related activities [28].

The DoH alludes that this short definition of eHealth covers vast domains, which includes Electronic Health Records (EHRs) for sharing of patient data at the points of care [5]. It is worth mentioning that the South African Medical Research Council is at the centre of developments for eHealth to deliver on its new role as a World Health Organisation collaborating centre for the Family of International Classifications [25]. In addition, the Technical Advisory Committee of the National Health Council is responsible to provide technical oversight required to ensure proper implementation of eHealth strategy [5].

These initiatives in South Africa are in agreement with the fifty-eighth World Health Assembly resolution adopted in 2005, established an eHealth strategy for World Health Organisation member states. In a similar viewpoint, the DoH adopted an eHealth strategy for South Africa to lay solid requisite foundations for future integration and coordination of eHealth initiatives in the country [5]. It was noted that the implementation of the National Health Insurance (NHI) was intended to provide universal coverage through eHealth initiatives [8].

Basically, the DoH has embarked on strategies aimed at the primary prevention of non-communicable and chronic diseases through educating individuals, households and communities on the benefits of healthy lifestyles [6]. The programme involves the utilisation of community health workers through a re-engineered and integrated Primary Health Care system. This is a collective effort, which involves other departments such as the Department of Social Development as well as the Department of Trade and Industry [7]. These programmes started after 1994, whereby the information systems of the public health sector were overhauled to support the new Primary Health Care approach aimed at changing the South African healthcare landscape. These initiatives were later endorsed in the national parliament in 1997, by then, the Minister of Health Dr. N.C. Dlamini Zuma, in the newly democratic South African government of Dr. Nelson Mandela [4].

The NHI then becomes an integral part of a regenerated initiative underpinned by Primary Health Care in changing the face of care service delivery in South Africa [8]. This initiative is based on a R300 billion NHI project, regarded as one of the most complex and multi-disciplinary in nature ever undertaken by the South African Department of Health [22]. The suggestion by the South African National AIDS Council (SANAC) is that the South African government should increase the funding of public health services closer to 5% of GDP [26].

The importance of ICT towards the implementation of the NHI cannot be overemphasised. In a report, "The National Strategic Plan 2012/16 on Human Immunodeficiency Virus (HIV), and Tuberculosis (TB)", SANAC states that, *"The primary focus of Strategic Objective 3 (SO 3) is to achieve significant reduction in deaths and disability as a result of HIV and TB"*.

Through the adoption of eHealth strategy, ICT remains a critical enabling factor to achieve the universal access to affordable and good quality health outcomes, diagnosis, treatment and care, as an essential part of the SANAC's Strategic Objective 3 [26]. It is not surprising for the DoH to accentuate that globally, ICT has emerged as a critical enabling mechanism to develop a HIS, capable of strengthening healthcare system effectiveness [5]. Enthoven and Tollen [1] are also in agreement that the evidence based healthcare system can be supported by the state-of-the-art IT platforms. However, [12] contend that although IT can enable a new value-based approach to care delivery and measurement; it alone cannot fix a broken healthcare system.

As argued by [17] on the basis that part of the six fundamentals strategic agendas to reform healthcare delivery is to "Create an Enabling IT Platform". Correspondingly, [12] agrees with [17] and attests that the organisations should utilise IT to enable restructuring of care delivery and measuring results rather than treating it as a solution itself. Notable in this regard, [10] similarly conclude that cloud computing technologies provide a promising approach to address the IT needs of integrated care delivery structures in the future.

Furthermore, [2] quite pertinently states that cloud computing will greatly impact the organisations that are involved in a vast array of IT equipment, software, support, and services. As illustrated in figure 1, it is important to note that the healthcare service quality, accessibility, reliability and affordability should be sustainable throughout the care cycle of the healthcare system [17].

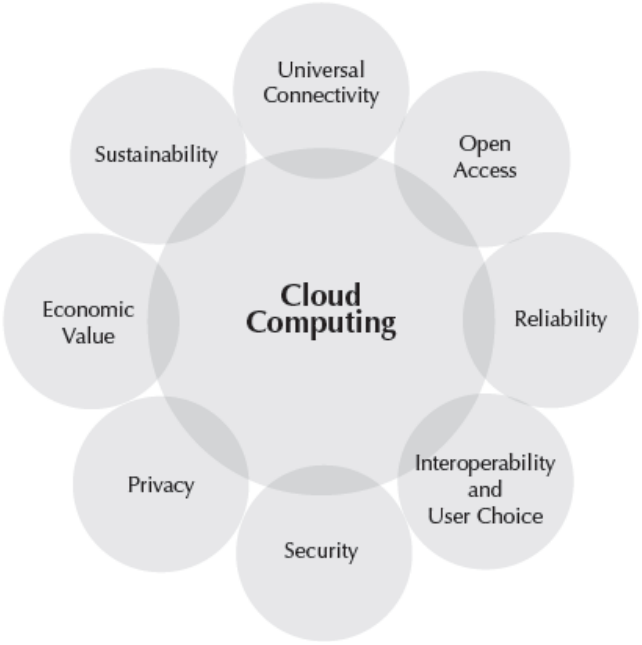

Figure 1. The 8 fundamental elements of cloud computing [2].

These noteworthy revelations are also supported by [9] due to the fact that cloud computing enables platforms of collaboration combined with rich abilities of communications and coordination. This includes opening up new and significantly more efficient business models. Frank and Moore [9] make an observation that cloud computing adoption models have a velocity, which has not been witnessed in technology space before. The emergence of cloud computing is observed as driving the need for better collaboration, coordination and interaction in the health sector [10].

3. OBJECTIVES OF THE STUDY

Preliminary investigations suggest that the healthcare system is not meeting the requirements to harness the vast amount of data to address multiple healthcare challenges in South Africa. As cloud computing looks set to scale up EHRs globally, in South Africa it is hindered by persistent reliance on using unreliable ICT platforms.

To achieve a collaborative and coordinated care that harnesses clinical data sharing, South Africa should find a proper balance between protecting personal health data from misuse and sharing data to accelerate healthcare improvements. This includes resolving concerns on regulatory frameworks for proper governance of eHealth standards implementation, whilst creating evidence value-based healthcare system.

The following list of formulated questions gives more insight into the problem statement:

a) What is cloud computing's real potential in the health sector?
b) How has the evolution of healthcare ICT infrastructure changed the nature of healthcare service delivery in South Africa compare to other developing countries?
c) What primary factors are inhibiting the use of cloud computing services within the South African healthcare environment?
d) What opportunities does cloud computing present to health sector for IT managers, and individuals?
e) What are the primary concerns for healthcare IT executives have about implementing emerging IT platforms especially one that may not be entirely familiar with including cloud computing solutions?
f) What are the challenges associated with acquiring and implementing large software applications, such as Electronic Medical Records (EMRs) and EHRs?
g) What are the main challenges facing the successful adoption and implementation of the national eHealth strategy within the healthcare environment in South Africa?
h) How has the lack of collaboration, coordination and interaction affected the implementation and adoption of the state-of-the-art ICT solutions within the healthcare environment in South Africa?

In order to address the research problem appropriately, the primary objective of the study is to identify key factors that are hindering the transformation of the healthcare system in South Africa. The objectives also take into account the new collaborative efforts for the creation of evidence value-based healthcare system. A key focus of a cloud-based open source computing platform is facilitating the flow of data from disparate sources into the clinical care process.

This will ensure that optimal treatments are offered to each individual patient at the point of care. Advances in cloud computing are starting to facilitate the development of platforms for effective data capture, creation, storage, search, sharing, modelling, transfer, analysis, visualisation, and manipulation of massive data.

4. CLOUD COMPUTING ADOPTION IN HEALTHCARE

The emergence of cloud computing in healthcare is increasingly gaining acceptance as an effective means of improving healthcare service delivery globally. According to [19], healthcare organisations are rapidly adopting cloud computing to enhance competitiveness within the health sector in China. This is part of the national health reform plan in line with the "Healthy China 2020" vision. Shen, Keskin and Yang [29] concur that cloud computing is being developed everywhere in China to different extents.

Bojanova and Samba [11] quite pertinently note that cloud computing is being adopted around the world by many countries through government programmes. This includes the U.S. Government's "Cloud Computing Mall" for government agencies, Japanese Government's "Kasumigaseki Cloud" and the U.K. Government's "G-Cloud" infrastructure project initiative. As a member of the BRICS nations (Brazil, Russia, India, China and South Africa), South Africa could stand to gain by tapping into collaborative best practices from other countries.

Through the implementation of the "National Development Plan: 2030 vision" on promoting health, the Presidency Republic of South African Government can also follow on the footsteps of other developing nations: Brazil, Russia, India and China. This insightful consideration could help South African government to leapfrog the leaders already gained vast experiences on cloud computing adoption within the healthcare environment in their respective countries. This includes the implementation of strategic partnerships to global health delivery system to reduce costs and lower the difficulty of enabling ICT infrastructure.

In the same way Marston *et al*. [23] also explain that to realise full potential of cloud computing services means removing the roadblocks to enabling IT-as-a- Service and overcoming the challenges of security, quality of experience and governance [23].

In order to resolve the identified challenges, healthcare organisations should collaborate with the world's top IT companies, international organisations and institutions that possess a great deal of expertise on eHealth related programmes. For that reason, it is important to note that the foreign based companies must familiarise themselves to the South African recommended eHealth interoperability standards in table 1 [15]. The use of interoperability standards is a core requirement to effectively integrate patient health information (PHI) from different medical systems.

As Rashid Al Masud [24] points out, in comparisons to locally-housed IT resources, cloud computing may improve security because Software as a Service (SaaS) providers are able to devote resources to solve security issues that many customers cannot afford. Cloud computing services are the enabling fabric of Health IT platforms [11], dramatically reducing the barriers to entry for developing economies. This includes transforming the cost base, agility and mobility of a well-developed HIS [11].

Table 1. Recommended standards for eHealth interoperability in South Africa [15]**.**

Standard	Description
ISO/TS 2222O:2011	Identification of subjects of health care
ISO/TR 20514:2005	Electronic Health Record – Definition, Scope and Context
ISO 13606 (1- 4)	Electronic Health Record Communication (Part 1 - 4)
ISO 180308:2011	Requirements for an Electronic Health Record Architecture
ISO21549 (1- 8)	Patient Healthcard Data – (Part 1 - 8)
ISO 170090 (1- 3)	Public Key Infrastructure (Part 1 - 3)
ISO/TS 27527:2010	Provider Identifier Standard
HL7	Health Level Seven
DICOM	Digital Imaging and Communication in Medicine
HL7 CDA	Clinical Document Architecture
HL7/ASTM Standard	Continuity of Care Document (CCD)
ICD Coders	International Classification of Diseases Codes
SNOMED CT	Systematized Nomenclature of Medicine – Clinical Terms
LOINC	Logical Observation Identifiers Names and Codes
NAPPI	National Pharmaceutical Product Index
ICHI	International Classification of Health Intervention
CPT	Current Procedure Terminology
MIOS 5.0	SITA – Minimum Interoperability Standards for SA Govt. Systems

Porter's [16] suggestion that transforming the healthcare system requires a holistic and phased approach as opposed to attempting to resolve all issues in one stroke, is duly noted. The DoH supports Porter's [16] suggestion by contending that the eHealth strategy aims to support the medium-term priorities of the public health service delivery, whilst paving the way for future requirements [5].

This includes laying the requisite foundations for future integration and coordination of eHealth initiatives in the country. Figure 2 illustrates the execution of cloud computing principles to guarantee national and international compatibility, eHealth standards interoperability, open architecture, modularity and capability for flexible capacity upgrades.

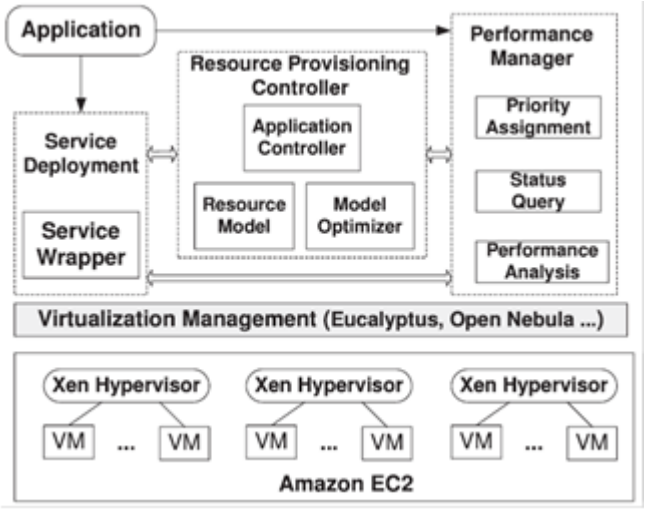

Figure 2. Cloud computing architecture for adaptive applications [21]

5. CLOUD COMPUTING CONCEPTUAL MODEL

The World Health Organisation put emphasis on the fact that developing HIS will depend upon how institutions function and interact, including ICT policy makers, in an effort to improve healthcare coverage, availability, dissemination and use of EHRs through the utilisation of computers, e-mail and internet access [27]. The DoH further reveals that the regulatory framework in South Africa is designed to place emphasis on the inter-linkages between quality assurances through regulation for the implementation of quality standards [7].

Of further significance, [14] also attest that a single organisation cannot provide all the technologies necessary to address healthcare system challenges. The argument is that interaction is needed between the medical schools and organisations, as well as between institutions and internet service providers, communication service providers and medical device developers as illustrated in figure 3.

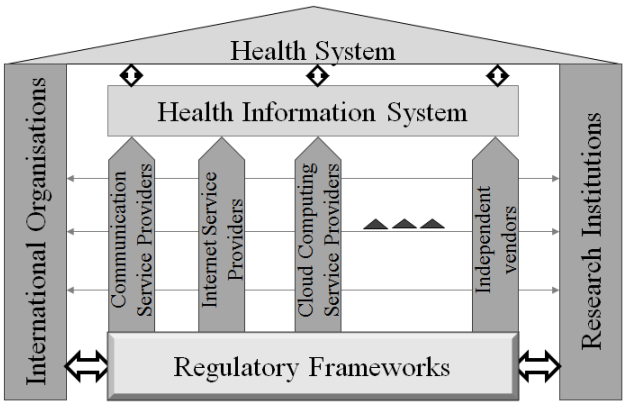

Figure 3. Proposed cloud computing model for the transformation of healthcare system in South Africa

The DoH agrees that eHealth is still facing many cavities in South Africa including the lack of clearly defined eHealth interoperability standards [5].

Other key concerns involve data integration as well as data security and privacy, broadband coverage and internet penetration, regulatory compliance standards, and the lack of competent professionals. While recognising the importance of instigating quality standards in the health sector, the World Health Organisation further acknowledges that there is a need to coordinate and align partners on an agreed framework for the improvement of healthcare system [27].

6. APPROACH TO RESEARCH DESIGN

To understand the dynamics associated with cloud computing adoption, [13] conducted interviews in 15 software organisations. The questionnaires were selected for an in-depth analysis based on a relatively progressive use of cloud computing and testing.

By the same token, [14] highlight that it is important to conduct interviews with the stakeholders concerned, to test the validity and completeness of the proposed model. In addition, Deloitte quite pertinently states that through analysis of the three stakeholder perspectives, it is possible to define an eHealth Architecture that identifies all the ICT components necessary to deliver eHealth Vision [3].

The cognitive behind such claims is that the eHealth architecture is structured into three segments that contain interrelated components necessary to delivery eHealth vision, highlighted as follows [3]:

a) The eHealth Solutions describe the systems and tools that consumers, care providers and health care managers will use to interact with the health system.
b) The eHealth Infrastructure describes the specific eHealth computing infrastructure components necessary to support the collection and sharing of structured and meaningful electronic information across the health system.
c) The eHealth Enablers describe the ICT components that must be in place to support the delivery of the overall eHealth strategy.

In this study, the participants consist of Managing Directors, Chief Technology Officers and Executives. The participant's roles were mapped according to the corresponding research subjects in table 2.

Table 2. Research subjects

Research Subjects	Participants Role on eHealth Initiatives	Description	Example
Health system in South Africa	Decision-makers	Strategic direction for eHealth (Department of Health, 2012:6)	National eHealth Steering Council
Health information system	Subject matter expects	Delivers HIS software (Mars and Seebregts, 2008:17)	Health ICT Service Provider
Cloud networking platforms	Key enablers	Enable connectivity (Shen *et al.*(2012)	Internet Service Providers
Cloud computing ecosystem	Key influencers	Enable utility computing (Winans and Brown, 2009:2)	Cloud Computing Service Providers
Enabling cloud computing ecosystem	Health IT innovators	Enhance ICT infrastructure performance (Calyam, 2011:2)	Technology Specialist Company

7. RESULTS

This section reviews responses from interviews conducted with respondents as per respective research subjects discussed in previous sections. The questionnaires were designed in such a manner so as to address a particular focus area, which is in agreement with proposed conceptual model in figure 3.

7.1. Research Subject 1: Healthcare System in South Africa

The collective viewpoint is that the eHealth strategy implementation and adoption is facing major stumbling blocks defined as challenges by the DoH within the South African context. Privacy and security is described as the biggest concern to the adoption of cloud computing within the health sector.

Therefore, this clear indicates that privacy and security are some of the critical areas that should be addressed and controlled for proper adoption of cloud computing within the South African healthcare environment.

South African government should advance regulatory policy frameworks in order to ensure effective interoperability standards to address key concerns surrounding privacy and security of sensitive medical data for clinical decision making.

7.2. Research Subject 2: Healthcare IT Service Providers

The insight gained is that the healthcare IT service providers have the capacity to delivery large-scale software platforms. However, the respondents are concerned about the key issues inhibiting the adoption of the state-of-the-art ICT platforms within the health sector in South Africa.

The major challenges highlighted include ICT infrastructure and high bandwidth costs, disparate systems and fragmentation of PHI systems.

On numerous occasions the respondents mentioned that there is a lack of governing principle on who owns the patient records. This includes lack of local standards adoption, policies which govern the EMRs, fundamental interoperability standards, and integration of dissimilar systems. If the identified issues are resolved and controlled, the respondents are of the opinion that cloud computing is a possible solution to improve healthcare service delivery. The respondents consider eHealth strategy document as the first step towards resolving the identified challenges.

7.3. Research Subject 3: Internet Service Provider

Overall, the respondents are of the view that the national broadband landscape has not transformed or changed the nature of healthcare service delivery in South Africa over the past decade.

The respondents argued that South Africa needs to adopt robust national eHealth policy standards and the commitment to execute within the agreed policy frameworks. There is a need for collaboration between the stakeholders to improve healthcare service delivery through ICT in South Africa. This includes a consolidated strategy around how the healthcare system is going to be implemented in South Africa.

To accelerate the adoption of cloud computing platforms, the implementation of strategic partnerships will help South African government to reduce costs and lower the difficulty of enabling ICT infrastructure. This includes developing a strategic vision on IT as an enabling platform for the creation of value-based healthcare system.

7.4. Research Subject 4: Cloud Computing Service Provider

The respondents were mainly concerned about the legislative frameworks governing the health sector. The respondents are of the view that the lack of coordinated regulatory framework in South Africa is the biggest challenge for the adoption of cloud computing. According to the respondents, the legislative frameworks and unwillingness for the companies to share information are some of the main issues hindering cloud computing adoption. This includes the sensitivity nature on PHI, which makes the organisation reluctant to move to the cloud computing platforms.

To resolve these challenges, it is necessary to achieve consensus between government, healthcare organisations and other key stakeholders to advance the development of eHealth initiate. Although the ICT has evolved in the private health sector, the respondents argued that the advanced ICT platforms are still lacking in the public health sector.

7.5. Research Subject 5: IT Specialist Company

The respondent mentioned that the organisations are now focusing more on the benefits offered by cloud computing and less on the challenges associated with ICT infrastructure. Furthermore, the respondent talks about enterprise mobility as one of the biggest benefits within the healthcare environment. This includes providing flexibility for health professionals and nurses to be more mobile across regions and in different parts of the world.

The respondent notes that cloud computing based applications are now available much easier and quicker. For example, the applications can be developed in India and be available in South Africa via cloud computing platforms. This clearly indicates that rapid advances in enabling ICT infrastructure can accelerate cloud computing adoption through partnerships with IT specialist companies.

8. CONCLUSION

The DoH describes eHealth as an integral part of the transformation and improvement of healthcare services in South Africa [5]. This includes enabling the delivery on the health sector's Negotiated Service Delivery Agreement for 2010-2014. In order to best overcome key factors that are hindering the transformation of the healthcare system, the DoH has put the programme of work that will lead eHealth strategy implementation. The DoH recognises that this programme of work should be underpinned by certain key principles at National and Provincial Departments of Health respectively. Finding competent data scientists to analyse healthcare data and extract value appear to be one of the major challenges across healthcare organisations.

Following the interpretation of the findings and supported arguments using existing literature review analysis, it can be concluded that the stated research objectives were achieved. Of further significance in this regard is the connection that existed between the results obtained and the literature review analysis. This noteworthy correlation was demonstrated by discussing the findings with respect to the research objectives.

The conclusive finding is that the HIS is not meeting the requirements capable of improving health system's effectiveness. Although cloud computing looks set to scale up EHRs globally, in South Africa it is hindered by persistent reliance on using unreliable ICT platforms. Therefore, it may seem counterintuitive for the South African government to implement cloud computing in the public health sector whereas the mandate to strengthen healthcare system effectiveness is not met.

The DoH quite pertinently admitted that the eHealth is still facing many cavities including the lack of clearly defined eHealth interoperability standards. Hence, South African government should advance regulatory policy frameworks in order to ensure effective interoperability standards to address key concerns surrounding privacy and security of sensitive medical data for clinical decision making. Furthermore, practitioners and researchers should consider investigating and accumulating information to determine the best possible ways of adopting cloud computing platforms within the South African healthcare environment.

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SESSION 4

ADVANCES IN NETWORKS AND SERVICES I

WHITENET: A WHITE SPACE NETWORK FOR CAMPUS CONNECTIVITY USING SPECTRUM SENSING DESIGN PRINCIPLES

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ABSTRACT

To this day, the technical challenges of accessing TV white spaces through spectrum sensing can be summed up into its inability to provide maximum protection to primary users from interference. Yet, off-the-shelf spectrum sensing devices, which are emerging on the market at low cost, and the low computation and implementation complexities of the sensing technique, make them more and more attractive to the developing world. Building upon "WhiteNet", a white space network management platform for campus connectivity, this paper proposes design principles that can be incorporated in a spectrum sensing-based white space identification system to minimise probability of causing interference to primary users. The principles are designed around the cooperative spectrum sensing model to further reduce chances of interference to primary users. Evaluation of the principles was done using real-world indoor measurements and based on a real TV transmitter-allocation at the University of the Western Cape in Cape Town, South Africa. The results reveal the relevance of using these design principles in white space networking using the emerging White-Fi protocol to boost the capacity of current Wi-Fi campus networks.

Keywords— White-Fi, cooperative spectrum sensing, detection threshold, spectrum sensing principles

1. INTRODUCTION

It has been widely recognized that in many regions of the developing world, poor Internet access in universities and research institutions is one of the causes of the scientific divide between developed and developing countries. In many of these regions, Wi-Fi has played a key role to connect campus communities by enabling inter-campus connectivity and access to the Internet but at lower access bandwidth compared to research institutions of the developed world. The transition from analog to digital television is a great opportunity to address this bandwidth issue in campus networks by using emerging protocols such as IEEE 802.11af, also referred to as *White-Fi* or *Super Wi-Fi* [1] to boost the current capacity of Wi-Fi networks with bandwidth acquired through secondary access to white space (WS) frequency. However, technologies and protocols have yet to mature to provide the proper WS equipment at affordable prices and WS identification, quantification and allocation techniques have yet to improved and move from the research boundaries to the implementation arena.

Two main approaches of accessing unused spectrum in the TV frequency band (white spaces) for secondary use have been suggested in the literature; geo-location database and spectrum sensing. At the moment, there is a trend towards the use of only geo-location database approach in the US and Europe [2] as it guarantees high protection of the spectrum incumbents from the interference. The trend is supported by the development of the protocols such as Protocol to Access White Space (PAWS) [3] by the Internet Engineering Task Force (IETF), the IEEE 802.11af standard [4] and the IEEE 802.22 standard [5] to access spectrum database. However, in some regions of Africa, the use of a geo-location database has been questioned as the best approach to accessing TV white spaces (TVWSs) [6] due to its limitations and the abundance of TVWSs that nullify the need for stringent constraints on primary user protection. In such regions, therefore, spectrum sensing is expected to play a key role as an alternative method of accessing TVWSs.

To this day, technical challenges of accessing TVWSs through spectrum sensing without causing interference to primary users have not been solved completely. In this paper, some design principles are being proposed that can be incorporated into a spectrum sensing-based WS identification system to minimise probability of causing interference to the primary users. These principles are designed around the concept of cooperative spectrum sensing. The proposed principles are: i) the use of different threshold values and ii) the deployment of virtual WSs pricing. These principles add an additional layer of protection to primary users after the cooperative spectrum sensing layer. The block diagram depicting the hierarchical flow of how the principles work is depicted in *Figure 1*.

The rest of the paper is structured as follows: Section 2 gives a background to some of the challenges of spectrum sensing

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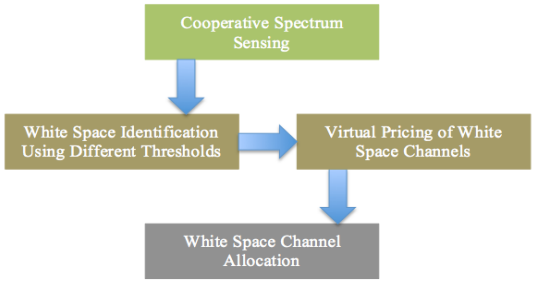

Figure 1. Hierarchical flow of how the principles work

as a method for identifying TVWSs; Section 3 introduces the principles and discusses how they foster protection of primary users; Section 4 discusses some major existing principles that can be included in a spectrum sensing-based WS identification system; Section 5 discusses how the proposed principles can be implemented; Section 6 is a discussion of the experimental evaluation of the principles and Section 7 concludes the paper.

2. BACKGROUND INFORMATION

There are several spectrum-sensing methodologies available but the most commonly used in WS identification is the energy detector-based sensing. Energy detector-based sensing works by measuring the energy contained in a spectrum band and comparing it with a set threshold value [7, 8]. If the energy level is above the threshold value, then the signal is considered present otherwise the spectrum band is considered vacant. This technique reigns superior over the other spectrum sensing techniques because of several factors: i) it is simple as it has low computational and implementation complexities [9, 8], ii) it has good performance [10, 11, 12] and iii) it is more generic as receivers do not need any knowledge on the primary users' signals [7, 8].

Much as the energy detector-based sensing has these advantages over the other spectrum-sensing methodologies, it has some inherent challenges that make it less desirable as a means of accessing TVWSs, which can be summed up into inability to provide maximum protection to primary users from interference. One of its major challenge in relation to identifying TVWSs is that there is no standardized way of selecting the signal detection threshold that gives optimal performance, i.e. simultaneously giving low false positives and low false negatives. The value chosen as the detection threshold has a major impact on the performance of the spectrum sensing equipment. If the value is too high, the technique fails to detect the presence of a TV signal in a channel thereby causing harmful interference, and if the value is too low, it gives false detection when there is actually no TV signal in a channel. Another challenge of this technique is that it suffers from multi-path fading or shadowing that results into the *hidden user problem* [9]. In this scenario, a WS device is unable to detect the presence of a primary user service in a channel due to obstacles that block the primary user's signal path as it propagates through the wireless medium. This leads to misinterpretation of measured data by the WS device where it thinks the channel is available and start to transmit, causing interference to the primary user.

3. PROPOSED PRINCIPLES

Design paradigm underlying any suggested model based on spectrum sensing aims at eliminating its technical challenges. This section discusses the proposed principles that are being incorporated in the spectrum sensing-based WS identification component of *WhiteNet*; a white space networking platform under development at the University of the Western Cape (UWC) in South Africa with the expectation of resolving some of the technical challenges associated with this method of identifying WSs.

3.1. Using more than one detection threshold

Deciding on the threshold to be used in spectrum sensing is a challenging issue that has been at the heart of debates concerning an absolute value to be used. To get around this problem, we are proposing to use more than one threshold value to compromise the two extremes, *many false negatives or many false positives*, the likely results when a single threshold is used.

Measurement studies have shown that the sensitivity threshold of *-114 dBm* for Advanced Television Systems Committee (ATSC) TV signal detection as mandated by the Federal Communications Commission (FCC) is too conservative [13, 14, 15, 16]. *-114 dBm* is said to be conservative because it leads to significant loss of WSs [16]. Some studies have confirmed that, for example, [13] found no TVWSs in all the locations where the studies were done in China when a sensing sensitivity threshold of *-114 dBm* was used. However, relaying on the analog terrestrial television (ATT) database as ground-truth data for the ATT channel occupancy situation in Beijing, setting the sensitivity threshold to *-97 dBm* was enough to find WS ATT channels in indoor scenarios.

On the other hand, different signal detection thresholds have been used by different studies to find WS. Therefore, using more than one threshold in the range from *-114 dBm* to a value that is dependent on a country's TV broadcasting allocation scheme for transmitting sites seems to be a logical solution and is being proposed here. The FCC's mandated detection threshold of *-114 dBm* is being proposed as the start threshold because it is conservative and also able to find WSs in some environments although it ends up with no WSs in others. Identifying WSs in this way helps to group WSs based on the threshold values used to detect them. If there is a request for WS use from WS devices, allocation starts with WSs detected with the lowest detection threshold and if they are not enough to satisfy the demand, then the next slot of WSs identified using the next higher detection threshold is used and so on. Based on the assumption that at each point in time, the demand for white space use from white space devices is satisfied well before using white

spaces identified with higher threshold values, the approach of identifying WSs using different thresholds and starting the allocation with WSs identified with the lowest thresholds minimizes the chances of interference to primary users due to false negatives than using random or haphazard allocation of WSs identified with a single threshold. WSs identified with higher thresholds are the most likely thresholds that may result into interference. The approach also solved the problem of resulting with either *too many false negatives* or *too many false positives* when one threshold is used to identify the TVWSs.

3.2. Virtual pricing of white spaces

Another principle being proposed in this work to minimize interference to primary users from WS devices is to virtual-price WS channels within each group based on some common quantity associated with all WSs. For example, a virtual price can be given to each WS channel based on the signal strength detected in each channel with the highest price given to a channel with strongest signal and the lowest price given to a channel with the weakest signal within each group. As mentioned in *subsection 3.1*, the groups of WSs are based on the signal detection thresholds used to identify them. When WS devices submit requests for WS use, the cheapest WS channels within each group are allocated first. In this way, the probability of a WS device causing interference to primary incumbents if there is any false negative within the group is minimized since channels that may result into false negatives have stronger signals than channels that are actually WSs, and as such, their virtual prices are higher than the channels that are actually WSs. Consequently, they cannot be allocated to any WS device unless all the channels that are actually WSs in that WS channel group are exhausted.

4. EXISTING SPECTRUM SENSING DESIGN METHODS

This section discusses existing spectrum sensing design methods that this work considers relevant to the implementation of a spectrum sensing-based WS identification system.

4.1. Cooperative spectrum sensing

Cooperation among sensing equipment is vital for the optimal performance of spectrum sensing when used as a method of identifying white spaces because a network of spectrum sensors sharing sensing information obtained from their individual locations with each other has a better chance of detecting the primary user compared to local spectrum sensing [9] by a single spectrum sensor. It is due to this reason why cooperation between sensing equipment is proposed in the literature as the solution to the *hidden user problem* [14, 15, 17, 18, 19] that may arise due to multi-path fading or shadowing. As mentioned in the introduction, our proposed principles rely on the results generated from cooperative spectrum sensing as the first step to minimising chances of interference to primary users. If there is a *hidden user problem* after cooperative spectrum sensing, then the proposed principles help to protect further that *hidden user* from interference.

4.2. Channel-clustering and location-clustering

As mentioned in [20] and [21], a spectrum sensing-based WS identification system must also take spectrum sensor cost as a major consideration in the design of the system as they can be expensive. To avoid random placement of the energy detectors, which could result into either waste of energy detectors, i.e., many unnecessary detectors deployed or not guarantee coverage, i.e., insufficient detectors deployed [20], it is vital to perform channel-clustering and location-clustering as proposed in [20]. Once the channel clustering and location clustering is done, the algorithm proposed in [20] can be used to determine placement positions for the energy detectors. Implementing these principles means WSs are calculated according to location clusters. Therefore, secondary users are required to identify their positions before sending a request for white space use. For detailed discussion of these principles and how they can be implemented, consult [20].

5. ALGORITHM IMPLEMENTATION

The proposed principles and the existing methods that have been discussed in this paper are not environment specific. They are general principles and methods that can be implemented in a spectrum sensing-based WS identification system meant for outdoor or indoor environment. This section shows how the proposed principles can be implemented algorithmically.

5.1. WS identification using different thresholds

The method for computing TVWSs using different signal detection thresholds is presented in ***Algorithm 1***. The algorithm shows how cooperative spectrum sensing is implemented with the principle of varying the detection threshold. The inputs to the algorithm are signal strength values of all the channels from the frequency spectrum sensors deployed and the channels under consideration. The algorithm first checks if a channel under consideration is an already identified WS using any of the previously used threshold values if any. This is done in lines *4* to *6*. This helps to make sure that each channel is not identified as WS more than once as the threshold values keep changing. Once it is found that a channel is not an already WS channel, the algorithm compares the signal strength values for that channel from all the sensors deployed from line *9* to *13* to find the representative signal strength value, which is the strongest signal measured in that channel from all the sensors deployed. The strongest signal is used to calculate the relative signal strength for that channel by subtracting the current threshold from it in line *14*. Then the algorithm checks if the channel is WS by checking if its relative signal strength is less than or equal to zero in line *15*.

If it is found to be WS, it is added to the set of WSs for that detection threshold in line *16*. The process is repeated for all the channels using the current threshold value (*lines 3 to 20*). Once all the channels are considered using the current threshold value, the next threshold value is considered (*line 24*) and the process is repeated from the beginning (*from line 2*). This process is repeated until all the threshold values have been considered. The output from this algorithm is the set of sets of WS channels ***SC*** identified using different thresholds and the set of sets of signal strength values ***SS*** corresponding to the set of sets of all WS channels ***SC***.

Algorithm 1: Identify white space channels using different thresholds

input : Two-dimensional matrix ***st*** of size ***m*** by ***n*** of signal strength values, set $CH = \{ch(1), ch(2), ch(3), ..., ch(m)\}$ of channels. {***m*** is the number of channels under consideration; ***n*** is the number of sensors deployed}

output: $SC = \{SC(1), SC(2), SC(3), ..., SC(x)\}$, where ***x*** is less than or equal to number of threshold values, $SS = \{SS(1), SS(2), SS(3), ..., SS(x)\}$. {***SC*** is a set of sets of white space channels; ***SS*** is a corresponding set of sets of signal strength values of the white space channels}

1 *initialize* $t \leftarrow startThreshold, x \leftarrow 1$;
2 **repeat**
3 **for** $i \leftarrow 1$ **to** m **do**
4 **if** *SC is not empty* **then**
5 ***check*** *if* $ch(i)$ *is in any of SC subsets*;
6 **end**
7 **if** $ch(i)$ *is not found in any SC subsets or SC is empty* **then**
8 $strongestSignal \leftarrow 0$;
9 **for** $j \leftarrow 1$ **to** *n* **do**
10 **if** $st[i][j] >$ *strongestSignal* **then**
11 $strongestSignal \leftarrow st[i][j]$;
12 **end**
13 **end**
14 $rss(i) \leftarrow strongestsignal - t$ `// rss(i) is representative relative signal strength for channel i`
15 **if** $rss(i) <= 0$ **then**
16 ***add*** $ch(i)$ *to* $SC(x)$;
17 ***add*** $st[i][j]$ *to* $SS(x)$
18 **end**
19 **end**
20 **end**
21 **if** $WS(x)$ *is not empty* **then**
22 ***add*** $SC(x)$ *to* SC;
23 ***add*** $SS(x)$ to SS;
24 **end**
25 $t \leftarrow t + increment, x \leftarrow x + 1$
26 **until** t *is equal to endThreshold*;
27 ***return*** *SC, SS*

5.2. Compute virtual prices of WS channels

Once WSs channels have been identified using the different threshold values, ***Algorithm 2*** follows to compute their virtual prices based on signal strength recorded in each channel.

Algorithm 2: Compute virtual prices of white space channels identified

input : $SS = \{SS(1), SS(2), SS(3), ..., SS(x)\}$.

output: $VP = \{VP(1), VP(2), VP(3), ..., VP(x)\}$. {***VP*** is a corresponding set of sets of virtual prices of white space channels}

1 ***initialize*** $j \leftarrow 1$, $strongestSignal \leftarrow 0$;
2 **for** $i \leftarrow 1$ **to** x **do**
3 **while** *SS(i) has elements* **do**
4 **if** $strongestSignal < ss(i)(j)$ **then**
5 $strongestSignal \leftarrow ss(i)(j)$;
6 $j \leftarrow j + 1$;
7 **end**
8 **end**
9 **for** $a \leftarrow 1$ **to** $(j - 1)$ **do**
10 $vp(i)(a) = |ss(i)(a)|/|strongestSignal|$;
11 ***add*** $vp(i)(a)$ to $VP(i)$;
12 **end**
13 ***initialize*** $j \leftarrow 1$
14 **end**
15 ***return*** *VP*;

The input to the algorithm is ***SS***, the output from ***Algorithm 1***. The algorithm first searches through the set of signal strength values ***SS(i)*** to find the strongest signal in that set in lines *2* to *7*. Then algorithm calculates the virtual price of each WS channel by dividing its absolute signal strength with the absolute strongest signal in lines *9* to *12*. The process is repeated for each WS channel group ***SS(i)*** using the strongest signal in that group and the signal strengths of WS channels in the group until all WS channel groups are considered. The output of the algorithm is the set of sets of virtual prices ***VP*** corresponding to the set of sets ***SS*** of signal strength values for the WS channels.

6. EXPERIMENTAL EVALUATION

To have a better understanding of how the principles can work in real spectrum sensing-based WS identification system and evaluate their performance, we conducted short time indoor measurements at the University of the Western Cape in Cape Town, South Africa in the ultra-high frequency (UHF) band used for TV broadcasting and used the measurement data in the spectrum sensing-based WS identification component of *WhiteNet*. The Department of Computer Science, occupying the ground floor of Mathematical Sciences Building, was used as the experimental site. It has a floor area of approximately 560 m^2. The layout of the ground floor of the building and the measurement points are shown in *Figure 2*. The environment for the measurement locations

Figure 2. Layout of the building and measurement points

was regarded the same since all the locations were on the same floor of the building and the locations covered a small area. We assumed that the spectrum sensors detected similar signal strengths from all the locations such that the same WS channels were identified from each location. That simplified the experiment since WSs did not have to be calculated based on location.

The hand-held RF Explorer model WSUB1G was used in the measurement process, which has a measurement frequency range of 240 MHz to 960 MHz. The complete technical specification of the model can be found in [22]. The model was fitted with a Nagoya NA- 773 wideband telescopic antenna with vertical polarization, which has wide band measurement capability. The RF Explorer was connected to an Android phone installed with an android code to measure spectrum on the go using an OTG cable.

6.1. Detection thresholds used

No WSs were detected when *-114 dBm* was used. Therefore, different threshold values were tried by incrementing the *-114 dBm* sequentially with *0.5 dBm* each time. The first WS was detected with *-103 dBm* threshold and it was taken as the start threshold. For the final detection threshold, an adequate criterion had to be used to select it to ensure maximum protection of primary users. We looked at the Draft Terrestrial Broadcasting Plan 2013 from the Independent Communications Authority of South Africa (ICASA) [23] to see how the UHF TV channels are arranged in the band. According to ICASA [23], UHF ATT frequency band (470 MHz and 854 MHz) contains 48 channels of each 8 MHz bandwidth. The 48 channels are arranged into 12 groups of 4 channels each, which mean that 4 channels are available for assignments at any transmitting site on a national basis. In areas of great demand, 7 to 11 channels are assigned to a particular area by either combining lattice node points or using both VHF and UHF channels [23]. The measurement site is a typical urban area, and as such, we considered it an area of great demand. This was confirmed when we examined the Tygerberg transmitting site in [23], which is the closest ATT transmitting site to UWC. There are 6 UHF channels being used by different TV stations at the site with the first TV station broadcasting from channel 22. A close examination of how these channels are allocated in the band shows that each allocated channel is spaced by at least 4 channels before the next allocated channel. We believe this allocation scheme was done to reduce interference coming from other transmitters from the same transmitting site. Based on this allocation scheme, we concluded that at least the first *24* channels could not be detected as WSs at the measurement site. That was achieved with the maximum detection threshold of *-102 dBm*, and was considered the end detection threshold. Since small variations in threshold values have a very big impact on the amount of white spaces found [24], our detection thresholds were spaced by an absolute value of *0.5 dBm* difference, resulting into the following detection thresholds; *-103 dBm*, *-102.5 dBm* and *-102 dBm*.

6.2. Measurement results

Since we were interested with the temporal distribution of WSs, the signal measurements were taken for only *120 seconds* at each location. The *120 seconds* included the signal amplitude stability time. Observation of the data showed that after about *90 seconds* into the measurement, the signal amplitude stabilised to within +/-5 dBm. Therefore, only the data recorded in the last *30 seconds* of the measurement at each location was used for calculating the average received signal strength, which was regarded as the temporal signal strength for that channel at that location.

Figure 3 shows the temporal signal strengths recorded in each channel from the *14* locations where the measurements were taken. The standard deviation of the signal strength for each channel recorded from the *14* locations is shown in *Table 1*. It is easy to see from the table that the standard deviation of the signals for most of the channels was below *2 dBm*. The largest standard deviation was *3.8 dBm* from channel 27. The small standard deviations signify that the signals collected in a particular channels from the *14* locations varied very little from one location to another. The results confirm the validity of our assumption that the spectrum sensors detect similar signal strengths for each channel under consideration from the locations.

The temporal signal strength recorded in each channel from each of the *14* locations was fed into the ***Algorithm 1*** to calculate the WSs. *Table 2* shows the the WS channels that were

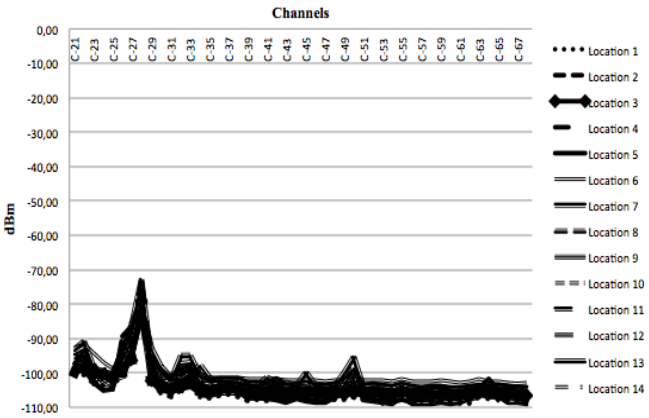

Figure 3. Signal strengths recorded from all locations

Table 1. Standard deviation of signal strengths collected from the 14 measurement locations (+/- dBm)

Channel	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
STDEV	2.6	3.0	2.2	2.2	1.8	3.4	**3.8**	3.4	3.2	2.2	1.9	2.9	2.7	2.7	2.0	1,6
Channel	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
STDEV	1.5	1.7	1.9	1.9	2.0	2.0	1.9	1.6	2.3	1.9	1.8	1.7	2.1	3.3	1.7	1.7
Channel	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
STDEV	1.9	1.9	1.7	1.9	1.7	1.8	1.7	1.7	1.7	1.6	1.4	1.5	1.4	1.5	1.6	1.8

Table 2. White spaces identified with different thresholds

Threshold(dBm)	No of WSs Identified	Channel(s)
-103	1	67
-102.5	8	54, 57, 60, 61, 62, 65, 66, 68
-102	12	43, 46, 47, 48, 49, 52, 53, 56, 57, 58, 59, 64

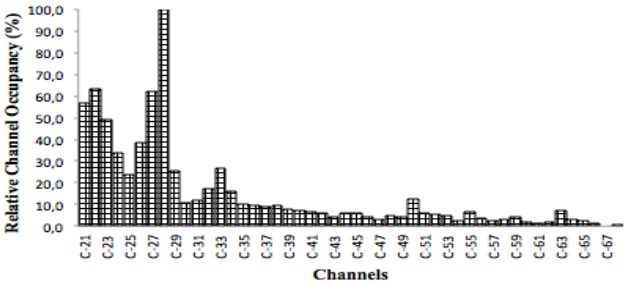

Figure 4. Spectrum occupancy with -103 dBm threshold

found with the three thresholds. The relative spectrum occupancy for all the channels for each of the three threshold is shown from *Figure 4* to *Figure 6*. The relative spectrum occupancy for each channel was defined by the following three equations:

$$O_{RS}(i) = 100 * R_{SS}(i, T_j)/M(i, T_j) \quad (1)$$

$$R_{SS}(i, T_j) = SS(i) - T_j \quad (2)$$

$$M(i, T_j) = max(R_{SS}(i, T_j)) \quad (3)$$

where $O_{RS}(i)$ is the relative spectrum occupancy in channel *i*, R_{SS} is the relative signal strength collected in channel *i* using threshold T_j, *SS(i)* is the representative signal strength in channel *i*, which is equal to the strongest signal measured in channel *i* out of the 14 locations and *M(i,*T_j*)* is the maximum relative signal strength in the band collected in channel *i* using threshold T_j.

The WS channels groups and the corresponding signal strengths of WS channels groups were fed into ***Algorithm 2*** to calculate their virtual prices, which are shown in *Table 3*.

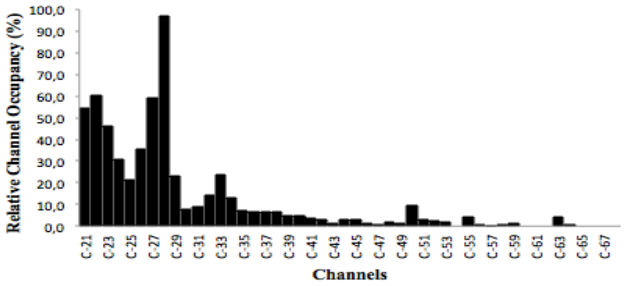

Figure 5. Spectrum occupancy with -102.5 dBm threshold

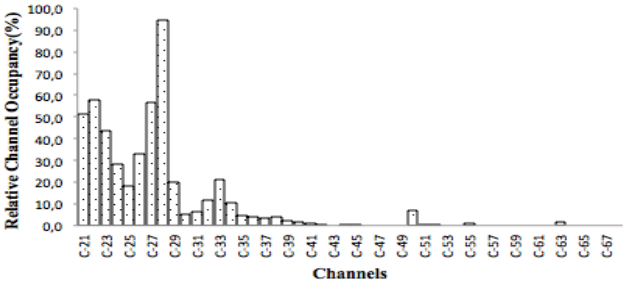

Figure 6. Spectrum occupancy with -102 dBm threshold

6.3. Discussion

The grouping of WS channels as show in Table 2 helps to start allocating them to WS devices with the *safest* group, which is the one detected with *-103 dBm* in this case. The least safe group of WSs out of the three groups is the one detected with *-102 dBm* threshold. WSs in this group is allocated only if the demand for WS use is not satisfied after

Table 3. Prices for white space channels

WS Channel Group	WS Channels With Their Prices
-103 dBm	67:1.000
-102.5 dBm	54:0.997, 57:0.996, 60:0.998, 61:0.998, 62:0.997, 65:0.997, 66:0.998, 68:1.000
-102 dBm	43:0.998, 46:0.997, 47:1.000, 48:0996, 49:0.998, 52:0.995, 53:0.996, 56:0.999, 58:1.000, 59:0.997, 64:1.000

using the WSs in the first two groups. If there are any false negatives in that group and the demand for WS use is met, then the primary users in those channels are protected from interference, as the channels are not allocated for secondary usage by WS devices. It is different if the WS channels are detected using one threshold and they are also allocated randomly to WS devices.

An additional layer of security is provided within a group of WSs if the channels are priced based on the signal strengths in the channels. Channels with stronger signals are priced higher than channels with weaker signals within each group as shown in *Table 2* because channels with stronger signals are the ones that are more likely to have primary users in them than channels with weaker signals. For example, WS channel group detected with *-102 dBm* in *Table 2*, allocating the cheapest channels such as 52, 53, 48 first to WS devices adds some protection to the expensive channels such as 47, 58 and 64, which are the most likely channels to result into false negatives in that group. In this case, allocating the channels sequentially based on the lowest prices, starting with channel 52, protects primary users that may be broadcasting in the expensive channels such as channel 47 or channel 58.

7. CONCLUSION AND FUTURE WORK

In this paper, we proposed two design principles that have been included in a spectrum sensing-based white space identification system to reduce further chances of interference to primary users due to false negatives after cooperative spectrum sensing has been done. The principles were experimented in the white space network (WhiteNet) platform for campus connectivity at the University of the Western Cape in South Africa using real measurement data in the UHF band used for ATT broadcasting. The results show that the application of the principles can reduce the probability of interference to primary users to some extent.

Spectrum sensing principles have been proposed and implemented as a first design step of *WhiteNet*; a white space network management platform for campus networking. For our proposed principles to work efficiently, they will require redesigning existing network management techniques to manage white spaces. Cost-based traffic engineering techniques such as proposed in [25, 26] will also be redesigned as primary user protection mechanisms using cost metrics to reflect the white space availability under primary and secondary usage. The integration of parallel path models [27, 28] in white space bonding deployments and the use of white space for long distance wireless deployments [29, 30] are other avenues for future work. The design of market pricing mechanisms to protect primary users while managing white spaces to meet quality of service (QoS) agreements between the offered traffic and the available spectrum is another avenue for future research. The design of low cost white space gateway devices building around the emerging Raspberry pi hardware and the flexibility and robustness principles proposed in [31, 32] is another direction for future research.

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A DCO-OFDM SYSTEM EMPLOYING BENEFICIAL CLIPPING METHOD

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ABSTRACT

The existing clipping researches in direct current biased optical orthogonal frequency division multiplexing (DCO-OFDM) systems generally originate from insufficient DC bias and the nonlinear transmission characteristics of physical devices which will distort the system performances. In contrast to conventional clipping theories, the beneficial clipping method demonstrated in this paper aims to improve the transmission effects of DCO-OFDM systems. Using the Bussgang theorem, the signal to noise ratio (SNR) and bit error ratio (BER) of DCO-OFDM systems with the beneficial clipping method are modeled mathematically. It is found that the beneficial clipping method can effectively reduce the system BER, compared with the no clipping situation, when the clipping ratio is mapped over an appropriate range. Also, the optimal clipping ratio changes with variation of the modulation depth. These results illustrate that the beneficial clipping method can enhance the performance of DCO-OFDM systems, although it does introduce clipping noise.

Keywords— Visible light communication, light emitting diode, orthogonal frequency division multiplexing, nonlinear distortion, clipping

1. INTRODUCTION

With the exponentially growing demand of the wireless communication, visible light communication (VLC) is deemed as a complement to the conventional radio frequency (RF) communication [1]. The VLC standard, IEEE 802.15.7, has completed in December 2011. The physical layer and the medium access control of VLC systems are presented in IEEE 802.15.7 [2]. In VLC systems, the light emitting diode (LED) is used as both lighting and communication device [1, 3, 4, 5, 6]. Unlike ordinary incandescent lamps, LEDs have excellent features such as long lifetimes, high intensities, low power consumption, rapid response times, and low costs [6], all of them promote the development of VLC technology. In addition, when compared with radio frequency (RF) signals, VLC optical signals are safer, more power efficient, harmless to human, and have no frequency spectrum limitations [7]. Therefore, VLC is a promising technology for indoor wireless communications, especially for applications in areas such as hospitals, aircraft, and industrial and nuclear facilities, where there are restrictions on the use of RF signals [3]. There are obvious differences between RF signals and VLC signals. In RF systems, the complex baseband signal is used to modulate the amplitude and phase of the carrier. In VLC systems, the envelope of optical signal conveys information. It is behaved as the variation of LED light intensity and named as intensity modulation (IM). In the receiver, the detection method using signal amplitude is termed as direct detection (DD). Then, the IM/DD technique is widely used in the VLC systems due to the simplicity of implementation [8, 9].

Orthogonal frequency division multiplexing (OFDM) is a form of multi-carrier modulation which has been used in many communication standards, such as IEEE 802.11, IEEE 802.20, 3GPP, power line communication and more [10]. Here, OFDM is applied to VLC systems due to its high transmission speed and resistance to intersymbol interference [9, 11, 12, 13, 14]. In OFDM systems, the use of quadrature amplitude modulation (QAM) brings complex data. Although RF systems can transmit complex signals directly, only real and positive data signals can be used to modulate the optical intensity in IM/DD VLC systems [11]. Therefore, Hermitian symmetry is added to transform the complex data into real data in an inverse fast Fourier transform (IFFT) block. To obtain a positive signal, one known method adds a direct current (DC) bias to the optical OFDM signal, and is called DC-biased optical OFDM (DCO-OFDM). Another known method asymmetrically clips the negative part of the optical OFDM signal and only transmits the positive part, and is called asymmetrically-clipped optical OFDM (ACO-OFDM) [15, 16].

In this paper, the beneficial clipping method is investigated, which is based on the DCO-OFDM systems. It is different from the pervious clipping studies because it is artificially formed, not the reasons of LED nonlinear transfer characteristic or others [15, 16, 17, 18]. In DCO-OFDM systems, the OFDM signal is the sum of multiple independently modulated QAM subcarriers in IFFT operations and the summation result is real. From the central limit theorem (CLT), the envelope of an OFDM signal is considered to have an approximately Gaussian distribution [8]. When using the Bussgang theorem, the truncated Gaussian signal $x_c(t)$ can be modeled as $x_c(t) = Kx(t) + n_{clip}(t)$. This is a linear attenuation of the original signal $Kx(t)$ and an independent clipping additive white Gaussian noise (AWGN), $n_{clip}(t)$; K is an at-

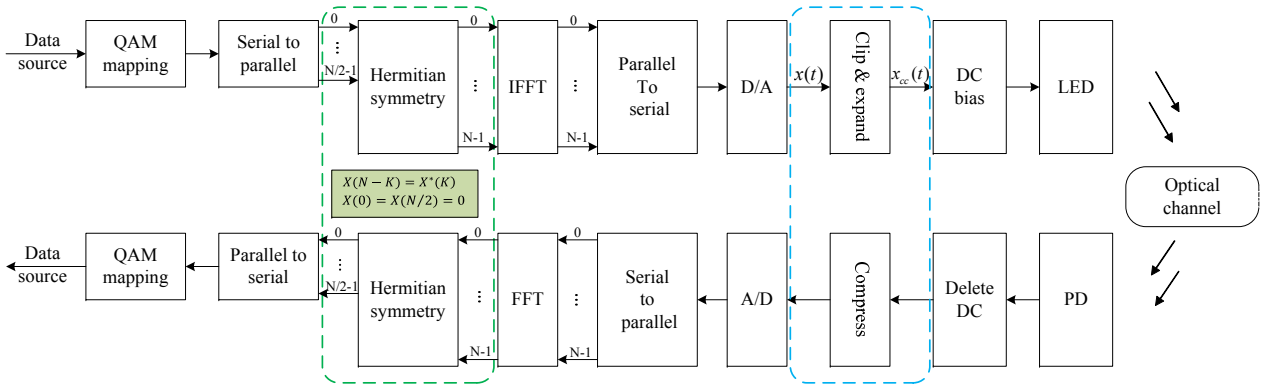

Figure 1. Diagram of the IM/DD DCO-OFDM system.

tenuation parameter [16, 17, 18]. In this paper, both of the Bussgang theorem and the approximately Gaussian distribution are used to analysis the beneficial clipping process and the BER variation derives from beneficial clipping method.

The paper is organized as follows. In section 2, the IM/DD DCO-OFDM system model and the beneficial clipping process are presented. In section 3, according to the Bussgang theorem and the approximate Gaussian distribution, the beneficial clipping process, and the corresponding system SNR and BER are analyzed. Section 4 presents and discusses the simulated BER performances of the DCO-OFDM system. Finally, we give our conclusions in section 5.

2. SYSTEM MODE

Fig. 1 shows the diagram of the IM/DD DCO-OFDM system using the proposed clipping method. The original data sink is modulated by a QAM mapping block with a complex output. The Hermitian symmetry block is used to produce the real time domain signal at the output of the IFFT block. In this block, all modulation data from the QAM block is regarded as the first part of the IFFT input and the corresponding conjugate symmetric data conducts as the second part, which can be denoted as $X(N-k) = X^*(k), k \in (0, N/2)$, where N is the IFFT size [19, 20]. Here, $X(0) = X(N/2) = 0$, so as to the real data is obtained in the IFFT block. The DC bias turns the bipolar signal into a positive signal. Finally, the real and positive electric current is used to drive the LED for communication. Here, $X(k)$ denotes the transmitted signal, which is carried by the kth subcarrier. The baseband signal of the DCO-OFDM is then derived as [9, 20]:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j2\pi f_k t}, 0 \le t \le T \qquad (1)$$

where T is the duration of the OFDM symbol, and $f_k = k/T$ is the center frequency of the kth subcarrier [21]. In this diagram, the clip and expand block is critical because it represents the beneficial clipping procedure. In the following part of this section, the detailed description of the beneficial clipping is presented.

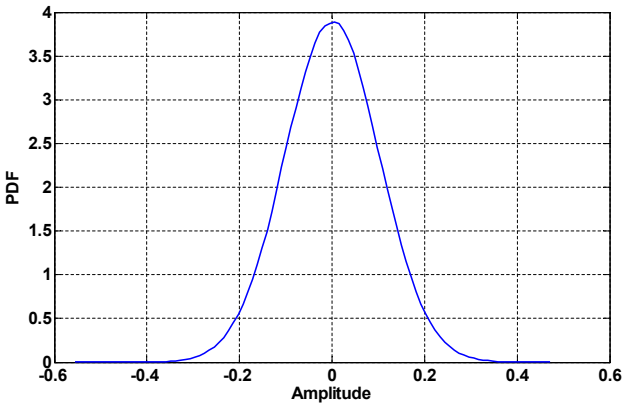

Figure 2. PDF of the Gaussian distribution with zero mean and variance of 0.01085.

The actual DCO-OFDM signal has a finite amplitude scope though the signal follows the approximately Gaussian distribution for large IFFT size [16]. In application, the amplitude range is limited to $\pm 4.8\sigma$, here σ is the standard deviation of the Gaussian distribution [22]. According to the probability density function (PDF) of the Gaussian distribution, the cumulative probability is 1.5866×10^{-6} when the amplitude expands beyond $\pm 4.8\sigma$. Therefore, it is reasonable that the amplitude of the DCO-OFDM signal without the DC bias has an approximately Gaussian distribution with a truncated range of $\pm 4.8\sigma$. The PDF of the Gaussian distribution with zero mean and variance σ^2=0.01085 is presented in Fig. 2. Here, the amplitude is limited to ± 0.5, i.e. the maximum signal amplitude is $A = 4.8\sigma = 0.5$. As shown in Fig. 2, the probability of signal amplitude mapped over $[-0.3, 0.3]$ is 99.6%. It illustrates that the majority of signal amplitudes are centered on a narrower scope, only fewer signal have the larger amplitudes. In this way, if the large amplitude, such as amplitude larger than 0.3, is clipped, its nonlinear distortion is little. In this context, the beneficial clipping is intro-

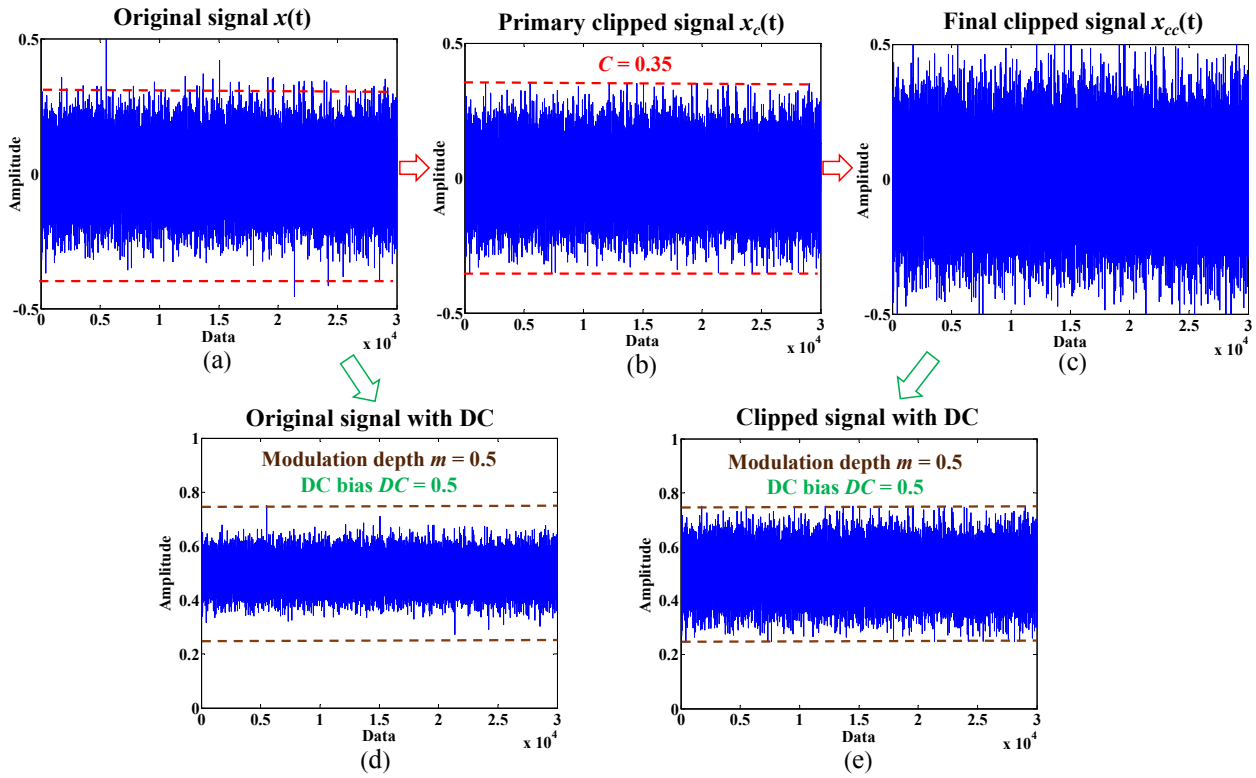

Figure 3. Process of the beneficial clipping method. (a) Original IM/DD DCO-OFDM signal $x(t)$ with amplitude range of $[-0.5, 0.5]$. (b) Primary clipped signal $x_c(t)$ with $C = 0.35$. (c) Expanded clipped signal $x_{cc}(t)$ with same amplitude range as $x(t)$. (d) Original signal with DC bias of 0.5 and modulation depth of 0.5. (e) Beneficial clipped signal with DC bias of 0.5 and modulation depth of 0.5.

duced. The unclipped baseband DCO-OFDM signal is $x(t)$, the clipped signal is $x_c(t)$, the amplitude of $x(t)$ is limited to $\pm A$, and the clip is operated at C. Then the symmetry clipping is presented as:

$$x_c(t) = \begin{cases} C & x(t) > C \\ x(t) & |x(t)| \le C \\ -C & x(t) < -C \end{cases} \tag{2}$$

CR is the clipping ratio, where $CR = C/A$. In this step, the signal amplitude scope is reduced from $[-A, A]$ to $[-C, C]$. For a certain modulation depth, expand the clipped signal amplitude to the original range can improve the signal power and anti-noise property. Then the expansion procedure is introduced.

$$x_{cc}(t) = \frac{Ax_c(t)}{C} = \frac{x_c(t)}{CR} \tag{3}$$

where, x_{cc} is the expanded signal and the final beneficial clipping signal. Then it is transmitted by the LED:

$$x_{tr}(t) = x_{cc}(t)m + DC \tag{4}$$

$$m = \frac{P_{\max} - P_{\min}}{P_{MAX}} \tag{5}$$

Here, x_{tr} is the transmitted signal as the light intensity, DC is the DC bias, m is the modulation depth, P_{MAX} is the rated maximum power of the LED, and $P_{\max}$ and $P_{\min}$ are the maximum and minimum LED transmission powers in actual transmission system.

As shown in Fig. 3, it expresses the entire process of the beneficial clipping. Fig. 3(a) is the original DCO-OFDM signal $x(t)$, here, the maximum signal amplitude is $A = 0.5$. Then the symmetry clipping process (2) is employed to $x(t)$ with $C = 0.35$, and the primary clipping signal $x_c(t)$ is presented in Fig. 3(b). Fig. 3(c) expresses the critical process of (3), it expands the signal amplitude from 0.35 to 0.5 and directly shows the growth of signal amplitude and power. At last the Fig. 3(d) and (e) represent the modulation process from electric signal to optical intensity signal.

3. BER ANALYSIS OF BENEFICIAL CLIPPING METHOD

Equation (4) shows that the transmitted signal $x_{tr}(t)$ is composed of two independent parts: the signal component and the DC component. Thus, in this paper, the DC bias is ignored and the analysis focuses on the bipolar signal. In general, the signal from the DCO-OFDM is an approximately

Gaussian distribution with zero mean, and the symmetrical clipping process of (2) is a nonlinear process. From the Bussgang theorem, there is a linear relationship between the autocorrelation of $x(t)$ and the cross-correlation between $x(t)$ and $x_c(t)$, $\mathrm{cov}[x(t)x_c(t)] = K\mathrm{cov}[x(t)x(t)]$, where $\mathrm{cov}[\cdot]$ denotes the correlation function. In addition, $x_c(t)$ is also composed of two parts: the linear attenuation $Kx(t)$ and the clipping noise $n_c(t)$.

$$x_c(t) = Kx(t) + n_c(t) \tag{6}$$

$n_c(t)$ is AWGN noise with a zero mean and variance of σ_{nc}^2. Based on the approximately Gaussian distribution, the attenuation parameter K can be derived from (2) as follows:

$$\begin{aligned} K &= \frac{E[x(t)x_c(t)]}{E[x(t)x(t)]} \\ &= \frac{\int_{-\infty}^{-C} -Cxp(x)dx + \int_{-C}^{C} x^2p(x)dx + \int_{C}^{\infty} Cxp(x)dx}{\sigma^2} \\ &= 1 - 2Q(\frac{C}{\sigma}) \end{aligned} \tag{7}$$

Here, $p(x)$ is the PDF of $x(t)$ with the Gaussian distribution, and σ^2 is the corresponding variance, where

$$p(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}} \tag{8}$$

The Q-function is defined as:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-\frac{u^2}{2}} du \tag{9}$$

Because the clipping is symmetrical, the mean of $x_c(t)$ is the same as the mean of $x(t)$, and $\mu_c = E[x(t)] = 0$. σ_c^2 and σ_{nc}^2 are the variances of $x_c(t)$ and $n_c(t)$, respectively, and can be determined based on the clipping function of (2):

$$\begin{aligned} \sigma_c^2 &= E[x_c(t)x_c(t)] \\ &= \int_{-\infty}^{-C} C^2p(x)dx + \int_{-C}^{C} x^2p(x)dx + \int_{C}^{\infty} C^2p(x)dx \\ &= 2(C^2 - \sigma^2)Q\left(\frac{C}{\sigma}\right) - \frac{2C\sigma}{\sqrt{2\pi}} \exp\left(-\frac{C^2}{2\sigma^2}\right) + \sigma^2 \end{aligned} \tag{10}$$

$$\sigma_{nc}^2 = \sigma_c^2 - K^2\sigma^2 \tag{11}$$

From (4) and (6), the effective electrical signal is $x_{elec}(t)$, which is mapped onto the drive currents of the LEDs:

$$\begin{aligned} x_{elec}(t) = x_{cc}(t)m &= \frac{m}{CR}x_c(t) \\ &= \frac{Km}{CR}x(t) + \frac{m}{CR}n_c(t) \\ &= x_{val}(t) + n_{val}(t) \end{aligned} \tag{12}$$

$x_{elec}(t)$ is composed of a combination of the valid signal $x_{val}(t)$ and the valid clipping noise $n_{val}(t)$. Because the clipping noise $n_c(t)$ is uncorrelated with the original signal $x(t)$, there is an uncorrelated relationship between $x_{val}(t)$ and $n_{val}(t)$. The variances of $x_{elec}(t)$, $x_{val}(t)$, and $n_{val}(t)$ are denoted by σ_{elec}^2, σ_{val}^2, and σ_{nval}^2, respectively. Also,

$$\sigma_{elec}^2 = \sigma_{val}^2 + \sigma_{nval}^2 \tag{13}$$

$$\sigma_{val}^2 = \left(\frac{Km}{CR}\right)^2 \sigma^2 \tag{14}$$

$$\sigma_{nval}^2 = \left(\frac{m}{CR}\right)^2 \sigma_{nc}^2 \tag{15}$$

The system SNR is determined based on the valid signal power σ_{val}^2 from $x_{val}(t)$ and the noise power σ_n^2. The noise power is composed of the valid clipping noise power σ_{nval}^2 from $n_{val}(t)$ and the optical wireless channel noise σ_{nvlc}^2.

$$SNR = \frac{\sigma_{val}^2}{\sigma_{nval}^2 + \sigma_{nvlc}^2} \tag{16}$$

Then, based on (14), (15), and (16), the function of the SNR can be derived as a function $f(\cdot)$, which is presented here as $SNR = f(A, CR, m, \sigma, \sigma_{nvlc})$. As shown in section 2, $A = 4.8\sigma$, and thus the SNR function can be simplified further as $f(CR, m, \sigma, \sigma_{nvlc})$.

The bit error ratio (BER) expression for the OFDM system with M-QAM in the AWGN channels is presented as [21]:

$$BER = \frac{2\left(\sqrt{M} - 1\right)}{\sqrt{M}\log_2\sqrt{M}} Q\left(\sqrt{\frac{6SNR}{M-1}}\right) \tag{17}$$

The BER can be expressed as a function $g(\cdot)$, and with all the required parameters, the BER function can be presented as $BER = g(CR, m, \sigma, \sigma_{nvlc}, M)$. This indicates that both the clipping ratio CR and the modulation depth m can influence the BER performance.

4. SIMULATION RESULTS AND DISCUSSION

The BER simulation results based on the setup are illustrated in Fig. 4 and 5 in order to analyse the performance of the beneficial clipping method in IM/DD DCO-OFDM systems. The parameters of the simulation are set as follows. The clipping ratio CR and modulation depth m are variables between 0 and 1. The optical wireless channel noise σ_{nvlc}^2 and OFDM signal power σ^2 are fixed. And the system SNR is set as 25dB, i.e. $SNR_{VLC} = 10\log\left(\sigma^2/\sigma_{nvlc}^2\right) = 25dB$. Meanwhile, the modulation mode is 64 QAM and the maximum baseband signal amplitude is $A = 4.8\sigma$. From (16) and (17), when the modulation mode is 64 QAM, the system SNR and the BER are only influenced by the clipping ratio CR and the modulation depth m.

Fig. 4 presents the BER performance under the influence of both CR and m in the proposed IM/DD DCO-OFDM system. The concave surface indicates that the BER decreases when m increases. However, for a certain m, when CR rises from 0 to 1, the BER shows a change in this trend, and it

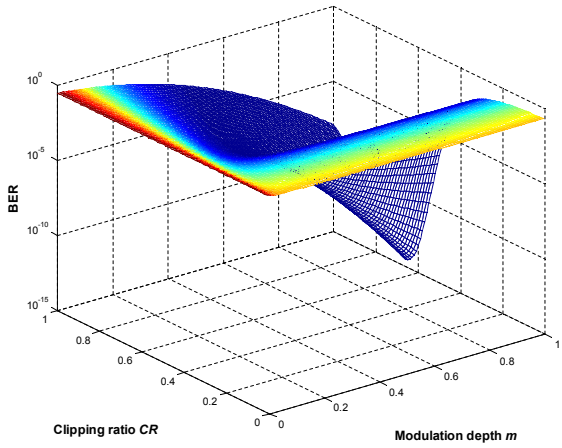

Figure 4. BER performance with variation of the clipping ratio CR and the modulation depth m.

changes from falling to rising. This trend shows that the beneficial clipping process can improve the system performance to a certain degree, but that it also introduces a high BER performance when the CR is low. For example, with full modulation $m = 1$, the BER decreases from 10^{-8} to 3×10^{-15} when CR decreases from 1 to 0.66. This shows that beneficial clipping can enhance the system performance when compared with the performance without clipping. However, the BER increases when CR decreases from 0.66 to 0, and the BER is more than 10^{-8} (no clipping) when CR is higher than 0.52. This shows that the beneficial clipping method is not always effective, because clipping also simultaneously introduces nonlinear distortion.

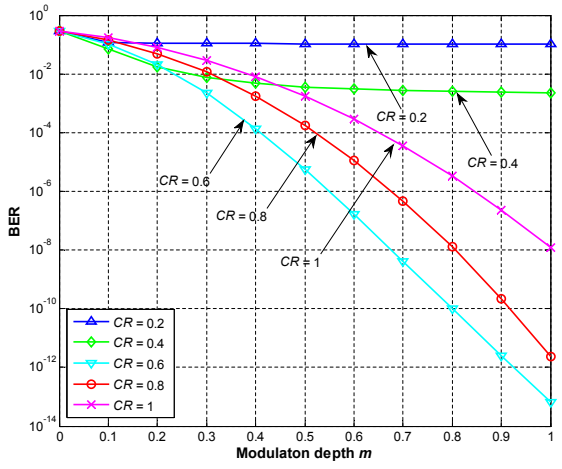

Figure 5. BER performances for different clipping ratios.

To investigate the BER performances for different clipping ratios, BER curves are plotted for $CR = 0.2$, 0.4, 0.6, 0.8, and 1.0 in Fig. 5. The curves clearly show that for a certain value of m ($m > 0.22$), the lowest BER is obtained not for $CR = 1$, but for $CR = 0.6$. When $m = 0.6$, the BERs for $CR = 0.6$ and 1 are 10^{-7} and 3×10^{-4}, respectively. But the BERs for $CR = 0.2$ and 0.4 are larger than the BER for $CR = 1$ at the same m. This is because there are two factors that affect the system performance: the proposed beneficial clipping method and the channel noise. As shown in (16), σ^2_{val} and σ^2_{nval} are both affected by the beneficial clipping process, while σ^2_{nvlc} is a constant when $SNR_{VLC} = 25dB$. As mentioned above, for CR values of 0.6 and 0.8, the proposed clipping process is mainly used to expand the signal power, although it also introduces clipping noise. Therefore, when $CR = 0.6$ and 0.8, the SNR values calculated using $SNR = \sigma^2_{val}/(\sigma^2_{nval} + \sigma^2_{nvlc})$ are larger than in the no clipping situation for $CR = 1$ and there are lower BERs than that for $CR = 1$. Also, when $CR = 0.8$, the BER is larger than the BER for $CR = 0.6$, because the expanded level in σ^2_{val} is smaller when $CR = 0.8$. In addition, the clipping noise is mainly a noise source when $CR = 0.2$ and 0.4, that is to say, the proposed clipping method degrades the system performance. The corresponding BERs are thus larger than the BERs without clipping, for example, when $m = 0.8$, the BERs of $CR = 0.2$ (10^{-1}) and 0.4 (3×10^{-3}) are larger than the BER of $CR = 1$ (3×10^{-6}). In contrast, the BER relationship among the different values of CR changes with m. When m is larger than 0.44, the BER for $CR = 1$ is lower than the BER for $CR = 0.4$. However, when m is less than 0.44, the BER relationship between $CR = 1$ and 0.4 changes. This is because the lower modulation depth will lead to lower values of σ^2_{val} and σ^2_{nval}, which then changes the system SNR. This shows that the proposed beneficial clipping method can enhance the system BER performance with a suitable clipping ratio and that the specific performance varies with m.

From the above discussion, both m and CR have been shown to affect the BER performance. Under the proposed simulation conditions, the system has the lowest BER of 3×10^{-15} when $m = 1$ and $CR = 0.66$. In practical applications, if the system has a fixed BER requirement, then the lowest m and best transmission speed can be obtained by varying the CR. For a specific m, a better transmission performance can also be attained by changing CR.

5. CONCLUSION

From a conventional perspective, the clipping process simply introduces nonlinear distortion without any merits. In contrast, the beneficial clipping method is used to improve the transmission performance of the IM/DD DCO-OFDM systems. In accordance with the Bussgang theorem and using an approximately Gaussian distribution, the clipping mode is illustrated. This shows that the system BER is affected by the modulation depth, the clipping ratio, the signal power, and the channel noise. Also, the mathematical results prove that the proposed clipping method can not only improve the valid signal power but can also enhance the system SNR. An improvement in the system BER from 10^{-8} to 3×10^{-15} was obtained for a clipping ratio of 0.6 with full modulation. In practical applications, the system modulation depth is limit-

ed to a narrow range for high transmission speed. However, lower modulation depths will lead to higher system BERs because of the reduction of the valid signal power. In this case, the system performance can be enhanced by the proposed beneficial clipping method. For example, when the modulation depth is 0.6, the BER decreases from 2×10^{-4} to 1.8×10^{-7} when the CR decreases from 1 to 0.6. Therefore, the proposed beneficial clipping method is an effective technique to improve the system performance. In addition, the method also can be used to obtain low modulation depths for specific BER requirements. Since more international standards are needed to support the VLC-OFDM system, in the future we plan to further pursue contributions to the standardization of VLC system.

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ADAPTIVE VIDEO STREAMING OVER HTTP THROUGH 3G/4G WIRELESS NETWORKS EMPLOYING DYNAMIC ON THE FLY BITRATE ANALYSIS

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ABSTRACT

The smooth video streaming over HTTP through 3G/4G wireless network is challenging as available bit rate in the internet changes due to sharing of network resources and time varying nature of wireless channels. The present popular technique Dynamic Adaptive Streaming over HTTP (DASH) provides solution up to some extent to stored video, but the effective adaptive streaming of a live video remains a challenge in a high fluctuating bit rate environment. In this paper, an intelligent algorithm based on client server model where client system analyses the incoming bit rate on the fly and periodically sends report to server which in turns adapts the outgoing stream as per the feed-back, is proposed. The bit rate analysis process at the receiver estimates the link data rate dynamically by comparing it with some pre-defined pattern. The proposed system was implemented and tested in real-time in CDMA 1xEVDO Rev-A network using internet dongle. An improvement of 37.53% in average PSNR and 5.7% increase in mean SSIM index over traditional buffer filling algorithm was observed on a live video stream. The proposed system was also evaluated on a stored video.

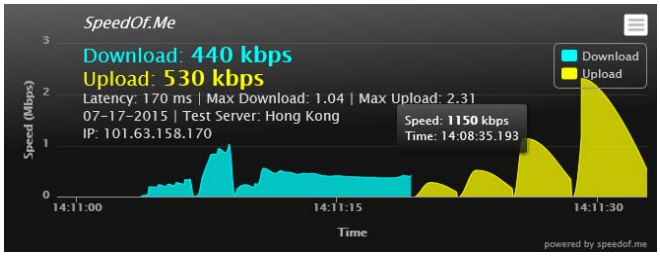
Keywords: *Video streaming, adaptation, client-server, Bit rate analysis, PSNR, SSIM*

1. INTRODUCTION

The adaptive video streaming over Hypertext Transfer Protocol (HTTP) in internet has become very popular today as HTTP is a widely used web technology, and it does not require any specific technique below it to support streaming. In this aspect to ensure interoperability, MPEG and 3GPP has developed a new standard called *Dynamic Adaptive Streaming over HTTP* (DASH) [1]. In DASH, each video is fragmented and stored with different quality parameters (e.g., resolution, frame rate etc.). The adaptation process at the client request the server to stream the appropriate quality segment based on the prevailing network bandwidth [2]. The present heuristic algorithms fail to respond an abrupt change in network bandwidth, which leads to freeze in the video at play, thereby degrading the quality of experience [3]. Furthermore, a new approach is needed in DASH in implementing live streaming.

In live streaming, even a highly adaptive buffer management technique which involves client monitoring the upper and lower threshold of the play out buffer, may not produce good result as content rate depends on live capturing mechanism at the source. This clearly justify the need for the on the fly Scalable Video Coding (SVC) mechanism. The SVC can support frame by frame adaptation provided the system permits to switch the video layers dynamically [4].

One of the main motivating reasons to develop an adaptive SVC based video streaming system here arises from the study of available bit rate in existing wireless internet dongles (3G and 4G). Although the system supporting these devices have been designed to meet the standard specification, in practice there is a lot of gap between what is mentioned by the service provider and the actual resource available to the end customer due to various reasons. Fig.1 shows the observation of a 3G dongle employing *CDMA 1xEVDO Rev-A* technique and a 4G dongle based on *LTE TDD Category-3* system. The measured data rate not only varies from locations to locations but also fluctuate in time.



(a) Data rate observed on a *Reliance Netconnect+* (CDMA 1xEVDO Rev-A) 3G dongle

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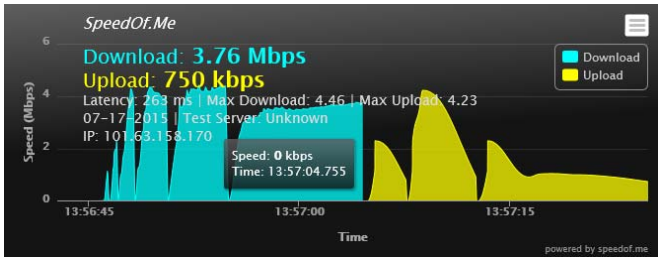

(b) Data rate observed on a *Airtel 4G Mobile Hotspot* (LTE TDD Category 3) dongle

Figure 1. Download and upload bit rate observed on wireless internet dongles at work place in a given time

So, there is enough incentive to develop a system which can cope up these impairments while offering best performance and hence quality to the end user.

The system performance needs to be evaluated using standard parameters and procedures. As per the ITU-T recommendation (J.247) on "objective perceptual video quality measurement", the *full reference measurement* method can be used when the original reference video signal is obtainable at the receiver (decoding point), and hence it is suitable to test an individual equipment or a chain in the laboratory [5]. The assessment techniques are applied on video in QCIF, CIF, and VGA format for testing. As listed in Table 1, these test factors provide a very low to high quality input to assess the system under test conditions. The proposed system intends to utilize these parameters with corresponding standard values for validation and testing.

Table 1. Test Factors as per the ITU-T J.247

S. No	Parameters	Values
1	Transmission	Errors with packet loss
2	Frame rate	5 fps to 30 fps
3	Video Codec	H.264/AVC (MPEG-4 part 10), VC-1, Windows Media 9, Real Video (RV 10), MPEG-4 Part 2
4	Video Resolution: QCIF, CIF, and VGA	QCIF: 16 - 320 Kbps CIF: 64 - 2000 Kbps VGA: 128 - 4000 Kbps
5	Temporal errors (pausing with skipping)	Maximum of 2 seconds

The traditional approach of link bandwidth estimation at the client/server used to send a ping packet to the server/ client and calculate the bandwidth with reference to the time taken by the packet to return back. This approach is not accurate as there are many factors like instant congestion that can delay the arrival rate of a ping packet. Thus the best approach to this problem will be to estimate the link capacity at the receiver/client by analyzing incoming bit stream on the fly. The incoming bit rate can be sampled periodically to send a feedback message to the server to carry out any remedial action on the outgoing stream such

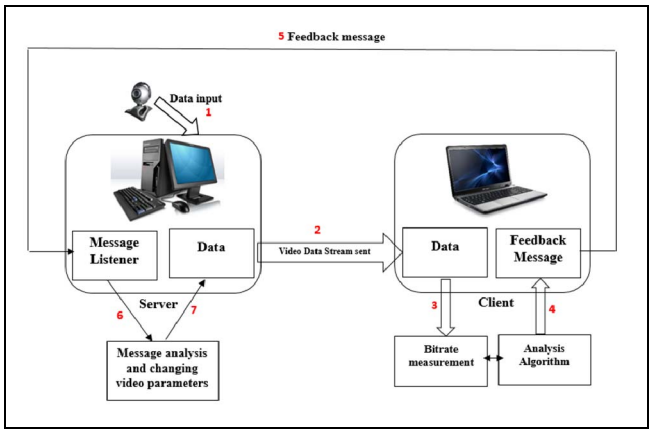

Figure 2. The schematic of an adaptive video streaming

that the end user enjoys a best quality of content all the time. Fig.2 shows a schematic of proposed system where client applies a predefine algorithm to estimate the incoming bit rate and report to the server. The action in the loop needs to be fast enough to respond the real-time requirement of the video communication.

3. RELATED WORK

Understanding the theory behind the bit rate adaptation and analysing factors like video segment scheduling, selection of bit rate, and bandwidth assessment with respect to the performance of commercially available solutions like SmoothStreaming, Akamai HD, Netflix, and Adobe OSMF could be rewarding [6]. Further, a proper modelling of the main process i.e., automatic switching of video stream in the system adopted by these commercial (video streaming) service provider, helps in improving system design as it involves analysis of feed-back control loops [7].

In HTTP based Adaptive Streaming (HAS), the switching of video i.e., bit-rate stream at client dictates the main parameter of quality of experience (QoE) [8]. The analytical model/framework of QoE needs to include the probability of play out buffer getting drained, running playback time, average quality of video etc. The client system can estimate buffer level over time, and there is need to maintain balance between the stability of buffer and quality of play out video [9]. Hence, any adaptation on layer switching in SVC needs to accommodate the probability of buffer underflow of the receiver [4].

There has been considerable interest in MPEG – DASH by many researchers. A proper mapping between DASH layers and SVC layers can not only help in estimating needed bitrates, but also enhancing the video throughput with reduced overhead of the HTTP messages [2]. It could be further rewarding to work on scheduling and resource allocation through a cross-layer approach which include DASH and radio layer. The DASH can be implemented to support streaming to hand-held mobile devices through multiple wireless network interfaces, but not only the energy efficiency but also the cost of service becomes an important factor [10-11].

Some researchers [12] have argued that when HAS occupies a considerable fraction of the total internet traffic

and multiple HAS clients start competing at a network resources, it will result in problem of its fair share of bandwidth and a possible solution could be a probe and adapt policy. Furthermore, a HAS client can apply machine learning of reinforcement type to adapts its behaviour leading to the optimization of its quality of experience [13].

4. PROPOSED SYSTEM

4.1 System Architecture

The proposed system architecture consists of two modules at the server side (Fig.3) to acquire and stream live/stored video and three modules at the client side (Fig.4) to receive, analyze, and play video. The server captures the live video stream through a high-definition (HD) video camera connected locally. The video stream is then encoded by a H.264 based codec. The live video stream is then streamed to the client, which is connected through a 3G wireless network. After receiving *N* frames (say *N*=100) of video steam the client starts playing it and simultaneously it also estimates the incoming bit rate of the video. A pattern estimate algorithm is applied on the receiving bit rate to pass feedback to the sender. If the pattern suggests that the bitrates are either high or low and point towards a degradation, a response message is sent to the server to make suitable changes to the video stream.

The system analyses the bitrates and categorize them into four different patterns (Fig.5) and adapts the ongoing session corresponding to each case. Case 1 represents a progressive type where the network bit rate will increase in time. After some fluctuation the bit may tend to become stable (Case 2). There may be a case when pattern of change in bit rate may diverge (Case 3). If the received bit rate continues to fall, it represents a serious problem in maintaining quality of service (Case 4). If the system is unable to resolve into any of these categories, it will resort to a root-mean-square (RMS) value.

4.2 Server side modules

The server continuously monitors the client feedback and decides the parametric values of outgoing video stream. The server side implementation contains two basic modules:

- The first module uses the *vlcj* framework including H.264 codec to capture and stream the video data continuously to the client through the *http* port.
- The second module listens to the feedback messages received from the client for adjusting parameters (e.g., resolution, frame rate) of the video stream.

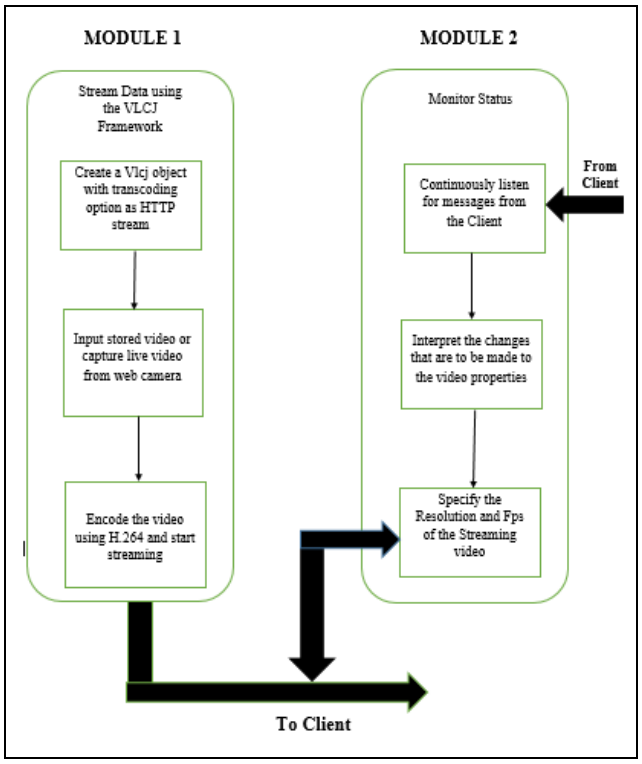

Figure 3. Server side modular flow diagram

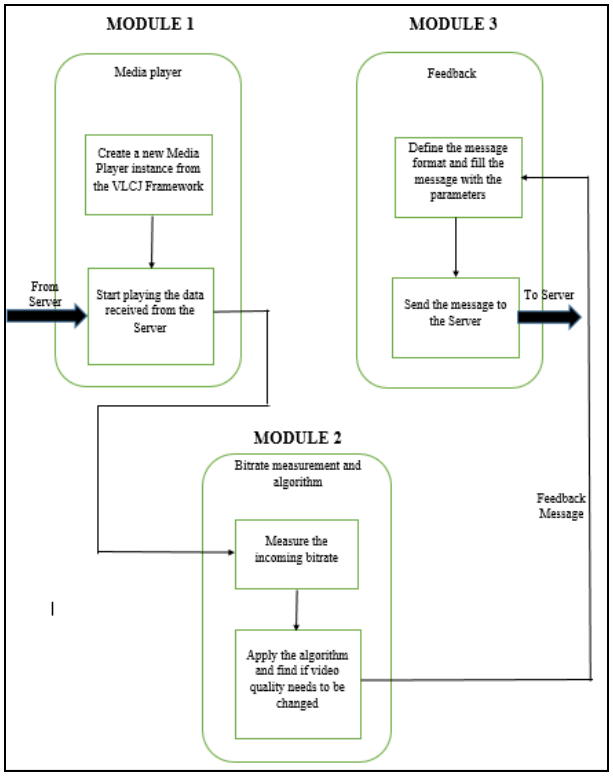

Figure 4. Client side modular flow diagram

4.3 Client side modules

The client analyses the incoming bit stream periodically to find out the pattern of variation of receiving bit rate. The client side contains three modules:

- The first module uses the *vlcj* framework to play the stream of data received from the server.
- The client system is responsible for estimating the bit rate from the received video and applying the algorithm to analyse the pattern of bit rate which is performed by module 2.
- The main job of the third module is to pack the feedback messages in agreed format and send to the server.

5. PROPOSED ALGORITHM

The proposed algorithm analyses periodically the sampled data (bit rate) and provide solution to the fluctuating available resource in the network. The fluctuating received bit rate is categorized it into any one of the predefined pattern (Fig.5). The algorithm at receive includes local maxima and minima of sampled data before it concludes the pattern as either of (i) progressive, (ii) stabilized, (iii) fluctuating, and (iv) degraded. Sometimes it may declare status as non-monotonic where it needs to find the RMS value. The algorithm at server side decodes the received message from the client and decides the video stream accordingly. The server also considers switching time as a metric in deciding change in outgoing stream. Any error in estimating pattern at client will result in non-remedial action by the server.

5.1 Client side algorithm

1) Read the bitrates and store in a buffer.
2) Find local maximum points and store it in an array "L_{max}"
   i) Read bitrates in pairs of 3 *// i.e., v_1, v_2, v_3*
   ii) If $v_1 < v_2 > v_3$, add v_2 to L_{max} array // set max.
   iii) Continue the process for the all the frames received.
3) Find local minimum points and store it in an array "L_{min}"
   i) Read bitrates in pairs of 3 *// i.e., v_1, v_2, v_3*
   ii) If $v_1 > v_2 < v_3$, add v_2 to L_{min} array // set min.
   iii) Continue the process for the N ($N=100$) frames received.
4) Max = Analyse (L_{max}) // Call function to get α, β, γ
5) Min = Analyse (L_{min})
   a) If $max = \beta$ and $min = \beta$, set status as **Progressive**.
   b) Else if $max = \beta$ and $min = \alpha$, set status as **Stabilized**.
   c) Else if $max = \alpha$ and $min = \beta$, set status as **Fluctuated**
   d) Else if $max = \alpha$ and $min = \alpha$, set status as **degraded**.
   e) If $max = \gamma$ or $min = \gamma$, Set status as **non-monotonic** and call **Find_rms(Bitrates)**

5.1.1 Analyse (Bitrates)

1) Find start
2) Find end
3) Locate median
4) If (start, median, end) are monotonically increasing, Return β
5) Else if (start, median, end) are monotonically decreasing, Return α
6) If (start, median and end) are neither monotonically increasing nor decreasing, return γ

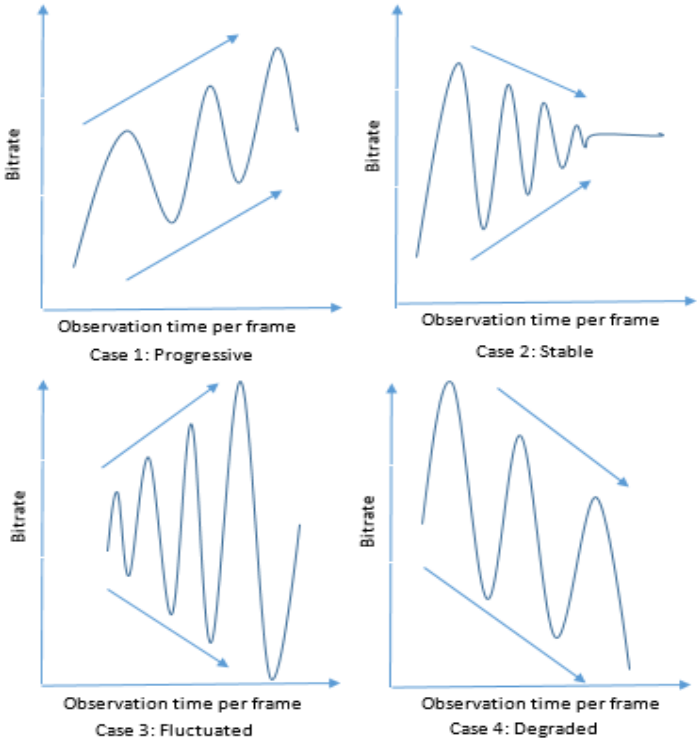

Figure 5. Different bitrate patterns

5.1.2 Find_rms (Bitrate)

1) Find the RMS value of the bitrates.

$$X_{rms} = \sqrt{\frac{1}{n}\left(x_1^2 + x_2^2 + ... + x_n^2\right)} \quad (1)$$

2) Split the N different ($N = 100$) bitrates into M parts ($M = 3$)**.**
3) Repeat the first step to find the RMS values of the each (three) parts. Let them be rms_1, rms_2, and rms_3.
4) Find the difference between the total RMS value and the RMS values of the parts.
   i) Compute $Diff_1 = RMS - rms_1$
   ii) Compute $Diff_2 = RMS - rms_2$
   iii) Compute $Diff_3 = RMS - rms_3$
5) *If* ($Diff_1 <= Diff_2 <= Diff_3$), then return *1*
6) *Else if* ($Diff_1 >= Diff_2 >= Diff_3$), then return *0*
7) *Else* return 2

5.2 Server side algorithm

// S = Spatial Resolution, T = Temporal Resolution
$S = \{S_1, S_2, S_3, S_4\}$, $T = \{T_1, T_2, T_3, T_4, T_5\}$
1) Initially set the resolution in QCIF at default value, T_d
2) Repeat
   i) Receive status from the client
   ii) *If* status = Good

a) Continue with same configuration.
iii) *Else if* status = Stable
b) Experiment with increased temporal resolution.
iv) *Else if* status = Fluctuated
c) Find_Switching_time (bitrate).
v) *Else if* status = Degraded
d) Reduce both spatial and temporal resolution.
vi) *Else if* status is non-monotonic
e) Wait for next feedback to make change

3) Until connection is terminated

5.2.1 Find_Switching_Time (bitrate)

1) Quality switching time $T_{switch} = TQ_{k+1} - TQ_k$ where TQ_{k+1} is the time-instant at the end of k^{th} quality request processed and TQ_k is the current time instant serving previous quality request.
2) Start a timer when each quality switch is encountered to find the time needed to switch from one quality level to another.
3) Wait till next feedback from the client.
4) *If* ($T_{switch} > Fluctuation\_time$)
   Do not alter the quality and wait till next feedback from the client
5) *Else*
   Alter the quality as per the current request.

5.3 Buffer Filling Algorithm

The buffer filling algorithm was implemented independently here which is based on traditional adaptive stream control method. The system at the client monitors the lower and upper threshold of the play out buffer and submits the report to the server. If the buffer reaches the upper threshold it ask for slowing down the stream rate but if the arriving contents approaches the lower threshold it signals the server to speed up the transfer rate. The server reduces or increases the stream bit rate by changing the video frame resolution and/or dropping frames accordingly.

6. IMPLIMENTATION ENVIRONMENT

We considered four standard video resolutions namely SQCIF, QCIF, CIF, and QVGA to be adopted dynamically by the server based on client feed-back. The four temporal resolutions (in fps) was: 10, 15, 25, 30, and 35; whereas the default frame and also initial set-up was fixed at 30 fps. The server system was programmed using our proposed algorithm to choose any of these combinations (spatial and temporal) to match the available outgoing bit rate in the communication channel.

The wireless internet connectivity was established by a dongle, *Reliance Netconnect+* [14] which works on CDMA 1x RTT & CDMA 1xEVDO Rev A. As per the specification mentioned by the service provider it is intended to provide a download speed up to 3.1 Mbps and up to 1.8 Mbps in uplink, but according to a real-time test conducted with the help of an online tool by *SpeedOf.Me* [15] the average uplink speed was found to be 0.54 Mbps and the average downlink rate was 0.45 Mbps during the experimentation. The internet bit rate fluctuation in *Reliance Netconnect+* in real-time during test and measurement provided us the perfect platform to asses our proposed algorithms.

The client and server were implemented on Dell Inspiron N5010 desktop computer separately which is configured with *Intel® Core™* i7-3770 CPU@3.4 GHz processor and 8 GB RAM. The *Window7 Professional* 32-bit operating system was installed to run the client/server program. The streaming operation was carried over http with UDP protocol.

6.1 Video Streaming and Bitrate Estimation in Java Framework

The VLCJ in a Java framework is used here as an instance of a native VLC media player. It helped in a higher level framework while hiding a lot of the intricacies of working with VLC libraries. Since VLC supports many video/audio formats under *libavcodec* it play back the H.264 streamed video.

JPCAP provide a packet capture function (library) for the network applications in Java specifically to analyse the real time network data. It is used here at client side to estimate the bitrate of the incoming video and to store it in a buffer (array) where the client program continuously evaluate it for further action.

6.2 Parameters Used to Evaluate the System Performance

Since the targeted application here is a high quality video communication services including tele-medical video, the full reference (FR) methods were used to evaluate the system performance. Moreover FR metrics usually provide the most accurate result. The two commonly used FR parameters are: Peak Signal to Noise Ratio (PSNR) and Structural Similarity (SSIM) index. One of the main aims of implementation here is that the system response to the changing network resource should result in higher PSNR and SSIM provided the communication link is maintainable.

6.2.1 Peak Signal to Noise Ratio (PSNR)

The PSNR reveals the overall degradation of processed video signals and it can be computed on luminance value (ITU-T recommendation [5]) and usually it is represented on a logarithmic scale as:

$$PSNR = 20 \log_{10}\left(\frac{Max}{\sqrt{MSE\ (m)}}\right) \quad (2)$$

where $Max = 2^{\text{no. of bit/sample}} - 1$ and for 8-bit per luminance value it is 255. The *MSE(m)* is the mean square error which is the difference between the reference video and degraded video in the m^{th} frame, and it is computed as:

$$MSE\ (m) = \frac{1}{M \times N}\sum_{i=1}^{M}\sum_{j=1}^{N}\left[Y_{out}(i,j,m) - Y_{in}(i,j,m)\right]^2 \quad (3)$$

The PSNR measurements were carried out on few selected decoded frame at the receiver resulting from the application of proposed adaptation algorithms. It was basically an offline process where at the end of experiment the recorded data were compared and analysed. The system was targeted to maintain an average PSNR of not less than 30 dB.

6.2.2 Structural Similarity (SSIM) Index

The SSIM index provides knowledge about perceived degradation due to structural deformation in an image reconstruction. In video pixels have not only the temporal dependency but also the spatial inter-pixel dependency. The spatial dependency offers details about structure of the objects in an image and hence SSIM becomes important quality evaluation parameters in video communication.

The SSIM index is evaluated on three different measures, the luminance, contrast, and structure comparison which is defined by the Joint Video Team (JVT) of ISO/IEC MPEG & ITU-T VCEG as [16]:

$$l(\mathbf{x},\mathbf{y}) = \frac{2\mu_x\mu_y + C_1}{\mu_x^2 + \mu_y^2 + C_1} \quad (4)$$

$$c(\mathbf{x},\mathbf{y}) = \frac{2\sigma_x\sigma_y + C_2}{\sigma_x^2 + \sigma_y^2 + C_2} \quad (5)$$

$$s(\mathbf{x},\mathbf{y}) = \frac{\sigma_{xy} + C_3}{\sigma_x\sigma_y + C_3} \quad (6)$$

where μ_x is the average of x, μ_y is the average of y, σ_x^2 is the variance of x, σ_y^2 is the variance of y, σ_{xy} is the covariance of x and y. The constants C_1 , C_2 , and C_3 are given by $C_1 = (K_1 L)^2$, $C_2 = (K_2 L)^2$ and $C_3 = C_2 / 2$, which are to stabilize the division with weak denominator. L is the dynamic range of the pixel values given by $L = 2^{no.\ of\ bit/pixel} - 1$ and $K_1 << 1$ and $K_2 << 1$ are two scalar constants.

Based on these metrics, the SSIM is formulated as

$$SSIM(\mathbf{x},\mathbf{y}) = [l(\mathbf{x},\mathbf{y})]^{\alpha} \cdot [c(\mathbf{x},\mathbf{y})]^{\beta} \cdot [s(\mathbf{x},\mathbf{y})]^{\gamma} \quad (7)$$

where α, β, and γ state the different weightage assigned to each measure.

The single scale SSIM is now formulated as [17]:

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \quad (8)$$

The aim of the proposed system was to maintain the SSIM index above 0.95. Like PSNR the SSIM too was computed offline on stored data at the end of experimentation.

7. RESULTS AND DISCUSSION

7.1 Inter-packet Arrival Delay

The variation of packet delay as a difference in end-to-end one-way delay between selected consecutive packets in a flow with any lost packets being ignored was observed during experimental set of video communication. The observed random variation in delay (Fig.6) is attributed to the prevailing internet traffic during test and measurement period on 3G wireless modem (dongle) used to connect with the internet. Although maximum delay requirement was not directly dealt with the proposed algorithm, the bit rate was adjusted by the server to meet the targeted quality. For the data shown in Fig.6 the average inter-packet delay is 69µs.

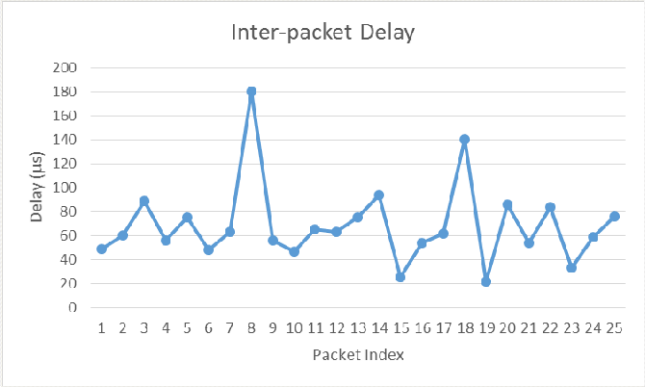

Figure 6. Inter-packet delay

7.2 PSNR Measurement

The PSNR measurement (Fig.7) was carried out on three approaches: (i) without any adaptation mechanism, (ii) buffer filling algorithm, and (iii) the proposed adaptation method. The proposed algorithm helps in achieving an average PSNR of 36.267 dB which is 37.53% higher compared to the buffer filling algorithm. Further it is much higher than the without adaptation approach. This reward of increase in PSNR is attributed to the high adaptation exhibited by the proposed method in real-time scenario which in turn permitted underlying networks to deliver packets with fewer losses.

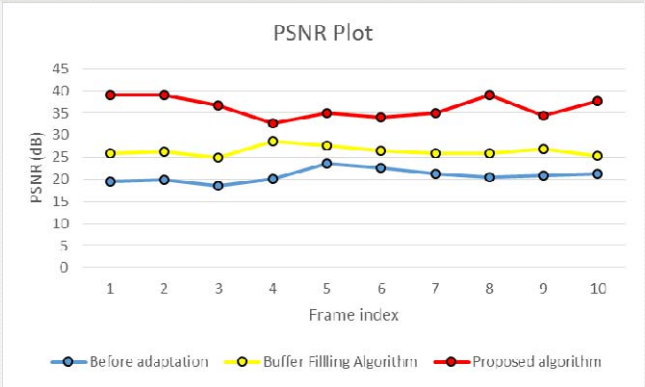

Figure 7. PSNR Measurements

7.3 SSIM Index

The SSIM index was computed in a similar way as that of PSNR on the three methods i.e., without adaptation, buffer filling algorithm, and proposed algorithm (Fig.8). The proposed algorithm offers **5.7%** higher average SSIM value than the buffer filling algorithm and much higher than the without adaptation approach. Because of dynamic adaptation it was possible to retain and maintain the structural information thereby resulting in higher SSIM

index value. Although the system designs do not include any parameter to retain the structural similarity during play out, a higher SSIM value is an additional reward of in time adaptation.

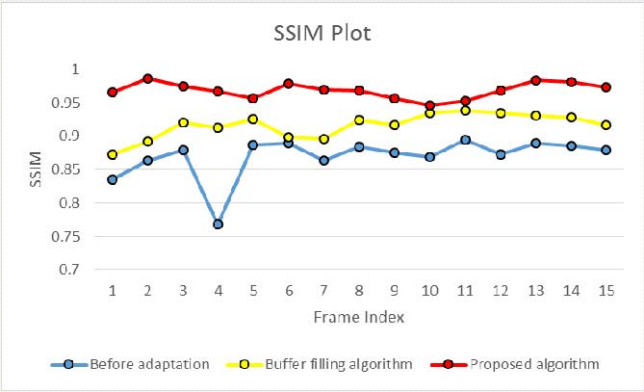

Figure 8. SSIM Index comparison

7.4 Some Selected Original and Received Decoded Frame

Fig.9 and Fig.10 show the original and received decoded frames captured during live video streaming and recorded Foreman video [18] respectively. Even a closer look at these frames does not reveal a noticeable loss in decoded video quality, which is highly desirable in high quality video communication services.

8. CONCLUSION AND FUTURE WORK

An adaptive streaming over the *http* to cope up with fluctuation in available bit rate in internet over the wireless network is highly rewarding. The proposed algorithm uses a maxima minima concept and an RMS approximation which tries to estimate the bit rate pattern in real-time. It also include the fluctuation time in the network along with the quality switching time for effectively decision making to switch between different video qualities. The proposed method in client server based network can be easily implemented as it runs on the top of the *http* and algorithm employs simple computations.

Although one of the targeted applications of the proposed system is tele-medical video streaming it can be used in many other applications. A sudden network congestion may cause extra delay on streaming packets and a suitable mechanism is needed to tackle it. Another future work includes implementation on cellular wireless network based hand-held devices, for example Android based cell phones.

Figure 9. Some selected frame from live video stream: Original (above) and received (below)

Figure 10. Some selected frame from stored Foreman video [18]: Original (above) and received (below)

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CLOUD BASED SPECTRUM MANAGER FOR FUTURE WIRELESS REGULATORY ENVIRONMENT

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ABSTRACT

The regulatory environment in radio frequency spectrum management lags the advancement of wireless technologies, especially in the area of cognitive radio and dynamic spectrum access. In this paper we argue that the solution towards spectrum Pareto optimal allocation lies with dynamic spectrum management as a policy and regulatory tool for addressing the dichotomy of technical, economic and socio-economic considerations. Different radio frequency bands have different technical characteristics and economic manifestation and, thus, a versatile tool would be desirable to deal with technical, economic and socio-economic objectives in various bands. While approaches based on geolocation spectrum databases and radio environment map architecture have served the cognitive radio and dynamic spectrum access industry, their focus has been on networks and technologies. In this paper we propose a cloud based spectrum manager as a tool focussed towards regulatory processes. With the proposed approach it is possible to deal with technical consideration of interference control resulting in achieving economic consideration of reducing rivalry and exclusivity with various spectrum policy and regulatory prescripts. The proposed spectrum manager should be able deal with all regulatory processes favouring cognitive radio and dynamic spectrum access, while enhancing economic value of radio frequency spectrum and achieving socio-economic benefits.

Keywords— Cognitive radio, dynamic spectrum access, radio environment map (REM), spectrum manager

1. INTRODUCTION

Cognitive radio (CR) and dynamic spectrum access (DSA) are important ingredients in efficient management of RF spectrum in order to address the current artificial radio frequency (RF) spectrum scarcity that is threatening the growth of wireless communications systems. However, the regulatory environment in RF spectrum management lags the advancement of these technologies.

Traditionally, RF spectrum is managed by national regulatory agencies through exclusive assignment of fixed portions of spectrum to individual users or services through a licensing process, also referred to as a command-and-control process, with the main goal being to control interference. The characteristic definition of a pure command-and-control approach is that a central body or agency is mandated to manage and control the RF resources using administrative processes, typically informed by technical and political considerations and purporting, correctly or incorrectly, to address socio-economic obligations. Several studies have shown that this approach has led to inefficient utilization and management of RF spectrum and is not in tune with current advancement in technology. It is not based on principles of the modern free market economy and, for most part, it does not even address socio-economic aspects [1, 2].

In the past two decades there has been a movement towards RF spectrum reforms. Unfortunately this has mostly been driven by activism as opposed to technical and economic rigour and, thus, diminishing the cause. Further, the focus has been unduly favouring telecommunications or broadband spectrum. Genuine reforms should take a holistic approach and include market or economic based approaches backed by unbiased technical and future-proof interventions, allowing spectrum sharing and trading across all bands. From economic point of view an optimal spectrum management model, addressing both technical and socio-economic considerations, should reduce the rivalry and exclusivity while promoting appropriate competition based.

In this paper we argue that current technological advancement allows technical means to encourage spectrum sharing and facilitate appropriate spectrum trading environment while addressing technical requirement of interference control. What is required is taking advantage of recently developed concepts in CR and DSA to facilitate a robust and versatile regulatory environment for spectrum management. The aim of this paper is not to provide or propose policy or regulatory prescripts, but to propose an economic and regulatory frameworks and to define a versatile architecture to allow regulators to adapt the progressive policy and regulatory prescripts already promulgated or to be promulgated depending on changing economic and socio-economic landscape as well as advancement in technology.

The remainder of the paper is organised as follows. Section 2 presents a perspective on RF spectrum chart, showing important areas and possible value with respect to usage. Sec-

tion 3 presents the dichotomy of spectrum efficiency from the economic and technical perspectives. Section 4 presents the state-of-the art technical interventions towards DSA. Section 5 presents the proposed cloud based spectrum manager (CBSM). Section 6 concludes the paper.

2. RADIO FREQUENCY SPECTRUM

Most popular RF bands are Very High Frequency (VHF), Ultra High Frequency (UHF) and Super High Frequency (SHF) ranging from 30 MHz to 30 GHz as shown in Figure 1. The popularity is even higher between 100 MHz and 6 GHz, where most commercial operations reside. The said popular spectrum has good characteristics, balancing geographic coverage and bandwidth capacity.

Frequencies below 600 MHz are suitable for narrowband applications. The main advantage of the spectrum below 600 MHz is the geographic coverage, which is the main determinant of its value. The spectrum range between 30 MHz to 600 MHz is predominantly used by Land mobile applications, Public Protection and Disaster Relief (PPDR), frequency modulation (FM) and television (TV) broadcasting. The value starts diminishing below 30 MHz due to high susceptibility to noise. However, due to its ability to cover long distances - across several countries and continents - the spectrum below 30 MHz has been attractive to amateur radio, short-wave and medium wave broadcasting, and long range navigation and communication in maritime and aviation. The advent of modern digital technologies is revitalising interest in this spectrum and all spectrum below 100 MHz for broadcasting and other narrow band applications, such as land mobile and broadcasting. However, it will always remain hard and costly to implement sharing in the lower bands without a good dynamic coordination. Appropriate coordinating tools will be able to make the lower bands suitable for public good, and improve its socio-economic value outlook.

Allocation of broadband access, broadcasting and other point-to-multipoint (PTMP) applications is predominantly between 600 MHz and 6 GHz making the range very attractive and suitable for spectrum sharing and carrier aggregation, as shown in Figure 1. Allocation of Microwave point-to-point (PTP) and some PTMP is predominantly above 6 GHz up to 40 GHz. There is a huge interest in spectrum bands higher than 30 GHz band for future wireless technologies and services. For example, there is world-wide interest to use 60 GHz in Extremely High Frequency (EHF) for data rates higher than 2 Gbits/s covering more than a kilometre. Frequencies between 70 GHz to 95 GHz are currently explored for PTP applications.

The above analysis show that RF spectrum is a broad continuum. Managing RF resources from a point of view of planning, interference control and licensing, as well as economic point of view, is very complex. RF spectrum regulatory processes include spectrum planning, assignment, licensing, interference control and enforcement. Spectrum planning involves allocation of spectrum to various services and allotment to type of users or technologies. Spectrum planning also includes channel arrangements and band clearance [3]. RF spectrum is policy related and should include technical and socio-economic considerations which form the basis for radio regulations. Therefore a regulatory coordinating tool will have to be modular and scalable to allow technical and economic considerations and ever changing socio-economic objectives.

3. ECONOMIC AND TECHNICAL EFFICIENCY ASPECTS OF RF SPECTRUM

The RF spectrum management issues go beyond engineering science and require economic aspects. The primary economic objective for any resource is to maximize the net benefits to society that can be generated from that resource. In spectrum management economic efficiency is achieved if redistribution and use of spectrum result in an increase in overall social welfare, achieving Pareto optimality.

From microeconomic point of view spectrum management models can be based on the concepts of exclusivity and rivalry [3]. Exclusivity is the degree in which a good can be restricted to only those who pay for it, while rivalry is the degree by which utilisation of a good by one individual diminishes the value for another individual. There is generally no reason to exclude if there is no rivalry, except for value preservation and creation.

The command-and-control regime tends to view spectrum as rival and excludable. The rival argument is backed up by the fact that as the number of users increase the number of spectrum bands available decreases and the potential for interference increases. The argument for exclusivity is based on the perceived requirement to guarantee exclusive access. The inability to diffuse the above arguments has primarily been due to "misunderstanding by some economist" of capabilities of new technologies and "misunderstanding by some engineers of flexibility of property rights and markets" or free market economy [4, 5].

Property rights regimes can support both market-based approaches and spectrum sharing regimes and vice-versa as argued in [3–5]. The economics of spectrum sharing in general are discussed in [6] and it is argued that successful spectrum sharing depends of property rights assigned, ensuring that each user is able to derive required value from the spectrum assigned. A new concept of property rights, fluid property rights, is proposed in [7] as a legal tool to facilitate new approaches in spectrum management. The fluid property rights concepts allow rivalry and exclusivity characteristics to be depicted in property rights bundles.

Reduction of rival and exclusivity is a function of economic, regulatory and technical considerations. Recent advancement in wireless technologies involving CR and software defined radio (SDR) has made DSA a reality. This in turn has a potential to address both economic and technical concerns, potentially remove a large degree of rivalry in the use of spectrum.

Table 1 attempt to map the current regulatory environment

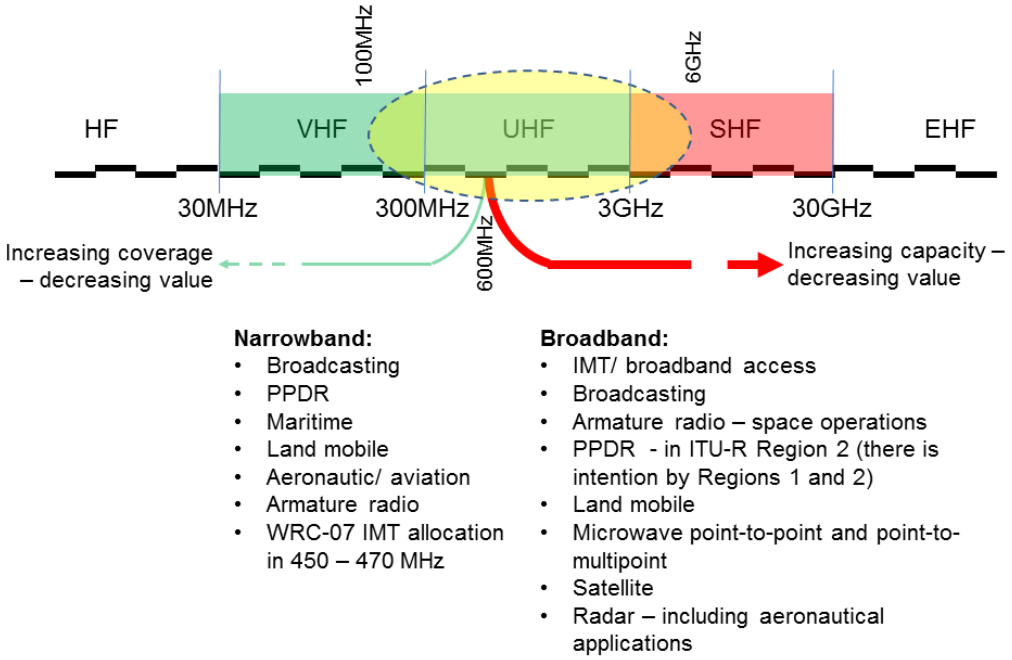

Figure 1: RF spectrum chart showing the most utilized bands which covers the upper part of VHF, the entire UHF and lower part of SHF, up to 6 GHz

on spectrum with economic consideration. Assignment for most broadband access spectrum, in particular International Mobile Telecommunications (IMT), is done on exclusive basis, making it Excludable good. With non-CR technologies it is hard to coordinate coexistence for different operators or services, creating a rival environment. Therefore IMT spectrum can be considered Private good in the current regulatory environment and without CR technologies. With CR technologies it is possible to reduce rivalry to a point where the IMT spectrum can be made a Club good. The same analysis applies to TV and FM radio broadcasting spectrum.

Aeronautical, maritime and PPDR RF spectrum is usually managed by the relevant communities involved and excludability is maintained within the community. There is generally no rivalry within the community. Therefore, the spectrum used can be considered Club good. However, usually each of these communities is very small and geographic areas covered are well designated and small, yet the protection tends to be too onerous leading to underutilisation of the spectrum.

Table 1: Current Spectrum Management Regime

	Excludable	**Non-Excludebale**
Rival	**Private Goods:** For example: Current licensing of IMT spectrum, TV and Radio Broadcasting Spectrum	**Common Goods** Spectrum commons such as Wi-Fi, point-to-point microwave
Non-rival	**Club Goods:** For example: Aeronautical, Maritime, Public Protection & Disaster Relief (PPDR) and other domain specific spectrum	**Public Goods** Currently no spectrum fits here

4. CURRENT TECHNICAL INTERVENTIONS

From the technical point of view, the evolution of wireless technologies towards SDR and CR are among the driving force towards efficient spectrum management and utilization. These technologies will also lead to the widespread deployments of cognitive radio networks (CRNs) which will enable the practical realization of DSA. Recent technological advancements towards the realization of CRNs and DSA includes the introduction of radio environment map (REM) [8, 9] and geo-location spectrum database (GLSDB) [10]. This section reviews recent technological interventions towards realization of DSA and efficient spectrum utilization.

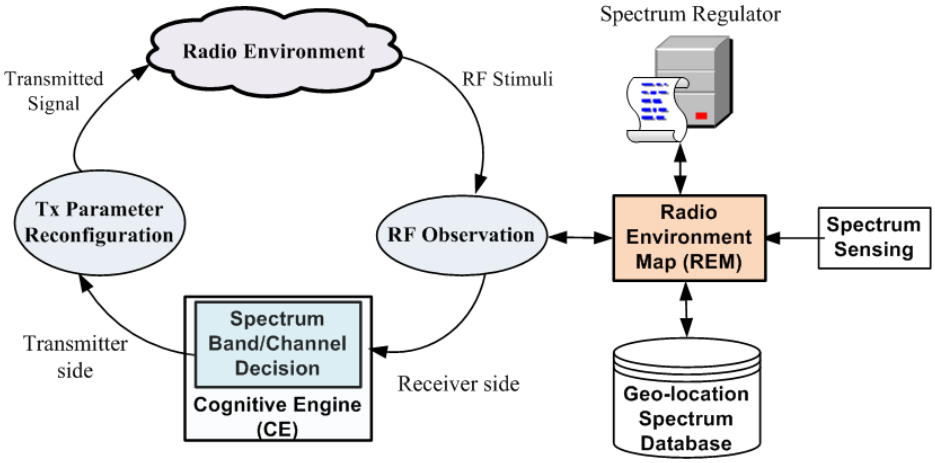

Figure 2: Cognitive cycle with integrated Radio Environment Map (REM)

4.1. Cognitive Radio Technology

An ideal CR is expected to be intelligent, self-aware, user-aware, and machine learning in order to change its transceiver parameters based on interaction with its external environment. CR is attractive due to its frequency agility which promises to address the inefficiency and scarcity of RF spectrum problems. The frequency agile CR allows DSA by secondary users to coexist with licensed users without causing interference. Practically, CR builds on the SDR architecture with added intelligence to learn from its operating environment and adapt to statistical variations in the input stimuli for efficient resource utilization. Furthermore, CR is expected to be RF aware for improved quality of service (QoS) and quality of information (QoI) which promises to bring a paradigm shift in spectrum management [11]. The ultimate goal of CR was to transform the radios from "blind executions" of predefined protocols to "radio-domain-aware" intelligent agents capable of delivering appropriate services [11]. Thus, in its original form, CR represents a much broader paradigm where many aspects of communication systems can be improved via cognition and reconfiguration.

CR technology provides powerful intelligent features to enable DSA using the *RF environment awareness*, *decision making* and *adaptation or reconfiguration* capabilities as shown in Figure 2. At the core of CR is a cognitive engine (CE), which is is responsible for reading the radio's meters (RF band observation), running some processing and algorithms (learning, optimization) and turning the radio's knobs (decisions, actions and orientation). Based on external environment, the CE will continuously adjust and reconfigure the parameters of the CR to some desired outcomes.

Recent advancements in CR technology allows the integration of cognitive cycle with supporting tools such as REM and GLSDB in addition to spectrum sensing in order to to fast-track the realization of CRNs. These advancements are due to ongoing challenges in finding optimal or practical wideband spectrum sensing schemes in CR technology [12]. Instead of limiting the spectrum opportunity identification or RF observation to spectrum sensing only, a combination of spectrum database and REM as well as spectrum regulations are included to the cognitive cycle. Based on the refined information from the REM, a CE can then make an informed decision on which channels and spectrum bands to access for interference free communications. After deciding on suitable spectrum, a CR will then reconfigure its transceiver to operate on the selected channel adhering to the rules of the regulator.

It is important to note that future wireless communication systems (such as fifth generation (5G) [13]) are expected to incorporate the CR functionalities. This means that CRNs will no longer be associated with secondary networks, but standard wireless networks with primary spectrum usage rights. This vision is supported in the recent study by Zander *et al.* [14] which found the commercial viability of secondary spectrum access unattractive for for most of the commercially interesting scenario in both business and technical perspective.

4.2. Geo-Location Spectrum Database

The concept of GLSDB became popular in the TV band which is one of the first spectrum bands to realize the implementation of CR technology. Its usage was mandated by some of the leading spectrum regulatory authorities such as the Federal Communications Commission (FCC) [15]. The key driver for GLSDB was to find a reliable and trusted mechanism to identify white spaces and to detect the onset of incumbents to a channel the is being used by secondary devices.

A spectrum database provides a repository of spectrum band incumbents or authorised licensees and uses such information to predict availability of unused spectrum or white spaces at a CR device location. The database then take into account the incumbents data (which includes transmit power, geographical location, usage status, antenna polarization, etc.) to compute and predict spectrum availability using RF propagation models [10]. The accuracy of a database de-

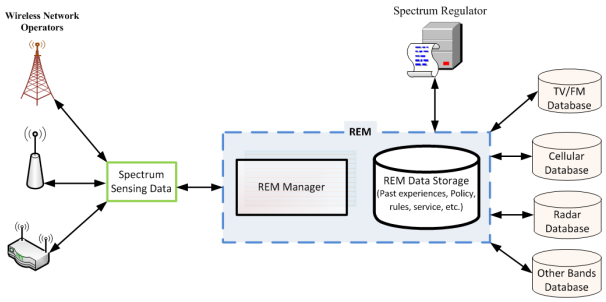

Figure 3: REM system built by integrating multiple band-specific databases, spectrum sensing data and regulation

pends on the reliability of incumbents data that is provided, in most cases, by the regulator as well as the validity of the RF propagation models used. Over the past few years, the accuracy of GLSDB and prediction of white space has been an open research question [16, 17]. Most of these literature found that field measurements remains the most reliable method for improving GLSDB accuracy. Thus, GLSDB which relies solely on RF propagation models have the high degree of inaccuracy when it comes to white space prediction than those which uses field spectrum measurements. However, building a GLSDB using field measurements is an expensive and lengthy exercise especially if one needs to cover wider geographical area [10]. As such, a combination of GLSDB and spectrum sensing promises to provide high level of accuracy when it comes to white space identification.Spectrum sensing becomes very useful when new incumbent transmitters are introduced in the field, or when the existing transmitter characteristics changes. Such combination can be achieve through a REM which is discussed in the next subsection.

4.3. Radio Environment Map

A REM is considered to be an enhancement of geo-location spectrum database (GLSDB) in order to realize a full functional DSA concept in CRNs. Unlike GLSDB, REM builds long-term knowledge map from real-time spectrum sensing data, band specific GLSDB, propagation environment, geographical terrain models and regulations [8]. In its simplest form, REM is built by integrating various band specific databases, spectrum sensing data, and national regulation. In this context, REM provides radio environment information in order to allow reliable spectrum access. It is viewed as a central database containing reliable information about the location of radio nodes, white spaces, national and local spectrum regulations, incumbents information (such as signal types, their location, activities, etc.), and history of past experiences [18].

A REM is typically deployed at the core CRN level, and can take the form of global or local REM [8]. Local REMs are mainly deployed to increase the response time and have lower processing capabilities compared to global REMs. The assumption is that every core CRN and their respective base stations (BS) or central node has some form of CE which communicates directly with the REM. This lessen the complex processing burden from the CR nodes by allowing REM to make some extensive processing [8].

4.4. Dynamic Broadcasting

Dynamic broadcasting allows the TV content to be flexibly transmitted using both broadcast and broadband networks in real-time and non-real time, and the broadcast network transmission parameters can by dynamically modified [19]. Dynamic broadcasting is easily realized in digital terrestrial TV (DTT) as opposed to the old analogue broadcasting. The efficient spectrum utilization of DTT makes it possible for broadband networks to broadcast TV content to a common DTT receiver (such as smart TV or set-top box).

While dynamic broadcast brings some level of flexibility in TV content transmission, it introduces new challenges for spectrum management [19]. These includes reconfiguration of multiplexers and transmission parameters, dynamic channel allocations. Such challenges can then be addressed through DSA and dynamic spectrum management. This will lead to optimal and efficient utilization of spectrum.

4.5. Towards 5G and Beyond

There is currently a move towards the development of 5G cellular networks which is viewed, by others, as the "convergence of evolved versions of current cellular networks with other complementary radio access technologies" which makes it a "network of networks" [13]. 5G networks are expected to use untapped mm-wave frequency spectrum in order to provide high aggregate capacity for many simultaneous users in licensed and unlicensed spectrum bands [20]. Among the vision of 5G is the co-existence of heterogeneous networks operating at different frequency bands using different air interfaces. Thus the vision is more on how to combine existing wireless technologies using advanced and efficient spectrum management techniques. Thus, our proposed CBSM is one of the solutions paving ways for efficient spectrum management for future wireless systems. It will allow spectrum regulators to dynamically manage existing and untapped frequency bands.

5. PROPOSED CLOUD BASED SPECTRUM MANAGER

The proposed Cloud Based Spectrum Manager (CBSM) is shown in Figure 4. The CBSM provides an end-to-end integration of existing and new spectrum management solutions to allow national spectrum regulatory authorities to automate the RF spectrum management function. It aims to leverage a number of recently developed technologies and techniques with the aim of advancing the RF spectrum regulatory environment.

At its core, the CBSM consists of five key components: 1) *Core Spectrum Manager Decision Engine (DE)*, 2) *RF Mon-*

Table 2: Mapping CBSM to regulatory processes

CBSM Based	Regulatory processes
Core Spectrum Manager Decision Engine	Spectrum allocation and assignment and workflow
RF Monitoring and Enforcement	Interference control and enforcement
Spectrum Brokerage Manager	Spectrum trading (currently not usual)
Spectrum Licensing Manager	Licensing and authorization
Spectrum Planning Workflow	Spectrum engineering

itoring and Enforcement, 3) *Spectrum Brokerage Manager*, 4) *Spectrum Licensing Manager*, and 5) *Spectrum Planning Workflow*. The spectrum planning workflow interfaces with a spectrum planning tool or tools owned by the regulatory agency or by a third party.

The CBSM interfaces with several networks through multiple REMs to obtain real time data on spectrum utilisation and to send commands and information for implementation of new policy and regulatory prescripts. A recently standardized Protocol for Accessing White Space (PAWS) [22] can be one of the suitable interfaces between the CBSM and REM. The CBSM also interfaces with band-specific GLSDBs which would typically consists of quasi-static allocation and assignment data. Examples include TVWS GLSDB and GLSDBs that would keep assignments for aeronautical and maritime. Specific and dynamic rules and regulatory elements for various bands and services could be implemented as for band/ service specific modules. A typical regulatory activity that could benefit from this feature is the clearing land mobile spectrum for security and emergency services. Another example is ability to dynamically switch spectrum usage based on some criteria. DSA is achieved by applying RF band specific regulations using real-time RF environment data sourced from GLSDBs and REMs. The CBSM should be able to facilitate spectrum brokerage based on surrender spectrum or utilisation spectrum. Interface to the operators will enable automation of licensing and authorisation processes. Table 2 maps the CBSM to regulatory processes. The next subsections provide detailed description for each of the key CBSM components.

5.1. Core Spectrum Manager Decision Engine (DE)

The decision engine (DE) is the main central nervous system of our proposed CBSM. This is where the advanced and dynamic spectrum management (DSM) intelligence sits. The core spectrum manager DE performs the actual DSA function. Other functions includes RF spectrum allocation, RF assignment and general spectrum administration which includes billing, security, authorizations, reporting, etc.

5.2. RF Monitoring and Enforcement

The RF Monitoring and Enforcement module is responsible for the policing of spectrum usage among the licensees and other spectrum users. It is also responsible for the resolution of complaints regarding technical issues and public safety. Technical issues involves interference control and management, spectrum sharing, co-existence management, and the concept of *use-it or lose-it*. The use-it or lose-it concept is a novel way towards efficient spectrum utilization, whereby license holders may lose portions of their spectrum if they are not using it for a certain period of time in a given geographic location. There are already technologies which performs most of these functions available in the market. Furthermore, the regulator can also decide to outsource some of these task to third party companies.

5.3. Spectrum Brokerage Manager

The main function of spectrum brokers is to control the amount of spectrum bandwidth and transmission power assigned to wireless operators in order to keep the desired quality of service and interference below the regulatory limits. An independent spectrum broker can act as an intermediary between a national spectrum regulator and players, and negotiates spectrum on their behalf of. The spectrum brokerage approach on the TV band was first proposed in Europe through the COGnitive radio systems for efficient sharing of TVWSs in EUropean context (COGEU) [21]. This creates the secondary spectrum market which is managed in the form of auctions. Similar spectrum brokerage approach can be applied in other RF spectrum bands to facilitate efficient secondary usage market.

5.4. Spectrum Licensing Manager

The spectrum licensing manager interfaces with the network operators or existing and potential spectrum users. It allows online application of spectrum license whereby potential spectrum users can apply or renew their short or long-term spectrum license online. The spectrum licensing manager also manages the type approval process, provides all licensing administration and has a graphic user interface which gives the regulators a full view of what is happen on the system in real-time.

5.5. Spectrum Planning Workflow

There are a number of commercial-of-the-shelf spectrum planning tool available in the market which the regulator may decide to own or outsource the such services. The spectrum planning workflow is crucial in spectrum license assignments since it invokes the spectrum planning tool which makes use of propagation modules to validate whether a license can be assigned for specific services and a given location. The spectrum planning process is automated with little human intervention.

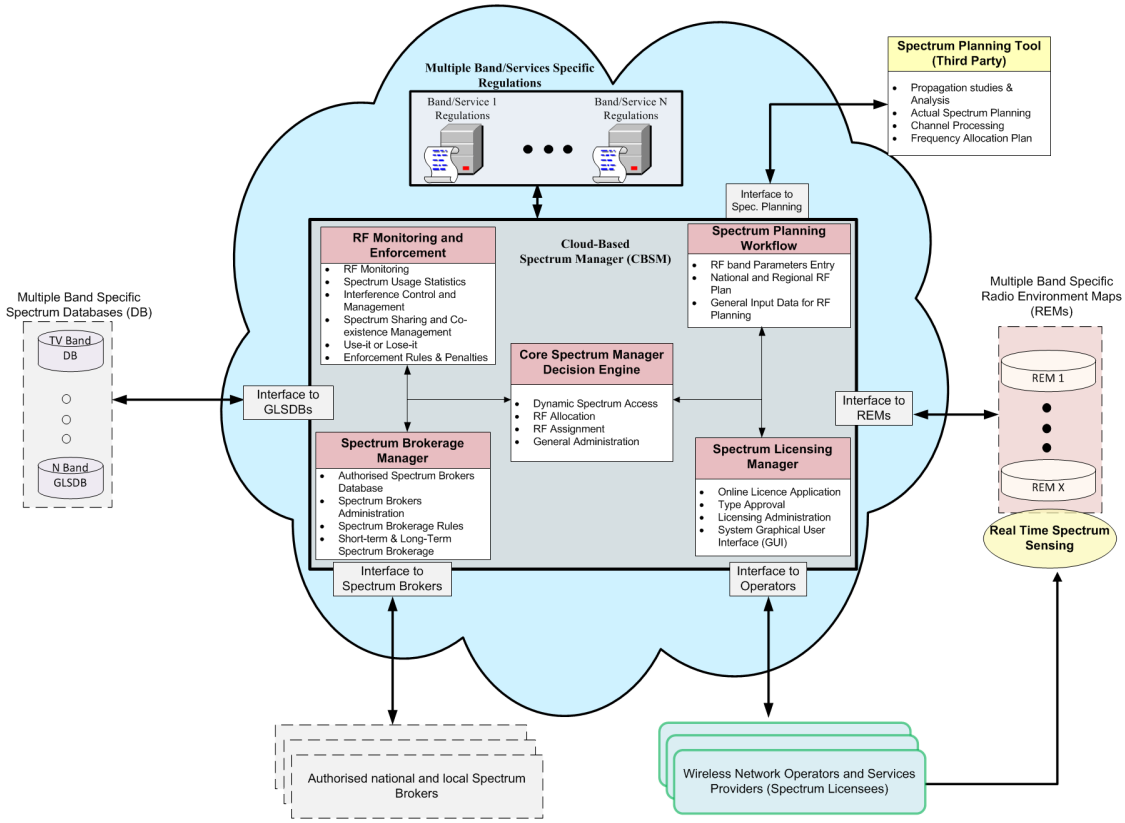

Figure 4: Conceptual view of cloud-based Spectrum Manager showing key building blocks

5.6. Interfaces

The CBSM supports a number of different interfaces with the external systems. Some of these interfaces are standardized, like the interface between a GLSDB and the CBSM or between GLSDB and the REM, whereas other interfaces might be proprietary. Interface to GLSDB is through the PAWS devices [22]. Interface to operators allows existing and potential spectrum users to interact with the CSBM system, for instances, when applying for spectrum license.

5.7. Unique features of CBSM

Table 3 provides a summary of key differences between our proposed CBSM with existing DSA technological solutions such as the REM and GLSDB. While CBSM provides regulatory intervention to spectrum management, REM and GLSDB provides a technological intervention to efficient spectrum management.

Table 3: Explicit Differences between CBSM and existing REM and GLSDB

Cloud Based Spectrum Manager	REM and GLSDB
Concerned with RF area sterilization	Assumes total cooperative environment between devices or operators
Global and long term interference control	Location based, immediate interference control
Scalable to cover the whole RF spectrum range	Quasi-static in specific bands such as TVWS (mainly GLSDB), whereas REM can address the quasi-static limitation
Policy and regulatory prescripts (e.g. Use-it or Lose-it policy)	Service and technology specific
Provides an integrated RF spectrum management workflow	Used as an enabler for CR network deployment
Focussed on regulatory processes (i.e. primary owner)	Network focussed - suitable for network operators or services providers

6. CONCLUSION

In the paper we have outlined, based on literature review, that in the current policy and regulatory framework spectrum remains predominately private good, which is rival and exclusive. This is despite technological advancement in CR and DSA, allowing sharing of spectrum. Current focus, using GLSDB and REMs, assume quasi-static and cooperative

environment. The focus is network-based and technology-based.

A regulatory focused approach can reduce rivalry and exclusivity and hence achieve Pareto optimality. We therefore propose a cloud based spectrum manager (CBSM) architecture focusing on regulatory processes and facilitating dynamic spectrum management in a DSA environment. Future work includes the development of CBSM from simulated environment to a small scale real-life or practical environment.

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SESSION 5

ADVANCES IN NETWORKS AND SERVICES II

S5.1 Seamless Mobility in Data Aware Networking.

S5.2 Proactive-caching based Information Centric Networking Architecture for Reliable Green Communication in Intelligent Transport System.*

S5.3 Network Failure Detection System for Traffic Control using Social Information in Large-Scale Disasters.*

SEAMLESS MOBILITY IN DATA AWARE NETWORKING

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ABSTRACT

The underlying networks (of the Internet) have been reworked to make way for new technologies, some serious inefficiencies and security problems have arisen. As a result, over the past years, fundamentally new network designs have taken shape and are being tested. In ITU Recommendation Y.3001 [1]*, four objectives are identified in line with the requirements for Future Network; one of them is data awareness. In ITU Recommandation Y.3033* [2]*, the 'Mobility' is addressed as one of the key problem spaces of data aware networking (DAN). This paper proposes Named-Node-Networking (3N), a novel architecture for DAN. We design a simulator (nnnSIM)* [3] *for evaluating our proposed 3N architecture which is the second major contribution of this paper. The nnnSIM simulator is written in C++ under the ns-3 framework* [4] *and has been made available as open-source software for the scientific community. Considering the importance of a unique DAN architecture, we propose a study for standardization work in the ITU as an initiative which can lead to its rapid adaptation.*

Keywords— Information Centric Networking; Mobile Communication; Named-Node Networking; 3N

1. INTRODUCTION

Real time mobile information retrieving and sharing throughout the network has continuously increased due to the explosion in use of multimedia capable mobile devices, such as smart phones, in people's daily life. Meanwhile, the current Internet's network architecture cannot handle the consumer's data exchange demand since it operates by a network attachment centric way, mapping each user through their IP addresses**.** One of the major goals of future network architecture is to be able to seamlessly retrieve content while moving.

Data aware networking (DAN) draws significant interest to the research community recently. In 2006, the concept of the content-centric networking (CCN) [5] is introduced. In CCN paradigm, the network layer provides with content instead of providing communication channel between hosts. In the Publish-Subscribe Internet Routing Paradigm (PSIRP) [6], Identifiers are defined in an information-centric manner and with the Publish-Subscribe internet architecture, Information Centric Networking (ICN) is explained which focuses on content rather than end point communication. In the context of our paper we use the terms DAN, CCN and ICN interchangeably.

In International Telecommunication Union (ITU) Recommendation Y.3033 [2], the overview of data aware networking (DAN) and its problem spaces are addressed precisely. In the document, three problem spaces are defined namely 1) Scalable and cost-efficient content distribution; 2) Mobility and 3) Disruption tolerance. The capabilities and benefits of DAN over conventional IP-based Internet Architecture are widely recognized [7][8]. In DAN, even though many scenarios have been analyzed, mobility support has not yet received enough attention despite wireless technologies being more widely adopted for Internet access. The common ICN technique of sending the desired content back through the breadcrumbs of the Interest route is challenging for the mobile user, since, while moving the access point may change before the user is able to satisfy their previous Interest. To address the issue, and with the objective of providing real-time mobility access, we are convinced that, in addition to naming the content, it is needed to assign names to the mobile nodes in a separate namespace. Our proposed scheme improves the way of information retrieval and addresses the mobility issue in ICN more efficiently. For evaluating performance, we simulate our proposal with nnnSIM in a scenario where the Mobile Node demands for live stream video service at various speeds. We compare our proposal with the Name Data Networking (NDN) [9] architecture. The simulation results showed the efficiency and feasibility of our proposed named-node based mobile ICN architecture.

The rest of the paper is organized as follows. In section 2 some related works are mentioned. In section 3, we focus on the standardization issue of ICN architectures. We explain our proposed Named-Node Networking architecture in section 4. We present the evaluation of our proposal through simulation in section 5. Finally, Section 6 concludes our paper and describes future work.

2. RELATED WORK

As early as 1982 in [10], the importance of network namespaces and the terminology that defines them is mentioned. This paper is considered a guideline to network naming and has been a fundamental point of consideration during the expansion of TCP/IP networks, eventually becoming RFC 1498 in 1993 [11]. In [12], authors proposed Opportunistic content pushing via Wi-Fi hotspots. In the work, the content delivery system predicts the routes of the roaming users and pre-locates the contents to Wi-Fi spots along their routes. However, their delivery scheme did not consider Wi-Fi spot conditions. In [13], the authors proposed proactive video caching scheme based on video popularity prediction. Authors use modeling tool, Latent Dirichlet Allocation, and frequent pattern mining algorithm, A priori. However the work doesn't cover user mobility. Selective Neighbor Caching is exploited for enhancing seamless mobility in ICN in [14]. In the proposal an optimal subset of neighbor proxies are selected as a prefetching destination of the content. The mobility behavior of users is considered to select the prospective neighbors. In [15], the authors proposed a proactive caching approach for seamless mobility support in NDN. Authors extend the NDN access routers with additional functionality such as prefetching and caching content items on behalf of the user. In [16] various approaches to achieve seamless mobility are proposed, however they all include restrictions on the ICN namespace, attempting to use Points of Attachment (PoA) names within the ICN namespace. This paper does not include any experiment data on the proposals. In [17] a new namespace and its associated functions is introduced between

IP and TCP in TCP/IP networks to attempt to create a clean service-level control / data plane split. The paper indirectly demonstrates some benefits of having a separate namespace between the service and network layers.

In our previous work [18], we proposed a proactive content caching. We propose a proactive content caching scheme utilizing transportation systems, specifically trains. In our system, we place content servers with CCN capability on a train and in every station. Segments of video contents are pre-cached by the station servers before trains arrive at stations. Trains receive the contents via high-speed wireless transport while they stop at the stations. We develop a prototype system based on IP and CCN Hybrid protocols. We evaluated its performance by field experiment and compared with traditional CDN scenarios using cellular networks. Evaluations concluded that our system could achieve high-speed and high-reliable video delivery without freezing.

3. ICN PROJECTS

Though ICN is in its infancy, it is candidate architecture for the future Internet. Currently, numerous projects are going on under the ICN theme. They vary in their design aspects. We cite here a few differences between major Information Centric Networking projects. In case of naming the content, CCN [5] uses hierarchical naming and PSIRP [6] uses flat naming. For security, CCN needs to trust signing key to establish integrity, where in case of PSIRP it is self- certifying. For name resolution and routing, name based routing using longest prefix of hierarchical names is used in CCN. On the other hand, a rendezvous function is used, within a specified scope to solve the issue in PIRSP. For transport and caching, CCN transport using named based routing; finds cached object through local search as well as on the path to the publisher. For PIRSP, transport routing and forwarding use separate forwarding identifier. The Data-Oriented Network Architecture (DONA) project [19] argues for a redesign of the current Internet name resolution system to achieve an ICN, leveraging TCP/IP functioning protocols and routing. Network of Information (NetInf) [20] concentrates more on the naming of content, content searching and network transport issues related to ICNs. This ICN distinguishes itself for using a multilevel distributed hash table (DHT) for routing and name resolution. A final example, NDN [9] attempts to completely redesign the Internet by replacing the current IP network layer with content chunks as the universal component of transport.

Though some points like naming, security, etc. deserve early initiative of standardization, the interest of this article is on standardization issues of a common architecture of ICN which support seamless mobility. Mobility is one of the key areas where conventional ICN architecture is still struggling. In this paper we propose a DAN architecture which can ensure seamless mobility. At present there is no unique standard for a DAN architecture. Therefore early initiatives of ITU will significantly contribute in the maturation process of the DAN architecture as well as architecture for the Future Internet.

4. PROPOSED NAMED-NODE NETWORKING ARCHITECTURE

4.1. Basic Principle

We try to use a more fundamental way to solve the mobility problem in ICN. We propose adding two new completely independent namespaces to the ICN network layer.

We maintain ICN's standard content naming namespace without any modifications to its structure. To avoid confusion between network layers and namespaces, we rename the namespace used to name content the Service namespace. The Service namespace is used to identify content or services that run within the network. These services run on top of nodes, which are identified by the Node name namespace. Names belonging to the Service namespace will be referred to as ICN names.

The Node name namespace is specifically created to name nodes participating in an ICN. Names belonging to this namespace will be called 3N names. This namespace complies with the requirements for being a metrizable topological space. This implies that names that are desired to be logically close, determined by a particular distance function, continue to be proportionally close to each other in any particular namespace mapping. The simplest type namespace that fits this requirement is a metrizable hierarchical namespace and is the one we use in our examples. The Node name namespace consists of a single, complex, multi-level structure into which all 3N names fit. The namespace is organized starting from a single root into which sectors are placed. Each sector can contain either individual 3N names or more specific sub-sectors. The name partitioning scheme used for a network will depend greatly on the network's physical distribution and its scale. We do not imagine any particular limit for the partitioning as long as topologically significant naming can be maintained. The Node name namespace will act as a level of indirection for the Service namespace and PoA namespace.

The PoA namespace consists of the names typically used by physical interfaces to identify themselves, such as the common Ethernet MAC address. Names belonging to this namespace will be referred to as PoA names.

With this new naming structure, a mobile node will get its 3N name from an edge node to which the mobile node is physically linked by any available medium. By getting a 3N name and having the network maintain updated mappings between the three defined namespaces, the mobile node can be reached, regardless of its current location as long as only one mapping at a time is changed. For instance, if a content packet returns from a content store, the content router finds the node's 3N name, checks the mappings for any updates and then uses the updated 3N name to reach its destination.

The network elements we consider are Mobile Nodes (MN), Content Routers (CR), Edge Nodes (EdgeN), which are CRs to which serve as gateways for clients joining the network and Content Providers (CP). All nodes using the 3N architecture have a Node Name Signature Table (NNST) that records the PoA names, the lease time for the 3N name and the 3N name that neighbor nodes were given when enrolling into the network. Thus the NNST maintains the 3N name to PoA name mapping. Each node in the 3N network architecture also has a structure called the Node Name Pairs Table (NNPT) that keeps records of pairs of old 3N names given by an EdgeN and the new 3N name given by a different EdgeN to an enrolled node. The NNPT thus maintains an updated 3N name to 3N name mapping. Any node enrolled into the 3N architecture can be delegated to generate 3N names for newly enrolling nodes. In the case of MN, the 3N names given will always come from an EdgeN.

In section 4.2 we explain the Protocol Data Units (PDUs) used in the architecture. From section 4.2.1 to 4.2.4, we briefly explain how a MN enrolls into the 3N architecture for the first time to obtain its own 3N name, how the MN reenrolls when it moves into a new sector and how, once a MN obtains its 3N name, the network will use the 3N name, the NNST and the NNPT to ensure real-time communication.

4.2. Protocol Data Units (PDUs)

To realize our network architecture, we create a set of Protocol Data Units (PDUs) that we describe in more detail in Table 1. We distinguish between 2 particular types of PDUs: data transmission

PDUs and mechanism PDUs. Data transmissions PDUs are encapsulating PDUs that carry information from ICN applications to other nodes using the 3N architecture. These PDUs can be manipulated, for example by direction, speed or delay by the ICN layer. Mechanism PDUs are PDUs whose function is to directly manipulate the ICN network layer, to get it to act in a particular way. All of the protocols in the 3N architecture are timer-based protocols as described in [21] to maintain protocol states and minimize PDU exchanges. The PDU types are shown in Table 1.

Table 1. PDU Types

PDU Types	
Data Transmission PDUs	
SO	Includes only Source node's 3N name
DO	Includes only Destination node's 3N name
Mechanism PDUs	
EN	Enrolls node into a sector
OEN	Offers a name to an enrolling node
AEN	Acknowledges the enrollment of a node into a sector
REN	Reenrolls a node into a new sector while the node still has a valid 3N name
DEN	Disenrolls a node from a sector
ADEN	Acknowledges the disenrollment of a node from a sector
INF	Informs sectors about nodes obtaining new 3N names

4.2.1 Enrollment mechanism

This mechanism describes how a MN with no 3N name enrolls into the network. The complete process is shown in the flowchart in Figure 1

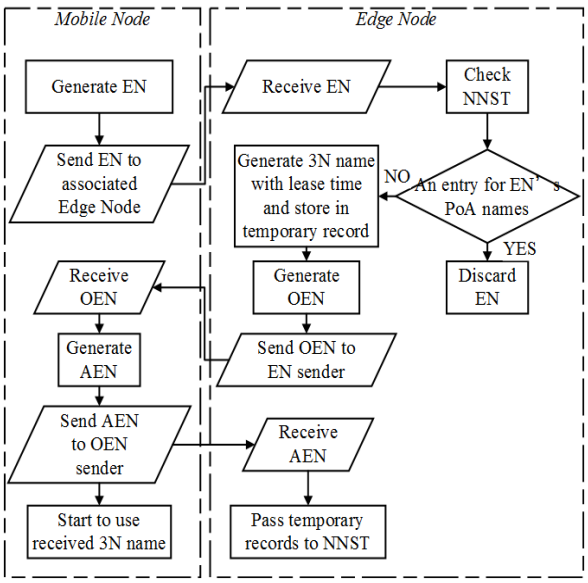

Figure 1. Enrollment procedure

The procedure for enrollment is not unlike TCP/IP's Dynamic Host Configuration Protocol (DHCP) specification [22]. The main differences are that we use timer-based protocols and that any device enrolling into a sector will obtain one single 3N name, regardless of the number of interfaces the device is capable of using. This is done by making sure that the authorizing CR receives all the possible PoA names the device can use when generating the EN PDU. In broadcast mediums, such as in any wireless type connection, this is of extreme importance in ensuring real-time communication.

4.2.2 Reenrollment mechanism

This mechanism describes how a MN that is changing sector and has a 3N name reenrolls into the network. The complete process is shown in the flowchart in Figure 2.

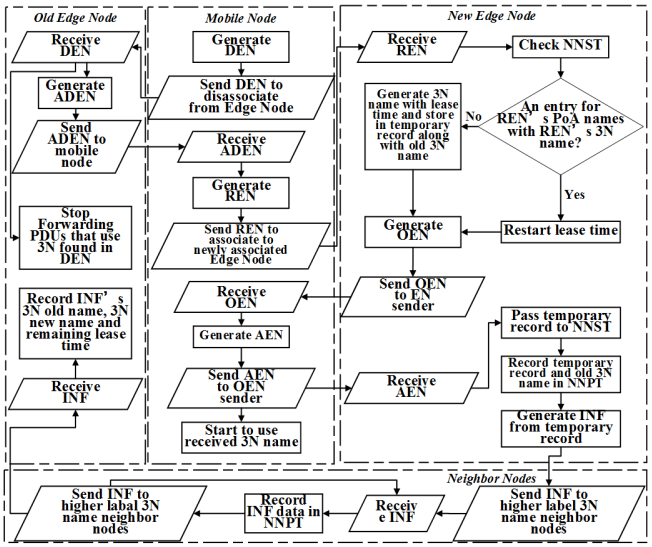

Figure 2. Reenrollment procedure

When the MN is about to disassociate from a sector, it pushes a DEN PDU. What this PDU does is inform the authorizing EdgeN that the MN will no longer belong to this sector. This allows the EdgeN to also create a buffer for the MN's 3N name for as long as the initial 3N name lease was given. The 3N name is not unbound at this point. The MN waits for the EdgeN to give an acknowledgement for the DEN via an ADEN to ensure that the network is aware of the mobile status of the MN. Once the MN obtains the acknowledgement, it can start looking for another EdgeN. If an MN does not push a DEN or doesn't wait for the ADEN, there is no way to ensure mobility. The decision to forgo mobility is up to the MN.

As soon as the MN finds another EdgeN and associates to it successfully, it pushes a REN PDU which includes its PoA names, the 3N name that it had in the previous sector and the remaining lease time for that name. The EdgeN, much like in the enrollment procedure, offers the MN a new 3N name, supplanting the MN's old 3N name. When this 3N name is acknowledged by the MN, the EdgeN then creates an INF PDU which is sent to the EdgeN that authorized the old 3N name.

The INF PDU is then routed throughout the network in order to reach the EdgeN that authorized the old 3N name. All nodes in the network that see the INF PDU, use the data contained to update the NNPT so that you have an updated 3N name to 3N name mapping. If any of these intermediate nodes come across a PDU whose destination is the old 3N name, they can rewrite the PDU and route the PDU using the information in the NNPT.

When the INF PDU finally reaches the EdgeN that authorized the old 3N name, the buffer created on that node is flushed, rewriting all PDUs with the new mapping, ensuring that the MN's movement loses as little time as possible retransmitting PDUs.

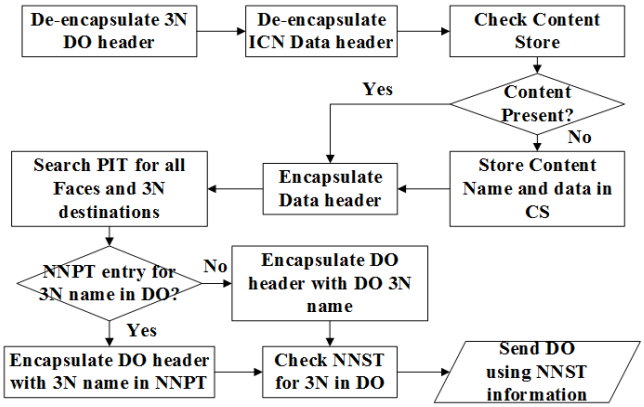

Figure 3. Content receiving process with DO PDU

4.2.3 Content solicitation process

The solicitation of a particular content follows the same process as transmission of Interest packets described in [5] with two modifications. First, all Interest packets are now encapsulated in SO PDUs when the node is mobile. Second, in the moment that the ICN aggregates the Interest incoming Face data, it also aggregates the 3N names the CR has seen in SO PDUs. Due to using a metrizable hierarchical namespace, this aggregation for 3N names is easily accomplished.

In a similar fashion, when the producer is mobile, Interest packets are sent in DO PDUs so that the mobile node can be located. This can only be done if the producer has at some point sent a Data packet in a SO PDU, signaling to consumers its location within the network.

4.2.4 Content receiving process

If the MN has no movement, the receiving process is exactly the same as the Pending Interest Table (PIT) based Data packet return in ICN [5].

When the MN is a consumer, then all Data packets received will be encapsulated in DO PDUs. If the MN has changed sector during it's time in the network, the 3N name included in the DO PDU is used to check the route to take. In a normal ICN, the PIT would be the final arbiter for routing. In the 3N architecture, the PIT has 3N names aggregated, meaning that we know the 3N source names. Since we are using DO PDUs, we also know where the PDU is headed. In this case we check the PIT, then check the NNPT for 3N name updates. If there is an entry in the NNPT, we use the obtained 3N name to pick the closest route to take by reading the NNST. Due to the fact that we are overriding the PIT's decision, we may find that we are sending a DO PDU through a route that has no prior PIT entry. In this case, the NNST becomes the final arbiter. Whether the CR proactively caches the Data packet is up to the network configuration. We assume proactive caching is beneficial in these cases. This process is briefly summarized in Figure 3.

In the case the MN is a producer, consumers tied to this producer would receive Data packets encapsulated in SO PDUs. The 3N name in the SO PDU would then be used to locate the producer.

5. RESULTS AND DISCUSSIONS

We simulate our proposed 3N architecture for ICN with nnnSIM (Lopez, 2015). Like NDN's simulator, ndnSIM (Afanasyev, Moiseenko, & Zhang, 2012), our simulator is a ns-3 (ns-3 Developers, 2015) module that implements our network architecture. The soundness of our proposed architecture is analyzed for the scenario where user on MN requires for live stream video service while moving. To ensure the quality of live stream video delivery, the Interest generation rate of MN should be equal to video bit rate divided by data payload size which is set as 1024 Bytes. We simulate for the tree topology in Figure 4.

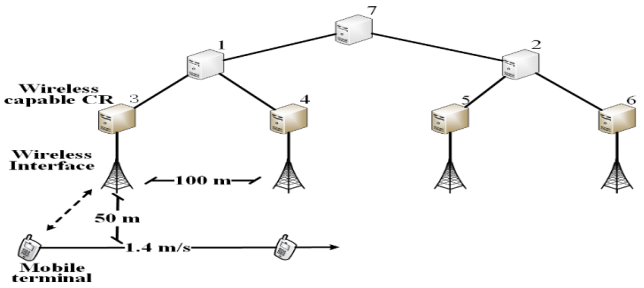

Figure 4. Simulation topology

Table 2 displays all the important simulation parameters. We also defined a default latency metric of 500ms for the delay-sensitive traffic to represent associated servicing requirements.

From previous papers we knew that standard ICN forwarding strategies were relatively good at consumer mobility, although they came with an elevated network resource cost [24] [25]. In [26], the authors propose for ICN forwarding strategies to maintain a stateful forwarding plane in order to reduce network resource use and improve forwarding without having to manipulate what we have called the Service namespace or greatly modify the standard ICN architecture. Their work was implemented in ndnSIM as Smart-Flooding and demonstrated clear improvements when compared to standard ICN flooding. Due to Smart-Flooding's properties we decided to test our 3N architecture against NDN Smart-Flooding.

Table 2. Simulation parameters

Simulation parameters	
Simulation time	(400 m / Mobile node speed) + 10s
Mobile node speed	1.4, 2.8, 5.6, 7, 8.4, 11.2 m/s
Bandwidth / Link capacity (wired)	100 Mbps
Link delay (wired)	1 ms
Link delay (wireless)	Constant Speed Propagation Three Log Distance Propagation Nakagami Propagation
Video bit rate	1200kbit/s
Interest packet generation rate	148 /s
Interest retransmit timer	50 ms
3N name lease time	300s
Forwarding strategy	Smart-Flooding
Content store size	10 million objects

All Wi-Fi capable CRs have wireless interfaces. All nodes have the standard Forwarding Information Base (FIB), Content Store (CS) and PIT [5] with the capability of turning on and off the 3N architecture components, the NNST, NNPT and the 3N name aggregation functions in the modified PIT. When all the 3N architecture components are turned off, the network works exactly like a NDN Smart-Flooding based architecture. We chose to set the CS at 10 million objects with a cache object eviction policy of Least Recently Used (LRU). All wireless interfaces have the ns-3 default settings and are separated from each other by a distance of

100 meters. The wired connection between the CRs is done via Point to Point links.

The mobile terminal has one wireless interface which it uses to connect to the network and is always 50 meters away perpendicularly from the Wi-Fi capable nodes and moves horizontally. We created and implemented a simple Received Signal Strength Indicator (RSSI) based EdgeN switch procedure that is based on distance. This procedure basically checks when the mobile terminal has moved 100 meters. When that timer has fired, the mobile terminal checks and changes to the Wi-Fi capable EdgeN who scores the highest with our RSSI based calculation. The use of our mechanism PDUs is put into play using only the information of when the Wi-Fi associates or disassociates from an EdgeN. There are better handoff and EdgeN switching procedures that could be implemented, however we wished to test our naming strategy and mechanism PDUs in a way that didn't require information leveraging from the wireless medium.

For our simulation the MN searches for a better EdgeN 4 times. This does not mean that the MN actually changes EdgeN 4 times as it could be possible that, at the given moment of EdgeN selection, the EdgeN to which the MN is already associated can be chosen. This method of EdgeN selection was favored for its simplicity. One interesting property of this selection method is that the MN could be associated with the first EdgeN in our simulation and then associates with a EdgeN that is on a different branch of the network distribution used. This would cause a huge delay for Data because the other network branch would have not seen any traffic and have nothing in its CS. Due to having connected to a network branch with no prior traffic the transmission would have to make a round trip to the server a second time. Interest retransmission from the MN becomes required and that only happens when the initial Interest retransmission time has been met. This would also have an impact on the MN's average data rate. In the 3N architecture, the notification of the MN's movement is expected to alleviate this delay.

We run two scenarios on this network distribution. In the first scenario we test out consumer mobility by placing an ICN Producer on node 7 and the ICN Consumer on the mobile terminal. In the second scenario we test out producer mobility by exchanging where we install the ICN Producer and Consumer. This means that for the second scenario, the ICN Producer is on the mobile terminal and the ICN Consumer is on node 7. We run both scenarios for the mobile terminal moving at 1.4, 2.8, 5.6, 7.0, 8.4, 9.8 and 11.2 m/s.

We evaluated the following performance metrics in our simulation.

Delay experienced by the consumer: For the goal of seamless mobile communication, network delay is a key metric. The average values for consumer mobility in Figure 5 show that the naming scheme used in out 3N architecture outperforms NDN Smart-Flooding. In the case of a consumer with a mobile producer, as shown in Figure 6, demonstrates that producer mobility would not be a hindrance for consumers as the delay is kept very well within tolerable levels when using the 3N architecture.

Average data rate experienced by consumer: The average data rate by the consumer, both when it is mobile and when the producer is mobile is a key metric to ensure a pleasant content viewing experience. As is shown in Figure 7, the data rate is affected by movement by how the MN associates to EdgeN. The faster a MN moves, the less times it may change its associated EdgeN but the more likely that the newly associated EdgeN is topologically distant from the prior EdgeN. It is however clear from Figure 7, that the 3N architecture outperforms NDN Smart-Flooding for consumer mobility even though it suffers proportionally from the EdgeN changes. In the case of producer mobility, shown in Figure 8, the 3N architecture far outperforms NDN Smart-Flooding and demonstrates an almost uniform data rate, making producer mobility completely possible while using the 3N architecture.

Average PDU percentage loss: The 500 ms delay sensitive cut-off point for sensitive real-time data demonstrates how the 3N architecture far outperforms NDN Smart-Flooding, both in consumer mobility, as shown in Figure 9 and in consumers with mobile producers, as shown in Figure 10. In both cases, the graph shows that the 3N architecture has a very low PDU loss throughout the whole scenario. The PDU percentage loss for NDN Smart-Flooding in consumer mobility is completely tolerable, but in producer mobility, even with a producer at walking speed you get a 3% PDU loss. The figures also hints to the importance of when a change of EdgeN occurs and how topologically distant the new EdgeN is compared to the prior one. Leveraging this information from the wireless medium would definitely improve both NDN's PDU loss as well as 3N architecture's PDU loss. However without this leveraging, it is clear that the 3N architecture alleviates this lack of information.

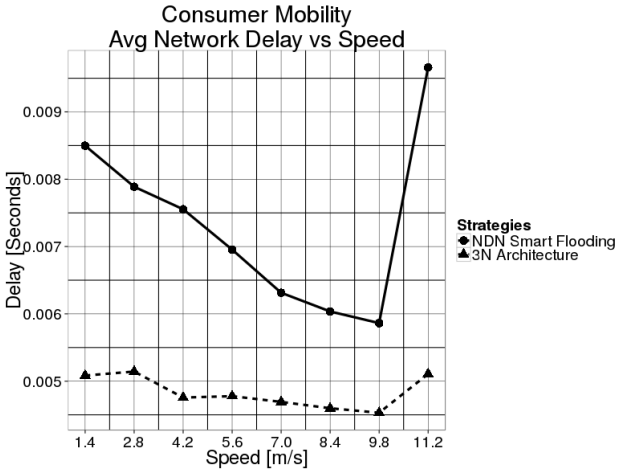

Figure 5. Consumer mobility - Delay vs Speed

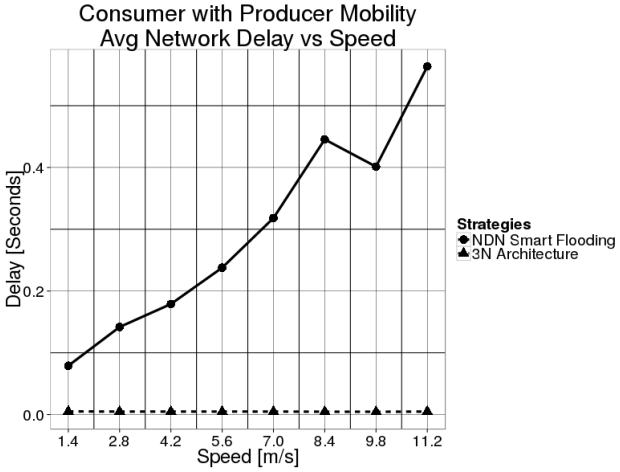

Figure 6. Producer mobility - Delay vs Speed

6. CONCLUSIONS AND FUTURE WORK

In the conventional ICN architecture, routing uses the Service namespace which is directly associated to the Face ID which is completely node local name. Thus it is evident that a mobile node that lacks an identifier cannot be found if it changes its physical location. There exists no particular method to deal with a nameless object. As mobile terminals are dominating as the named data

object (NDO) access device, in the revised draft of (ITU-T, ITU-T Y.3033 Recommendation, 2014) it is requested to have functions to easily support mobile consumers attempting to access NDOs without stress. In particular, streaming, which is already a major service in current mobile communication, needs a smooth roaming mechanism. NDO consumer mobility should be inherently supported. In addition a mobility support function for producers support is requested.

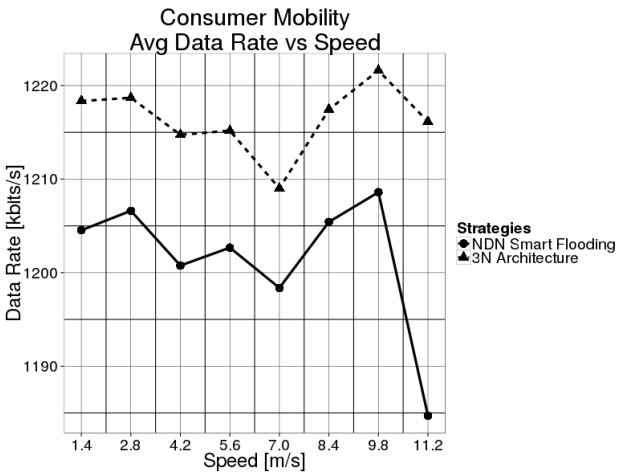

Figure 7. Consumer mobility - Data rate vs Speed

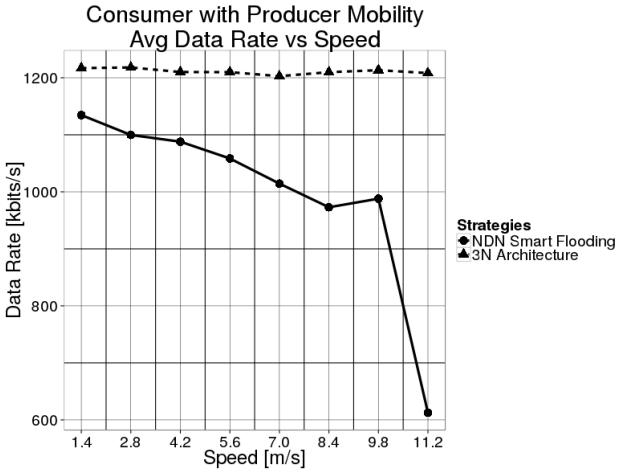

Figure 8. Producer mobility - Data rate vs Speed

To address these ITU-R recommendations, in this article, we propose the Named-Node-Networking (3N) architecture for Mobile Information Centric Networking, describing the basic PDUs and mechanisms required to drastically improve mobility. In addition to naming a data object, the metrizable topological naming of mobile terminals is proposed. This method permits flexibility without modifying or restricting ICN names and is completely independent of the data transmission medium used. It is evident that a mobile node that lacks an identifier cannot be easily located after it changes its point of attachment. We also design a simulator (nnnSIM) for evaluating our proposed 3N architecture. The nnnSIM simulator is written in C++ under the ns-3 framework and we have made the simulator available as open-source software for the scientific community. Considering the importance of a unique DAN architecture, we propose a study for standardization work in the ITU as an initiative which can lead to its rapid adaptation.

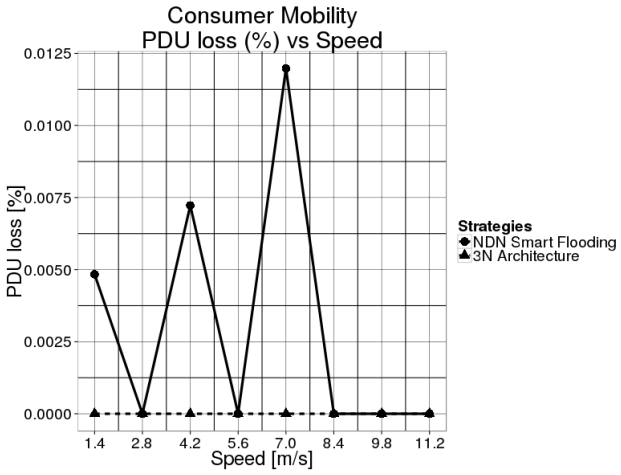

Figure 9. Consumer mobility - PDU loss (%) vs Speed

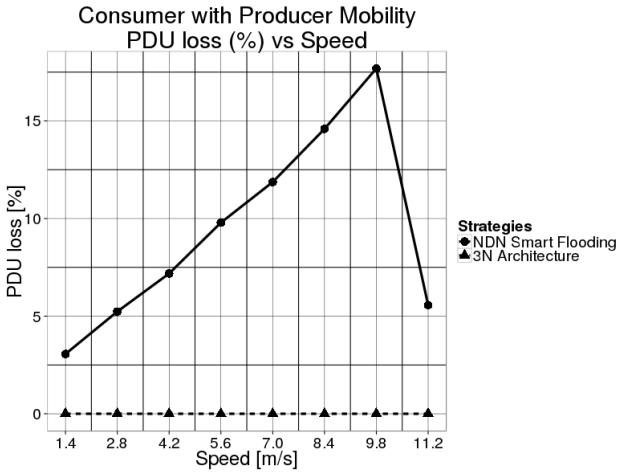

Figure 10. Producer Mobility - PDU loss (%) vs Speed

The integration of a network naming scheme of global scope is a laborious task. As the TCP/IP standardization procedure has shown, it is a task with many issues [27]. Part of the initial advantages of an ICN was the fact that we could do without a complicated naming structure, keeping only one global namespace. The choice of a simple scenario for simulation was done to demonstrate that even in the simplest of mobile scenarios, the unmanaged single namespace advantage does not hold. The simple symmetric network distribution with one mobile node moving in one direction shows that even a stateful ICN has issues, particularly if support for provider mobility is desired. We believe that the results show that a DAN, and any type of mobile network, is in need of a namespace to provide indirection when a node is mobile. The results show that this type of network naming architecture is worth further investigation.

As a scope of future work, we will do more extensive simulation to evaluate the performance of other applications like VoIP, HD Video Delivery etc. The implementation of this architecture under more practical network distribution settings will also be required. Among the tests that should be made is the leveraging of the ICN layer's underlying handoff information, the use of a heterogeneous network and multiple and more complicated MN mobility with background traffic.

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This paper is a research achievement by authors at Waseda University.

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PROACTIVE-CACHING BASED INFORMATION CENTRIC NETWORKING ARCHITECTURE FOR RELIABLE GREEN COMMUNICATION IN INTELLIGENT TRANSPORT SYSTEM

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ABSTRACT

In this article, we construct a concrete model as the prototype of efficient and reliable wireless Information Centric Networking (ICN) within the context of Intelligent Transport System (ITS). This research proposes a novel proactive-caching technique in ICN providing the robust and effective content delivery to the mobile nodes (commuters) for transportation system and fitting numerous ICN mobility scenarios of transportation system thanks to our "smart scheduler". We also propose a wireless ICN architecture which can adapt the power consumption of network nodes to the actual values of their optimized utilizations for greening the transportation communication network. Moreover, we identify that there are currently various ICN-based models and emphasize the need of an official international standard for wireless communication in general and transportation system in particular. Then by evaluating our proposal, we show that our proposal is a promising and feasible contribution for the ITU standardization process of Data Aware Networking (DAN) by integrating Green networking into DAN to combine the benefits of innovated rate-adaptivity and proactive-caching based schemes for achieving highly scalable, reliable and energy-efficient network performance in future transportation Information-centric communication system with data-awareness.

Keywords—Data Aware Networking (DAN), Information Centric Networking (ICN), Standardization, Intelligent Transportation Systems (ITS), Green Networking, Next Generation Mobile Communication.

1. INTRODUCTION

Information-Centric Networking (ICN) [1][2] has drawn substantial consideration over past few years and become a pioneer for the Future Internet architecture by deploying extensive cache structure to distribute and deliver information.

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Although ICN will bring a lot of benefits for all the stakeholders, better support for mobility and especially for the scope of location and content, supporting smooth connection in ICN mobility is still a problem and ICN mobility concern has not been received adequate exploration, despite of the fact that wireless technology is becoming more and more popular for Internet users to get information/data. This problem becomes more challenging for mobile user in the case of wireless communication in transportation system because the period of time a transportation vehicle stops at a station is relatively short, then the Point of Attachment (PoA) may be changed before the content user gets satisfied content data.

In ITU documentations, the concept of ICN is stated and reflected as Data Aware Networking (DAN) for future networks [3]. Then, in order to address the DAN architecture's mobility problem and enhance the reliability along with efficiency of DAN in case of transportation systems' wireless access, the aim of our work is building a proactive-cache based flexible DAN architecture to support the seamless wireless communication with energy saving for the Intelligent Transport System (ITS).

By considering the different practical scenarios to prevent possible unnecessary content traffic and reduce congestion as well as low-cost feature of Wi-Fi technology, we believe our proposal can become a feasible and efficient pioneer solution to ITU DAN standardization for utilizing in transportation industry.

2. RELATED WORK

Nowadays, mobility content access in real time has become a challenging issue due to bandwidth limitation and exponential Internet growth.

Pre-caching/proactive caching is recognized as one of the major schemes to reduce the response time, latency and enhance the user experience. Regarding the proactive caching approaches for mobility, a selective neighbor caching (SNC) scheme is stated in [4] to reduce signaling overhead and handover delay in WLAN. The authors introduced a predefined threshold value of handoff probability considering handoff frequencies between APs (Access Points) to select neighbor APs for their SNC model. Another selective neighbor caching scheme is

exploited for enhancing seamless mobility in ICN as defined in [5]. In the proposal, an optimized subset of neighbor proxies are selected as a pre-fetching destination of the content and the mobility behavior of users is considered to select the prospective neighbors.

For Green networking, Adaptive Link Rate (ALR)[6] is one of the well-known techniques to reduce the power consumption of network systems by dynamically varying link rate to its utilization, hence response to link utilization quickly. A real-time hardware-prototype ALR system is implemented and analyzed in [7] as a practical way to evaluate the real-time performance of ALR, instead of simulation. Though ALR technique is mainly applied to IP-based architecture at this moment, we consider its novel working mechanism is also useful for the future Internet architecture (ICN) by adapting network links to a rate which is proportional to the content interest traffic to save energy as our previous work for wired-connection network model [8].

To the best of our knowledge, this proposal is a pioneer work which integrate the benefit of Green networking into ICN by utilizing our novel rate-adaptivity and proactive-caching based schemes to offer content users more reliable and effective Information and Communication Systems (ICS) when they travel with public transportation.

3. VARIOUS ICN MODELS AND RESEARCH MOTIVATION FOR TRANSPORTATION COMMUNICATION STANDARDIZATION IN DAN

Currently, there are multiple recent works based on state-of-the-art ICN to realize the innovated mechanism of Information-Centric Internet for the Future Internet (FI) architecture.

However, our proposal is mainly based on NDN (Named Data Networking) prototype since NDN is considered as the only architecture among these models that possesses the backward-compatible capability [1][9]. NDN also provides data integrity and authentication verification. In addition, NDN has a hourglass architecture with Content chunk layer as a "narrow waist" and top layers focus on streaming services rather than HTTP as in IP-based architecture. This matches the mobile users' growing content interest demand tendency of interactive services via their mobile devices, in case of transportation system.

In this paper, we state the railway/train system for the case of ITS because of following reasons: Firstly, nowadays, train is considered as a popular public transportation vehicle especially in urban areas and big cities, e.g. Tokyo, London, Moscow, etc. because of its positive characteristics including punctuality and convenience. Besides, train's commuters have high tendency to use their mobile devices for getting their interested information/content from Internet during the period of time which they spend on train. Better still, the motion of a commuter can be predicted from the path of a train line and the moving direction, stopping time at a specific station along with the moving time between two different stations can be pre-determined in the normal case (relatively fixed schedule).

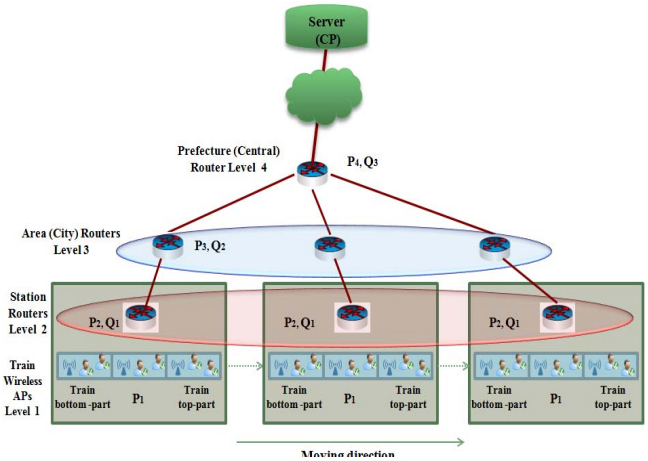

Fig. 1 Proposed network topology for ITS

In fact, some previous researches also deal with mobility issues of mobile nodes in transportation system. For example, the authors of [10] proposed a commuter router infrastructure for public transportation system, but their scheme is mainly equipping additional routers with store-and-forward rather than maintaining an uninterrupted connection via Internet. The "PUll and SHare (PUSH)" model is presented in [11] for the case of collaboration between users for content sharing based on a peer-to-peer (P2P) scheme to deliver video content. Its objective is to improve user's Quality of Experience (QoE) under expected periods of disruption, in case of commuter trains.

However, this article is different from the above researches as we focus on both cost-efficiency (low energy consumption) and reliability perspective of wireless communication, as a practical approach in order to address and solve the key problem spaces of DAN, namely: scalable, cost-efficient content distribution, mobility and disruption tolerance as identified in ITU Recommendation Y.3033 [3]. The simulation results in ndnSIM corroborate our proposal efficiency by diminishing the delay time substantially for supporting seamless wireless communications and save about 20% energy consumption compared to conventional ICN model (NDN design).

Thus, we do believe that our proposal is a promising and feasible contribution for the ongoing ITU standardization process of Data Aware Networking (DAN), which will lead to significant impact for the prevalent large-scale deployment of making ICN (DAN) as our next Internet architecture in the near future with lower energy consumption.

4. PROPOSED GREEN ICN TRANSPORTATION MODEL AND ITS WORKING MECHANISM

4.1. Communication Topology and Assumptions

Our ICN system topology design for railway/train transportation communication system is shown in Fig. 1. We propose a 5-level tree based network topology including of a server as a root node and distinguished Content Routers (CRs) accompanying Wireless Access Point

(Wireless APs) belong to remaining levels. We also assume that all contents have same size and each ICN CR can cache the same maximum number of contents. It can be seen from Fig.1 that we design ICN system topology of a prefecture with the idea that each prefecture has a central CR connected to the content server act as Content Provider (CP) for ITS.

In this model, we assume one wireless AP is equipped at each part (railroad car) of a train, as a first-level CR. Hence, a commuter (mobile user) can connect to correspondent wireless AP of his/her current railroad car (Wifi) via connection between this AP and CR at a station when the train stop at a station. However, connection is not available during the moving periods of time. Due to the fact that the moving time is longer than the stopping time, the commuter is expected to endure the intermittent connection when connecting to wireless network of transportation system in current Internet architecture. CRs at stations (router level 2) are connected to higher level CRs including: Area (or city) CRs act as level 3 routers and prefecture (central) CRs act as level 4 routers via high-speed wired transmission.

When the train arrives and stops at a station, suitable wireless AP will get the pre-cached content segments from CR of station via high speed wireless access based on proactive caching scheme. Consequently, the ratio of packet loss and latency in case of our proposal can be reduced compare to existing network system. Further detail of this proactive caching scheme and the way to divide the a content into segments are clarified in to next part of this section (part 4.2).

4.2. Proposed proactive-caching based strategy

In our proactive caching scheme, we select Aggregation points as the location of proactive caching in the similar way as our previous work [12] and as can be seen from Fig.2, station routers act as Aggregation node (under the assumption that all the routers and wireless APs are CRs as defined in [9]). Let C be the set of all content. When a mobile device first expresses its interest for a specific content $c \in C$ to its current railroad car's wireless AP, the interest goes to the CP through wireless AP, then Aggregation node (current CR station) and respective higher level content routers (CRs at level 3 and level 4). Our goal is to populate the different segments of content on the en-route of the interest path as well as the disjoin-neighbor path. When the CP receives an interest asked for a content, that content data is divided into several segments and then these segments are pre-cached to a number of appropriate Aggregation nodes (station CRs at level 2).

Let N be the expected number of stations that one commuter stays on the train, then our proposed system pre-caches content's segments to total of (N-1) stations' CRs away from the first station location where the content request is sent to CP, according to the moving direction of the train line. With this mechanism, a commuter is expected to get his/her full content within a total of N stations and the value of N is also used to identify the size of different

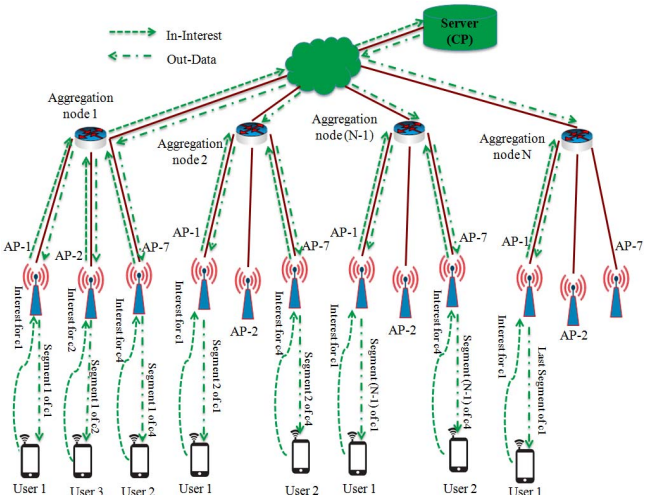

Fig. 2 Flow of interest and content delivery path with proposed proactive caching in Station Router node for ITS

segments of content will be pre-cached to different stations' CRs. The way a content be pre-cached to stations is defined by a delivery scheduler, namely "smart scheduler". This "smart scheduler" decides the appropriate location (station) for pre-caching by applying our proposed proactive caching strategy and can calculate the amount of content segment should be cached. Moreover, in order to prevent the redundant content traffic, the pre-caching process for a suitable segment of a specific content $c \in C$ to station N's CR only happens in the case that station (N-1) still gets the interest for that content from same user at the time train stops at a station to prevent possible congestion. Otherwise, the next segment is dropped, i.e. the time that the commuter expresses his/her interest for a content at station (N-1) is the time the next segment of content is pre-cached to the station N (the upcoming station of station (N-1) in the train line). This mechanism deals with the situation that a commuter leaves the train earlier than expected.

In order to do that, the system generates fake interest (for same content) from the neighbor aggregation node (next/nearby station's CR). Thus, the both aggregation points (en-route and out of route) fetch the content and cache the content. Then the cached segments in APs can be accessed by all matched subsequent mobile content users, hence diminishes the network bandwidth consumption. In Fig.2, at first, there are three users who send three interests for three different contents from three APs (i.e. three wagons of the train) at a specified station (aggregation node 1) on train line: user 1 sends interest for content c_1 to wireless AP1, user 2 sends interest for content c_4 to wireless AP7 and user 3 expresses interest for content c_2 to wireless AP2. However, only user 1 gets the full data of his interested content c_1 by receiving the last segment of c_1 from aggregation node N (user 2 and user 3 do not get the whole data they get interest because they leave the train earlier than expected). Thus, this proactive caching strategy provides a higher efficiency, better congestion control and reliability for the network system and mobile users. In addition, because we design the wireless AP for each railroad car of the train so during the period that train

moves between different stations, users also can get their interested data from the suitable wireless AP which acts as an ICN CR (after this AP gets appropriate data segment of interested Data from the station CR), then better support for the seamless connection.

In more detail, in our ICN system, a commuter (mobile content user) only sends the interest for a specific content to the CP at first station by reason of our proposed proactive caching strategy whereas in conventional ICN design, a content request from a commuter needs to come to a server in the case that no content node contains that content. Worse still, getting data from server is the only way to retrieve a content/data in current IP-based network system. Hence, the delay will be diminished substantially since the interest does not need to go to CP. This scheme also offers a reliable communication since information is firstly served by authorized and authenticated CP of service provider. Then suitable segments of contents can be transmitted to lower level nodes and mobile users can get continuous content segments from appropriate AP via smart scheduler during period which they stay on train with expected lower latency. Therefore, the proposed scheme provides higher QoS as well.

4.3. Link rate adaptive operating policy for Greening ICN-based ITS

In this part, we state our proposed adaptive strategy of Content Node (CN) equipped with aforementioned ALR technique (some of which were introduced in our previous paper [8]).

Firstly, we define p_k as the probability that one content user can find a specific content c ∈ C at a CN level k, under consumption that all CNs located at the same level k of the tree network topology share the same value of p_k since we assume network topology is symmetric and the requests generated by all users are homogeneous.

In the case of current IP-based Internet architecture, we can infer that $p_1 = p_2 = p_3 = p_4 = 0$ and $p_5 = 1$ since as aforementioned, different from ICN design, the only way to get a content/data is sending the request to server via routers. Moreover, the more popular content is expected to be closer to the users because it is replicated more frequently compared to non-popular one. Therefore, the popular contents have tendency to possess higher value of p_1 than the un-popular contents and we define two kinds of content:

$$\begin{cases} popular\ content: & p_1 \geq T_p \\ non-popular\ content: & p_1 < T_p \end{cases}$$

where T_P is the threshold value of p_1 for all Content c ∈ C.

Let Q_k be the probability that a content user traverses k-level (or k hops, where k ≥ 1) of the proposed tree topology to find an interested content c ∈ C, then Q_k can be defined as following:

$$Q_k = p_{k+1} \prod_{l=1}^{k}(1 - p_l) \quad (1)$$

Different Q_k and p_k are shown in the Fig. 1. Then, we match the operating power of ICN CRs to its optimized utilization by adjusting the correspondent link rate of CR based on the popularity of the contents that the ICN node serves.

Let R_k be the incoming link rate to level-k CR for a content c ∈ C. Since a popular content has higher tendency to be found at the first levels, the maximum link rate is set for the level 1 CRs (Wireless APs) as in case of Conventional ICN:

$$R_1 = R_{ICN} \quad (2)$$

where R_{ICN} is the link rate which enters a CR in Conventional ICN model. Then R_k (with k > 1) will adapt to the operating link utilization of ICN node based on popularity level of content and the value of R_1 for every interest for content c ∈ C come to it, i.e.

$$R_1 > R_k \ (k > 1) \quad (3)$$

Let S_k be the set of content c come to a level k content router, then optimized value of R_k for a level k-ICN router, namely *Optimized* $R_{k,ICN}$ ($1 < k \leq 4$), in the case that there is at least one popular content is asked:

$$Optimized\ R_{k,ICN} = \alpha \{ R_{ICN} \ [1 - \min (P_{1c} + \sum_{l=1}^{k-2} Q_{lc})]\} \quad (4)$$
$$\forall Content\ c \in S_k\ and\ |S_k| \leq S$$

where α is the proportional coefficient of link rate and power consumption of Content Nodes (APs and CRs). $\alpha \geq 1$ and $\alpha = 1$ means link rate is directly proportional to power consumption of network devices. In addition, c in the equation refers to all content(s) arrive to the CR level k.

and

$$Optimized\ R_{k,ICN} = \alpha \{ R_{ICN} \ \frac{\max P_{1c}}{T_P} \ [1 - \min (P_{1c} + \sum_{l=1}^{k-2} Q_{lc})]\} \quad (5)$$
$$\forall Content\ c \in S_k\ and\ |S_k| \leq S$$

otherwise, i.e. user only expresses interest for unpopular content(s).

The min function in Equation (4) and (5) returns the minimum value of argument for various values of c, i.e it guarantees that the adapted link provides adequate utilization for the content with highest utilization request in Equation (4). Similarly, the max function in Equations (5) returns the maximum value of all arriving content c to enable enough link utilization for most popular content from all (unpopular) contents at that level.

Since α may get value > 1 then in case device is not fully support ALR function and value of *Optimized* $R_{k,ICN}$ indentified from Equation (4) or (5) is higher than R_{ICN} (i.e. *Optimized* $R_{k,ICN} \geq R_{ICN}$) then let: *Optimized* $R_{k,ICN} = R_{ICN}$.

We then define the Power Adjustment Factor P_A:

$$P_A = \frac{Optimized\ R_{k,ICN}}{R_{k,ICN}} \ (0 < P_A \leq 1) \quad (6)$$

Let $P_{R2\text{-}ICN}$ be the operating power consumed by a CR in conventional ICN design (more detail in Section 5). Since we assume that all CRs are equipped with ALR function, the optimized value of operating power consumption of

Content Node at level k in ICN (*Optimized* $P_{R2\text{-}ICN,k}$) can be identified as:

$$Optimized\ P_{R2\text{-}ICN,k} = P_A \ \ P_{R2\text{-}ICN} \quad (7)$$

Therefore, for this DAN proposal, when a content gets more popular then the load of the network decreases and diminishes the transport energy notably.

5. ANALYTICAL MODELS FOR ENERGY-EFFICIENCY EVALUATION

The total energy of network system can be considered as sum of the energy consumed by all network components and devices that make up the network system.

For scope of our research, we do not consider the overhead power consumption of network, e.g. cooling and lighting energy, and assume that each network system comprises two major elements: *N* content nodes (CRs and APs) and 1 server (CP). Then, for energy-efficiency evaluation, we build our proposed ICN system model for energy savings evaluation compared to the power consumption of the two existing system designs (IP-based system and Conventional ICN), refer to [13] and our prior research model [8].

5.1. IP-based network system energy consumption

$$E_{IP} = N\ E_{R-IP} + E_S = N\ P_{R1-IP}\ T_w + N_1\ P_{R2-IP}\ T_w + N_2\ P_{R2,AP-IP}\ T_w + (P_{S1}\ T_w + P_{S2}\ T_w + P_{S3}\ T_w) \quad (8)$$

where $E_{R\text{-}IP}$ and E_S are the energy consumed by a IP router and energy consumed by the server; $P_{R1\text{-}IP}$, $P_{R2\text{-}IP}$ and $P_{R2,AP\text{-}IP}$ are the embodied power of a network node (router/AP), working power of a IP router, and working power of an AP, respectively; N_1, N_2 and N are the number of routers, number of APs, and number of CNs respectively ($N_1 + N_2 = N$) and P_{S1}, P_{S2}, P_{S3} are the embodied power, power for server storage and operating power of a server (same value for both ICN and IP based network system), respectively. Besides, T_w is the working time of the whole network system.

5.2. Conventional ICN system energy consumption

$$E_{ICN} = N\ E_{R-ICN} + E_S = N\ (P_{R1-ICN}\ T_w + P_{R3-ICN}\ T_w) + N_1\ P_{R2-ICN}\ T_w + N_2\ P_{R2-ICN,AP}\ T_w + (P_{S1}\ T_w + P_{S2}\ T_w + P_{S3}\ T_w) \quad (9)$$

where $P_{R1\text{-}ICN}$, $P_{R2\text{-}ICN}$ and $P_{R3\text{-}ICN}$ are the embodied power, working power and power to cache memory of an ICN CN (CR/AP), respectively. For the purpose of power consumption evaluation, both the current IP-based network system and conventional ICN system share the same power consumption for servers, whereas an ICN node consumes slightly higher power compared to a normal IP node because of the CN's caching function. In more detail, ICN CN need to endure an additional energy of $P_{R3\text{-}ICN}$ and the values of embodied power and working power of an ICN CR are higher than those values in the case of an IP router as well.

5.3. Proposed ICN model for Green ITS energy consumption

The optimized value of total energy consumed by our proposed Green ICN system is a combination of two optimized values:

$$Proposal\ E_{ICN} = \sum_{k=1}^{N} Optimized\ \ E_{R-ICN,r_k} + Optimized\ \ E_{S-ICN} \quad (10)$$

where optimized energy consumption of all CNs:

$$\sum_{k=1}^{N} Optimized\ \ E_{R-ICN,r_k} = N\ (P_{R1-ICN}\ T_w + P_{R3-ICN}\ T_w) + \sum_{k=1}^{N} Optimized\ \ P_{R2-ICN,r_k}\ T_{Or_k} \quad (11)$$

and optimized value of server (CP):

$$Optimized\ \ E_{S-ICN} = (P_{S1}\ T_w + P_{S2}\ T_w) + [P_F\ T_{O_s} + P_I\ (T_w - T_{O_s})] \quad (12)$$

where T_{Or_k} is the operating time of CN r_k with proposed ALR design, and T_{O_s} is the operating time of server S. Besides, assume that systems uses server (CP) with two specific states: Idle mode when no content interest send to server and Full mode otherwise (there is at least one interest come to CP during a period time T). Then let P_F and P_I are working power of Full mode and Idle mode and $P_I = 0.3\ P_F$.

6. RESULTS AND DISCUSSION

In this part, we verify the benefits of our proposed proactive caching strategy together with greening mechanism in DAN architecture to enhance the user experience of the mobile users in case of commuter train's passengers. We simulate our proposed ICN based system in ITS with ndnSIM [14], which is a scalable emulator of Named Data Networking (NDN) under the NS-3 framework [15]. The network topology used in the simulation is tree topology as depicted in Fig.1. We assume that a train has seven distinguished railroad cars, and each car has its own dedicated wireless AP. There are two commuters (mobile content users) at each railroad car and a content user/client is connected to his/her wireless AP level 1. The period of time for staying at each station and moving between two stations are 18s and 90s, respectively. For simplicity, we take N (expected number of stations that a user stays on a train line) equal to four. Wireless APs is connected via IEEE 802.11g standard. Assume all the ICN nodes have the functionalities of PIT (Pending Interest Table), FIB (Forwarding Information Base) and CS (Content Store) as described in [9]. The other key-parameters for the simulation is shown in Table 1. The network elements and their respective power consumptions for evaluation are referred to data presented in [13][17]. Then we make simulation and make comparisons between two existing network system designs and our proposed ICN system, in terms of hop count and energy consumption with the above parameters. For the scope of this paper, we do not address the way how long a segment of content is cached in CR may affect the power consumption. The

Table 1. Key-parameters for simulation in ndnSIM

Simulation key-parameters	
Connection bandwidth	1Gbps
Content Size	1000MB
Payload (content-chunk) size	1024 bytes
Content Store size	20,000 objects
Number of Station CRs (Aggregation Nodes)	4
Content request rate	25% of network available bandwidth
Cache object eviction policy	LRU (Least Recently Used)
Content popularity distribution	Zipf distribution (similar to the Zipf-like distribution in [16])

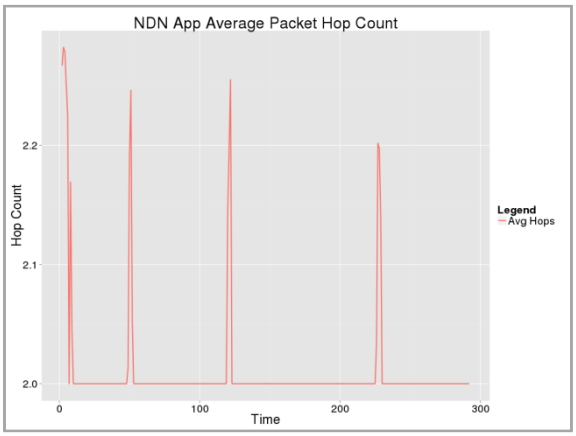

Fig. 3 Performance evaluation for Average Hop Count of proposed ITS system

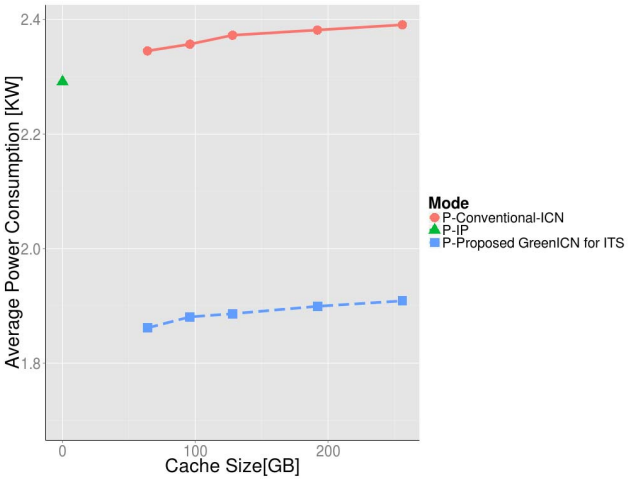

Fig. 4 Average power consumption of different network systems versus the different cache size of ICN content router

following metrics are evaluated:

• Average Packet Hop count of proposed ITS system: the Average Packet Hop count is almost stable with the simulation time as showed in the Fig.3 except the cases that the Mobile Node (MN) is involved in the Hand-offs period

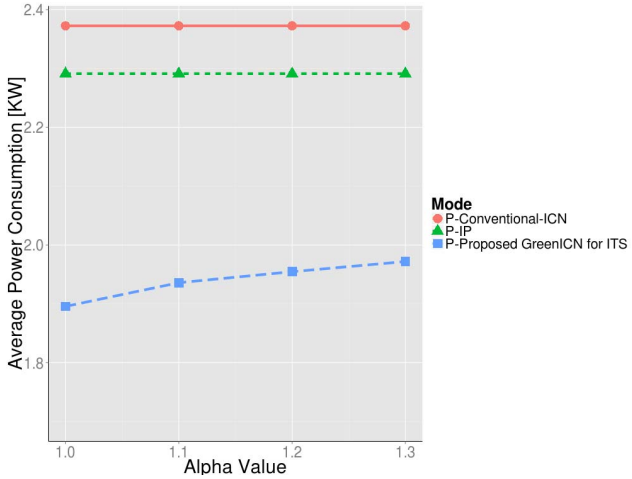

Fig 5. Average power consumption of network systems versus α value

when it moves to change the PoA to another Station node (when train stops at a station). The period taken to hand-off is very short, thanks to our "smart scheduler" and innovated proactive caching strategy.

• Impact of ICN CN caching size on average power consumption: From our simulation result as shown in Fig. 4, the average power consumption of both Conventional ICN and our proposed ICN model increase when we increase the size of the content cache of each CN (five different ICN CN cache sizes: 64 GB, 96 GB, 128 GB, 192 GB and 256 GB with α = 1). This is because ICN system need to endure additional caching energy for the CN as stated in part 5.2 (the respective values of CNs' power consumptions can be found in [13]). Moreover, our proposed model can save significantly power consumption compared to other current network designs.

• Impact of Alpha value (α) on average power: As can be seen in Fig. 5, the value of α and average power consumption of the network system have a linear relationship. Typically, we take value of α ranges from 1 to 1.3 for the evaluation. Though Conventional ICN consumes slightly higher energy consumption compared to our current IP-based architecture due to additional energy for caching capability, from Fig. 5, our proposed Green ITS model can substantially decrease energy consumption. In more detail with α = 1 (the ideal case with ALR-fully support CN), our proposed system can save about 21.16 % energy compared to conventional ICN in the same scenario, whereas this ratios are decreased to 18.57 % with α = 1.3.

7. CONCLUSION AND FUTURE WORK

In this article, we have designed a model utilizing innovated dynamic pre-fetching and ALR based scheme together as a practical ITS solution to offer reliable and effective wireless content access for the commuters in transportation system (particularly railway system). Our proposed system also supports seamless communication to raise content robustness and reliability, then secure the mobile content user's security and can be used in a wide range of transportation system in the future to realize

advanced mobile communication. By showing the significance of setting up the standardization of DAN (ICN) wireless communication in the transportation system perspective and efficiency of our proposed scheme, in terms of reliability and effectiveness, we propose our work for DAN standardization process of ITU. We do believe that our proposed DAN model for ITS with early initiative taken by prestigious international standardization body ITU will make the difference to the future mobile communication and become the key technology which strengthens the development of various mobility services for a reliable and safe human-centric system toward an ubiquitous intelligent and trusted society.

For the scope of future work, the realization of the scheme under field experiment with larger scalability as well as simulation for various and practical use-cases (e.g. identifying high and low content traffic period of time during one day in case of transportation system) with distinguished kinds of content services and applications, such as real-time services videos, multimedia streaming are needed to further evaluate proposal's efficiency. We also plan to take the train experiment data to find an optimized location for Wireless APs of a train's railroad car in different scenarios including user arrival rate and the position together with mobility of commuters in each railroad car.

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NETWORK FAILURE DETECTION SYSTEM FOR TRAFFIC CONTROL USING SOCIAL INFORMATION IN LARGE-SCALE DISASTERS

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ABSTRACT

When the Great East Japan Earthquake occurred in 2011, it was difficult to grasp all network conditions immediately using only information from sensors because the damage was considerably heavy and the severe congestion control state occurred. Moreover, at the time of the earthquake, telephone and Internet could not be used in many cases, although Twitter was still available. In an emergency such as an earthquake, users take an interest in the network condition and provide information on networks proactively through social media. Therefore, the collective intelligence of Twitter is suitable as a means of information detection complementary to conventional observation. In this paper, we propose a network failure detection system that detects candidates of failures of telephony infrastructure by utilizing the collective intelligence of social networking services. By using this system, more information, which is useful for traffic control, can be detected.

Keywords— Twitter, social information, failures of telephony infrastructure, traffic control

1. INTRODUCTION

Large-scale disasters such as earthquakes often cause network failures because base stations and network facilities are damaged and many users are trying to access the network at the same time. In cases of emergency, it is important that telephone and Internet be available. Therefore, the necessity for failure detection in large-scale disasters is high. Usually, network conditions are monitored by sensors. However, when the Great East Japan Earthquake occurred in 2011, it was difficult to grasp all network conditions immediately using only information from sensors because the damage was considerably heavy and the severe congestion control state occurred. [1].

In subsequent research on the Great East Japan Earthquake [2], survey participants responded that they were able to use Twitter [3]. Twitter is also advantageous in that it can obtain information from users in real time. In an emergency such as an earthquake, users take an interest in the network condition and provide information on networks proactively through social media. Hence, Twitter can be used to obtain information on the locations and causes of network failures and on the degree of impact to users, which cannot be obtained using only sensors. Therefore, the collective intelligence of Twitter is suitable as a means of information detection complementary to conventional observation. Against this background, we propose a network failure detection system that detects candidates of failures of telephony infrastructure by utilizing the collective intelligence of social networking services. This system is targeted to network managers, who wish to detect failures of telephony infrastructure automatically in case of emergency.

Here, there is an issue if Twitter will be accessible when Internet services are down. However, if a wireless LAN access is not available, other services such as 3G network and LTE may be able to be used. Moreover, people in areas where failures don't occur provide information on the failures of telephony infrastructure.

Among the earthquakes that occurred in 2014, we detected failures of telephony infrastructure with a high degree of accuracy [4]. However, in the case of large-scale earthquakes such as the Great East Japan Earthquake, more information, which is useful for traffic control, is needed. For example, when our system detects telephone trouble, we want to classify whether users cannot get through *to* the detected location or cannot get through *from* the detected location. In this case, the areas where a failure is likely to occur should be the former. Therefore, in this work, we investigated tweets sent out during the Great East Japan Earthquake and used our findings to develop a method that uses machine learning to classify the detected locations into two groups.

The remainder of this paper is organized as follows. Section 2 introduces related research studies and Section 3 gives an overview of our proposed system. Sections 4 and 5 respectively discuss the candidate data detection method and the location classification method that are a part of our proposed system. In Section 6, we describe a visualization of the results of the location classification method and the external information. We conclude in Section 7 with a brief summary and a mention of the future direction of our research.

This work is partially supported by the Strategic Information and Communications R&D Promotion Programme (SCOPE).

2. RELATED WORK

There are currently a number of methods that detect events occurring in the real world (earthquakes, landslides, fire, etc.) by analyzing the data in social media [5][6][7][8][9]. Sakaki et al. [5] introduced a method to detect earthquakes early and estimate their locations by considering each Twitter user as a sensor. The Ministry of Land, Infrastructure, Transport and Tourism [6] introduced a method to detect the signs and occurrences of landslides early on the basis of the tweets of residents of the areas where a disaster is likely to occur. Our current work differs from these existing methods in that 1) the existing methods restrict their focus to the occurrence of an event and do not detect more detailed information when large events occur, and 2) they do not utilize the external information issued by public agencies, which would be useful in terms of increasing the accuracy.

Our method is unique in that it 1) increases the accuracy of network failure detection using collective intelligence by filtering out irrelevant tweets, and 2) detects information for traffic control. Moreover, we use social networking services for network management. Tongqing et al. [10] reported that users posted messages on Twitter before they called a customer service center if they experienced network failures, and Takeshita et al. [11][12] had a similar motivation to our own in that they use tweets related to network performance issues in order to oversee network operation. However, our present work differs from these in that 1) we focus on natural disasters and 2) we detect failures of telephony infrastructure using more that just tweets.

3. OVERVIEW OF PROPOSED METHOD

An overview of our proposed network failure detection system is given in Figure 1. Figure 2 gives an overview of the candidate data detection method that is a part of the proposed system.

The process flow of the proposed method is as follows.

(1) Set specific keywords that can detect failures of telephony infrastructure and collect tweets containing the keyword.
(2) Classify the tweets in accordance with location information into each location group.
(3) Collect tweets without location information but specifying the same failure to increase the amount of candidate data. We calculate characteristic words with the data set of (2) and add tweets containing the words into the data set of (2).
(4) Consider post time of each tweet and apply temporal filtering to cut irrelevant tweets.
(5) Classify location from tweets detected by our system as to whether the failure happened at this or another location.
(6) Obtain external information such as Earthquake Early Warning and match this with the failure information detected by (5).
(7) Visualize failure information on Google Maps.

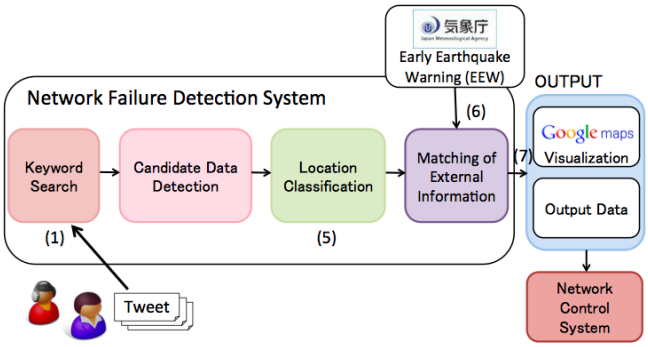


Figure 1. Network failures detection system.

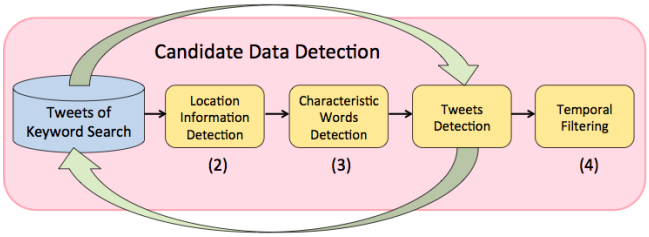


Figure 2. Candidate data detection.

It is important that failures of telephony infrastructure be detected immediately. For real-time processing, we collect tweets every minute and use tweets in the last 60 minutes as potential tweets for failure detection. This system then outputs failure information for each detected location.

4. CANDIDATE DATA DETECTION METHOD USING SOCIAL NETWORKING SERVICES

4.1. Keyword Search

We set specific keywords that represent telephone trouble using a Search API supported by Twitter Inc. to collect tweets about failures of telephony infrastructure. The keywords are phrases that mean users cannot get through by telephone in Japanese.

4.2. Location Information Detection

Various tweets can be associated with location. For example, Twitter users may register their location on their profile, and sometimes they attach Geotagging to a tweet. We conducted a morphological analysis of tweets and their registered Geotagging locations by using MeCab [14], which separates sentences into a set of words. Latitude and longitude details of the Geotagging are converted into a city name using the Yahoo! reverseGeoCoder API [15] supported by Yahoo! Inc. We counted the number of occurrences of location names and

detected them that appeared more than a certain number of times. In this work, we define the threshold of occurrences as five times. Then, we classified the tweets of Section 4.1 in accordance with the detected location information into each location group.

4.3. Characteristic Words Detection

To collect tweets that do not contain the same location but refer to the same failure, we detect characteristic words in the tweets. We then collect tweets that contain the detected characteristic words and not the other location information and add them to the tweets for each piece of location information.

"Characteristic words" are found in tweets for each piece of location information by detecting only nouns using MeCab. We exclude byte symbols and half-width letters and numbers. Then, we calculate a TFIDF (Term Frecuency Inversed Document Frequency) value for each detected noun and define a noun that has a TFIDF value greater than or equal to 0.2 as a characteristic word.

TFIDF is a numerical statistic that is reflected how important a word is to a document. TF value is the term frequency. Therefore, words that appear many times are important. IDF value is the inverse document frequency. The smaller it is, the greater the number of tweets that a word appears is. Therefore, it has a role to increase the importance of words that only appear in specific tweets. TFIDF value is calculated by multiplicating a TF value and a IDF value.

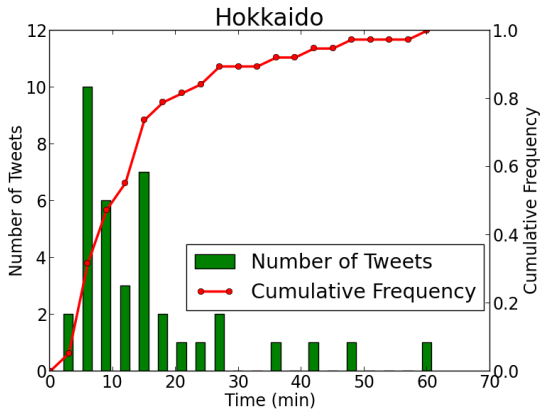
In this study, TFIDF value is calculated as follows; where the number of detected nouns is N, experimental tweets that are classified into each location group of Section 4.2 are TW_e, and the roughly 100,000 tweets obtained using Twitter Inc.'s Streaming API [16] are TW_{10}. These TW_{10} are tweets of normal period that are not be set any keywords, and they are utilized to calculate IDF value. By introducing TW_{10}, N can be compared with words of normal period.

$$TF\text{value} = \frac{\text{the number of times } N \text{ appears in } TW_e}{\text{the total number of words that appear in } TW_e} \quad (1)$$

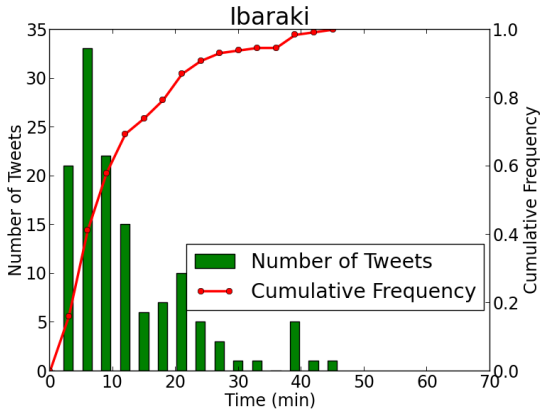
$$IDF\text{value} = \frac{\text{the total number of tweets of } TW_e \text{ and } TW_{10}}{\text{the number of tweets that contain } N \text{ in } TW_e \text{ and } TW_{10}} \quad (2)$$

4.4. Temporal Filtering

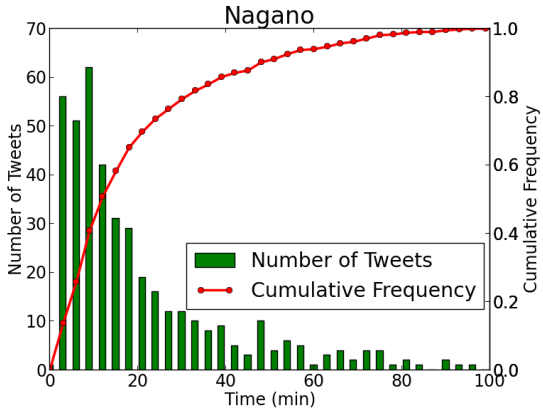
In each piece of location information, there are a number of tweets that are unrelated to failures of telephony infrastructure. Therefore, we consider the timestamps of tweets and discard any tweets that are unrelated. Twitter users tend to simultaneously post similar tweets when large-scale disasters happen, and in this study, we consider this feature and determine a certain threshold of time to eliminate tweets. To determine this threshold, we examine the time variations of the number of tweets that refer to failures of telephony infrastructure and generalize them.



(a) Earthquake in Hokkaido



(b) Earthquake in Ibaraki



(c) Earthquake in Nagano

Figure 3. Time variations of tweets that refer to failures of telephony infrastructure.

Figure 3 shows each time variation of the number of tweets that refer to failures of telephony infrastructure in the case of an earthquake in Hokkaido on July 8, 2014, an earthquake in Ibaraki on September 16, 2014, and an earthquake in Nagano on November 22, 2014 (green bar graph).

As shown in Figure 3, the number of tweets increased rapidly after earthquakes occurred and then eventually saturated.

This result shows that time variations of the number of tweets in earthquakes are characteristic. In this study, we consider cumulative frequency since the number of samples is small. Figure 3 shows the actual data of cumulative frequencies (red line). The time variations of cumulative frequencies are similar to the cumulative distribution function of an exponential distribution. Hence, we fitted each time variation of a cumulative frequency to the cumulative distribution function of exponential distributions. This cumulative distribution function is defined as

$$f(x) = 1 - e^{-\lambda x} \tag{3}$$

Figure 4 shows the results of fitting earthquakes in Hokkaido, Ibaraki, and Nagano.

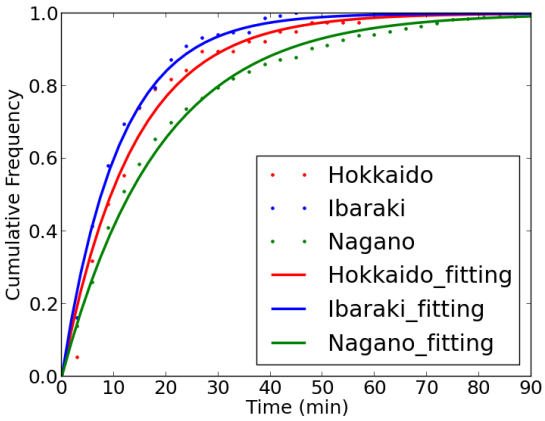


Figure 4. Results of fitting cumulative distribution functions of an exponential distribution.

Results showed that all time variations of cumulative frequencies were fitted to the cumulative distribution functions of an exponential distribution. This indicates that the time variations of the number of tweets can be approximated to an exponential distribution. Moreover, since this is an exponential distribution, we can capture 80% of the events in 60 minutes. Hence, for real-time processing, we collect tweets every minute and use tweets in the last 60 minutes as potential tweets for failure detection.

5. LOCATION CLASSIFICATION METHOD USING MACHINE LEARNING

Among the earthquakes that occurred in 2014, the candidate data detection method (Section 4) was able to detect failures of telephony infrastructure with a high degree of accuracy [4]. However, in the case of large-scale earthquakes such as the Great East Japan Earthquake, more information, which is useful for traffic control, is needed. For example, when our system detects telephone trouble, we want to classify whether users cannot get through *to* the detected location or cannot get through *from* the detected location. In this case, the areas where a failure is likely to occur should be the former. Therefore, on the basis of our analysis of tweets sent out during the Great East Japan Earthquake, we developed a method that utilizes machine learning to classify the detected locations into two groups. Table 1 shows examples of tweets that were detected with the candidate data detection method.

Table 1. Examples of tweets of candidate data detection method.

A.「宮城へ電話繋がらないよ... 心配だ」 (I cannot get through to Miyagi...I'm worried.)
B.「渋谷なう 電話繋がらない」 (I'm in Shibuya now. I cannot get through.)

Here, tweetA shows that the user cannot get through *to* the detected location (Miyagi) while tweetB shows that the user cannot get through *from* the detected location (Shibuya). Therefore, tweetA and tweetB are different kinds of tweets. Classifying tweets in this way enables us to obtain more information, which is useful for traffic control. Hence, we classify tweets detected with the candidate data detection method. The detected tweets can be classified into the following three types:

(1) tweets that mean users cannot get through *to* the detected location (= Data Set A)
(2) tweets that mean users cannot get through *from* the detected location
(3) undeterminable tweets

There is a possibility that tweets from the location of the failure are classified as (1). Therefore, we focus on Data Set A of (1). In this paper, we classify the tweets into tweets that mean either users cannot get through to the detected location of (1) or other tweets, which include both (2) and (3). We propose tweet detection with a rule-based approach and tweet classification using machine learning.

5.1. Tweet Detection by the Rule-Based Approach

Figure 5 shows the flow of tweet detection with the rule-based approach.

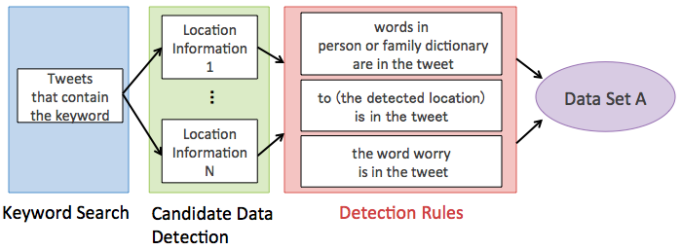


Figure 5. Flow of tweet detection with rule-based approach.

First, we perform the candidate data detection method and collect the tweets that are obtained by the keyword search

for each item of location information. Next, for each detected location, we judge whether the tweets satisfy the extraction rules. We extracted the patterns common to Data Set A and then made rules to classify the tweets. The extraction rules are:

(1) words in person or family dictionary are in the tweet
(2) *to (the detected location)* is in the tweet
(3) the word *worry* is in the tweet

The person or family dictionary is a dictionary that includes words related to people, e.g., mother, son, and sister. In this work, we selected these rules because an evaluated value was the best among other rules. Table 2 shows examples of tweets that satisfy these rules.

Table 2. Examples of tweets that satisfy these rules.

(1) 「岩手の**母**に電話がつながらない」 (I cannot get through to my *mother* in Iwate.)
(2) 「**仙台に**電話つながらないよ」 (I cannot get through *to Sendai*.)
(3) 「宮城のほうはかなり揺れてたみたいです。 今は電話しても繋がらないので、**心配**です。」 (Miyagi seems to have shaken quite a lot. I cannot get through now, so I'm *worried*.)

If a tweet satisfies any one of these rules, the tweet is classified as Data Set A.

5.2. Location Classification with the Machine Learning

In order to classify whether the detected tweets are Data Set A or other tweets, we created a classifier using a support vector machine (SVM). SVM-light was used as a classifier. In the classification with machine learning, we use only Bag of Words (BoW) and the rules of the tweet detection with the rule-based approach as features. When rules are added as features, the subjects of BoW are nouns, verbs, and adjectives.

5.3. Evaluation

Table 3 lists the results of tweet detection with the rule-based approach and the location detection with machine learning. Tweets in the Great East Japan Earthquake that were detected with the candidate data detection method were used as evaluation data. These data are made up of 726 tweets that mean users cannot get through to the location and 300 other tweets. We use leave-one-out cross validation as an assay method of the classification with machine learning.

Adding the rules of the rule-based approach as features can increase F-value, which demonstrates that adding rules is effective. Furthermore, when rules were added in the classification of the machine learning, F-value increased by about 10 points in comparison to tweet detection with the rule-based approach.

Table 3. Evaluation of data classification.

Method	Precision	Recall	F-value
Detection with rule-based approach	0.8170	0.8058	0.8114
Classification with machine learning (only BoW)	0.8166	0.9752	0.8889
Classification with machine learning (with rules)	0.8606	0.9862	0.9191

6. VISUALIZATION OUTPUT OF DETECTED FAILURE

We match the disaster information issued by public agencies in order to determine the cause and the location of failures that were detected using our proposed method. External information such as Earthquake Early Warning (EEW) issued via Twitter was used here.

In this study, we obtain EEW through tweets, which broadcast EEW contents indirectly. We then analyze the warnings and obtain the time, position, and strength of the earthquake.

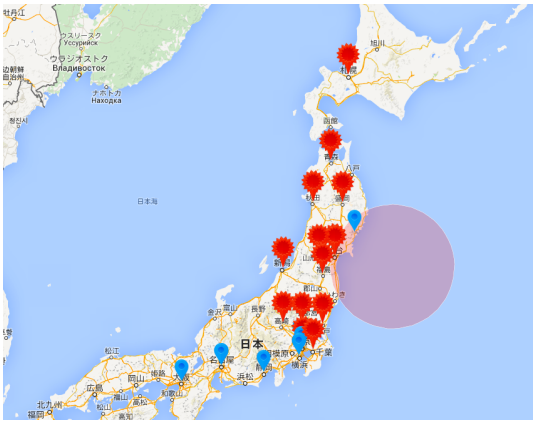
We take the results detected with the candidate data detection method and location classification method using the data of Section 5, match them with the external information, and then visualize them on Google Maps. We visualize the correct classification results manually to obtain the correct data on the location classification method. Therefore, we can confirm the effectiveness of the proposed method. Figure 6(a) shows the results using the proposed method and Figure 6(b) shows the manual classification results.

Colored pins represent the situation in the area where the pin is stuck, with red indicating that users cannot get through to the area and blue indicating the other situation (users cannot get through from the area, etc.). Seismic intensity obtained by EEW is set to the center of a circle, with the radius of the circle dependent on the magnitude of the quake. In Figure 6(a), the red pins are close to the circle, indicating that a major failure occurred near the seismic intensity. The blue pins are located further away from the seismic center, indicating that a failure had not occurred in this area but that users could not get through to people near the seismic center.

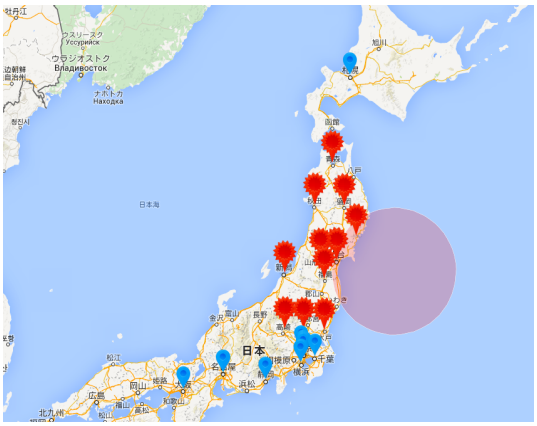
When we compared the results in Figures 6(a) and 6(b), no difference could be seen. This demonstrates that our proposed method performs well.

7. CONCLUSION

When the Great East Japan Earthquake occurred in 2011, it was difficult to quickly grasp all network conditions because the amount of information on the damage and the congestion control state, which is needed to understand the damage, was enormous. Moreover, at the time of the quake, telephone and Internet could not be used, although Twitter was still available. In an emergency such as an earthquake, users take an interest in the network condition and provide information on networks proactively. In this paper, we proposed a network



(a) Results using proposed method



(b) Results classified manually

Figure 6. Visualization results of Great East Japan Earthquake.

failure detection system that detects candidates of failures of telephony infrastructure by utilizing the collective intelligence of social networking services.

Among the earthquakes that occurred in 2014, we detected failures of telephony infrastructure with a high degree of accuracy. However, in the case of large-scale earthquakes such as the Great East Japan Earthquake, more information, which is useful for traffic control, is needed. Therefore, we proposed a method that uses machine learning to classify locations that had been detected with the candidate data detection method into two groups. By visualizing tweets sent out during the Great East Japan Earthquake, along with information obtained by EEW on Google Maps, we showed that the location classification method using machine learning works effectively.

In this work, network failure information was detected using our system. As the next step, we plan to use the detected information to construct a system that can control the network.

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SESSION 6

THE NEED FOR SPEED (MEASUREMENTS)

S6.1 5G Transport and Broadband Access Networks: The Need for New Technologies and Standards.*

S6.2 A unified framework of Internet access speed measurements.

S6.3 Why we still need standardized internet speed measurement mechanisms for end users.*

5G TRANSPORT AND BROADBAND ACCESS NETWORKS: THE NEED FOR NEW TECHNOLOGIES AND STANDARDS

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ABSTRACT

In addition to new radio technologies, end-to-end transport networks will play a vital role in future 5G (and beyond) networks. In particular, access transport networks connecting radio access with core networks are of critical importance. They should be able to support massive connectivity, super high data rates, and real time services in a ubiquitous environment. To attain these targets, transport networks should be constructed on the basis of a variety of technologies and methods, depending on application scenarios, geographical areas, and deployment models. In this paper, we present several technologies, including analog radio-over-fiber transmission, intermediate-frequency-over-fiber technology, radio-on-radio transmission, and the convergence of fiber and millimeter-wave systems, that can facilitate building such effective transport networks in many use cases. For each technology, we present the system concept, possible application cases, and some demonstration results. We also discuss potential standardization and development directions so that the proposed technologies can be widely used.

Keywords— 5G transport networks, fiber and wireless convergence, ubiquitous networks, coverging technologies.

1. INTRODUCTION

Recently, 5G networks and beyond are gaining a lot of interest from both industry and the academic community. Although an official definition of the 5G network has not yet been specified, there have been many efforts and proposals regarding its targets and goals. Many research projects and forums have been established worldwide with the aim of setting out a common platform, possible targets, and underlying technologies. Among the many forums and projects related to 5G networks are the International Telecommunication Union (ITU) 's International Mobile Telecommunication (IMT) 2020, Next Generation Mobile Networks (NGMN), 5G Forum (Korea), and 5G Mobile Communications Promotion Forum (5GMF) (Japan). On the basis of the current studies, 5G will be a user- and machine-centric communication network in which access to information and sharing of data can be done anywhere and anytime by anyone and anything [1]. It should be capable of supporting a higher number of simultaneously connected devices, better coverage, higher spectral efficiency, lower battery consumption, lower outage probability, lower latencies, lower infrastructure deployment costs, and higher reliability of communications. It should also be able to provide a variety of services with various features, including machine to machine, Internet of Things (IoT), delay-sensitive services such as real-time 8K ultra high-definition video, and other new services. Consequently, 5G networks will pose significant requirements and challenges to the transport networks. With continued site densification and larger numbers and various services to be provisioned, the role of the transport network will become increasingly crucial [2]. The transport network should be able to support a wide range of 5G services, massive numbers of simultaneously connected devices, new radio access technologies, and deployment models. It should be capable of supporting high-reliability communications at any time and in any situation, even when aboard fast-moving vehicles, during major social events with massive numbers of users, or in the event of disasters or accidents. Such transport networks should help to enhance the user experience and trust on the information and communication infrastructure. However, most ongoing research efforts on 5G are now focusing on radio technologies and interfaces, whereas the transport network-related issues have not been paid much attention.

On the other hand, the development of broadband access networks, especially to underserved communities and rural remote areas, is another important issue that should be addressed to improve the quality of lives by means of information and communication technology (ICT). Recently, ITU proposed a "Connect 2020" program with an ambitious vision for the ICT sector for the year 2020 [3]. The vision highlights the role of ICTs as a key enabler for social, economic, and environmentally sustainable growth and development. Among the ambitious goals, achieving 90% broadband coverage for the rural population worldwide by 2020 is a key target. In the developed countries, broadband services can be provided to users by means of high-speed wired networks such as fiber or copper cables to homes. However, there are many underserved areas, especially in the developing countries, where broadband infrastructure is still lacking. Services provisioned by means of satellite communications can partially satisfy basic demands, but it is still far from meeting the target of providing broadband services to end users because of its limited available bandwidth.

Motivated by these significant facts, in this paper, we present several technologies that can be used for future mobile transport and/or broadband access networks to achieve the targets of 5G networks and the Connect 2020 program. We present the concept, possible use cases, and some demonstration results for each technology. We also discuss potential standardization and development directions that need further efforts in order to promote the technologies for future uses. The paper is organized as follows. In Section 2, we discuss challenges of 5G mobile transport and broadband access networks. In Section 3.1, we present analog radio-over-fiber (RoF) technology. In Section 3.2, intermediate-frequency-over-fiber (IFoF) technology is discussed. In Section 3.3, we present the radio-on-radio (RoR) concept and related topics. In Section 3.4, the convergence of fiber and millimeter-wave (MMW) systems is presented. We also discuss other open topics that need efforts both in research and standardization to support future mobile networks. Finally, Section 4 concludes the paper.

2. CHALLENGES OF 5G TRANSPORT AND ACCESS NETWORKS

As mentioned previously, 5G transport networks will face many challenges because of the requirements of new functions and capabilities to support various services, scenarios, use cases, and models. Recently, the EU METIS project [4], which is considered an official model of European 5G networks, has defined five future use cases that the network should be able to support, including: (1) amazing speed, (2) great service in a crowd, (3) ubiquitous devices communicating, (4) super real-time and reliable connections, and (5) best experience follows you. Each of these use cases introduces a challenge to the transport networks. Future applications may impose different challenges to the networks because they can be associated with one or several of these scenarios [2]. Support for very high data rates will require both higher capacity radio access nodes as well as a densification of radio access sites. This, in turn, translates into a challenge to the transport networks that need to support more sites and higher capacity per site. The great service in a crowd scenario will put requirements on the transport networks to provide very high capacity on-demand to some specific geographical locations such as during social events. In the ubiquitous communications of things, the radio access and in turn the transport networks should support a massive number of users and devices that are connected to the networks simultaneously. Support for delay-sensitive services would be one of the important aspects of 5G because it requires extremely high bandwidth in the underlying infrastructure to deliver various delay-sensitive services. The overall latency must be extremely low to deliver real-time content such as ultra high-definition video. In the best experience follows you use case, the transport resources should be able to flexibly and quickly re-configure resources.

Together with these challenges, the transport networks should be capable of providing seamless mobility for enhancing user experience even when they are on fast-moving vehicles. The networks should also support ultra-dense small-cell deployment in ultra-dense urban areas. At the same time, the expenditure and maintenance cost, power consumption, and timeline to service rollout should be as low as those of the current networks. These requirements and challenges motivate the development of new transport networks.

3. SOLUTIONS FOR FUTURE MOBILE TRANSPORT AND ACCESS NETWORKS

In this section, we present some promising technologies that can be used for 5G transport and broadband access networks to realize a more cost effective, low latency, fast provision of services, to increase user experience and trust on information and communication infrastructure.

3.1. Analog radio-over-fiber systems

3.1.1. The needs of radio-over-fiber systems

In macro-cell-based mobile networks, digital photonic links are typically used owing to their relatively good performance. Interface protocols such as the common public radio interface and the open base station architecture initiative are widely used for data digitization and transmission. However, the small cell-based network, which is considered one of the key techniques in 5G, as shown in Fig. 1(a), poses many challenges to digital photonic links. First, the bit rate of the links must be very high [5]. Second, simultaneous transmission of multiple wireless standards and radio access technologies (RATs) over the same system presents another challenge. In addition, strict requirements on latency and jitter in emerging wireless standards ultimately limit the fiber distances. The use of high-frequency radio signals such as in the MMW band will bring another challenge because very high-speed analog-to-digital (A/D) and digital-to-analog (D/A) converters are needed at the remote sites. Considering these key challenges, new transmission methods should be considered for future mobile transport networks.

Analog RoF technology is a promising choice for future mobile transport networks using MMW signals [6]. Compared to digital transmission, as shown in Fig. 1(b), analog transmission of radio signals over photonic links, as shown in Fig. 1(c), can greatly simplify remote radio heads (RRHs). By avoiding the digitization process, analog links help to reduce the transmission data rate, reduce latency, and avoid the use of expensive A/D and D/A converters at RRHs. This approach can enable a coexistence of multiple radio signals in the same system simultaneously [6]. This helps to reduce the system cost, power consumption, and complexity, and enhances cooperation between cells. Nevertheless, many drawbacks are also associated with this method because of its reduced dynamic range, nonlinearity distortion, and fiber dispersion effect. A comprehensive study of the system performance evaluation, especially for transmission of

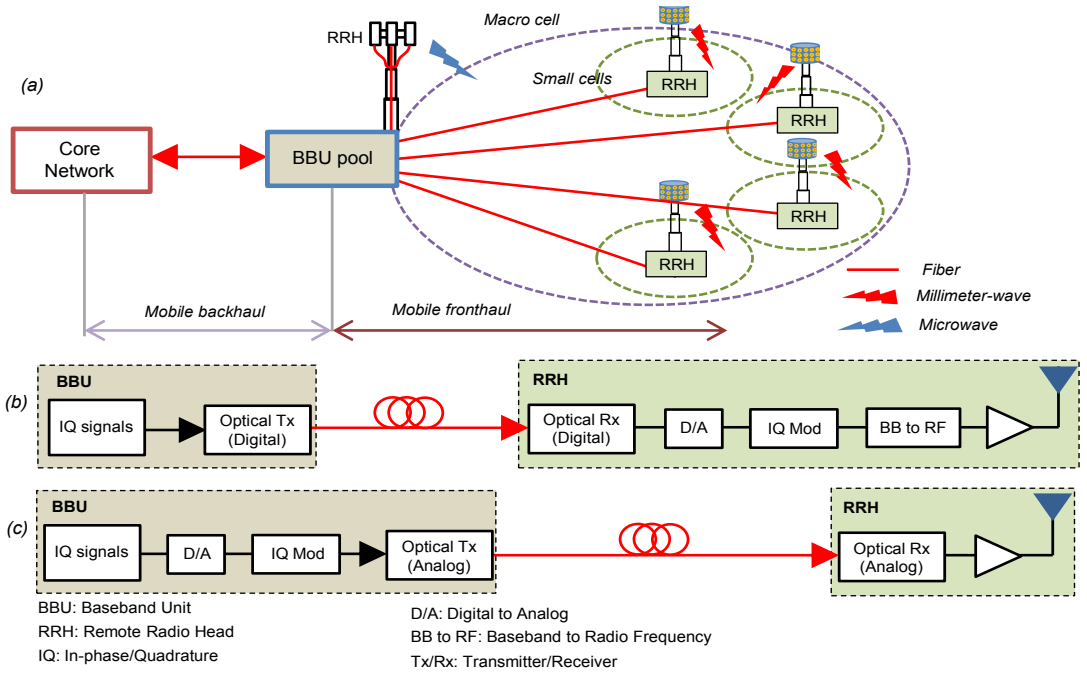

Figure 1: (a) Concept of using analog RoF for dense small-cell deployment. (b) Block diagram of digitized RoF system. (c) Analog RoF system.

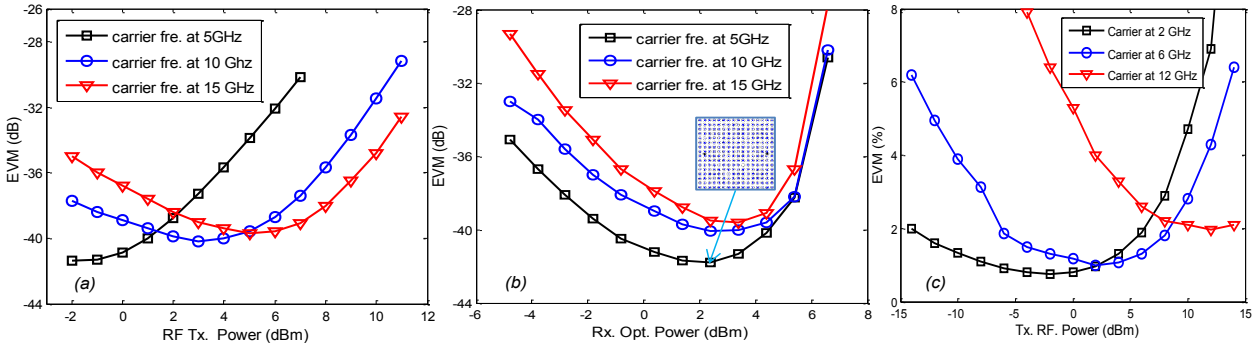

Figure 2: (a) 802.11ac signal performance versus transmission powers. (b) 802.11ac signal performance versus received optical powers. (c) LTE-A signal performance versus transmission powers.

new wireless standards at high-frequency regions, should be conducted to confirm its potential.

3.1.2. Experiment demonstration

In this subsection, we present an experimental demonstration of transmitting a very-high throughput IEEE 802.11ac signal and a high-speed long term evolution-advanced (LTE-A) signal over an analog photonic link. The experimental setup is similar to the diagram shown in Fig. 1(c). These standards-compliant signals are generated by signal studio software and downloaded to vector signal generators (VSGs). The generated signals in turn modulate a light-wave signal from a laser diode by an optical modulator. The modulated optical signal is amplified by an optical amplifier and transmitted over a 20-km single-mode fiber (SMF) to an optical receiver. The signal is then converted to the originally transmitted wireless signals by an optical to electrical (O/E) converter. The recovered signal is connected to a vector signal analyzer (VSA) and finally demodulated offline by VSA software. It should be noted that in practice, direct modulation of wireless signals on an optical signal can be also performed using a direct laser modulator [7].

We evaluated the transmission performance using the error vector magnitude (EVM) parameter, which is one of the main performance metrics for transmitter tests. Performance for a 20-MHz IEEE 802.11ac signal and an LTE-A signal is shown in Fig. 2. Required EVM values for 256-QAM signals using the 3/4 and 5/6 code rates are -31 dB and -33 dB, respectively [8]. Measured results for different transmission powers are shown in Fig. 2(a). Here the RF transmit power is the power at the input of the optical transmitter. Compared to the requirements, the transmission was successful for all signals. However, transmission powers of high carrier frequency signals should be shifted to higher values because

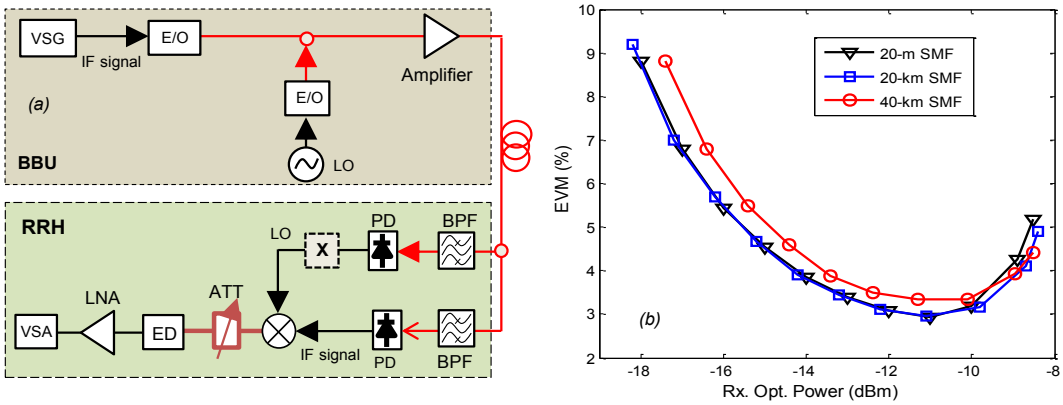

Figure 3: (a) Experimental setup for IFoF and remote delivery of an LO signal. (b) Performance of LTE-A signal transmission over the IFoF system.

of fiber dispersion effects. We should note that EVM value degradation in low transmission power regions is because of low signal to noise ratio, and that in the high transmission power region is because of nonlinear distortion effects. The performance for different received optical powers is shown in Fig. 2(b). It is observed that the performance degrades with increasing signal carrier frequency. Fig. 2(c) presents the performance of the carrier aggregation (CA) LTE-A signal for different transmission powers. The required EVM value for a 64-QAM signal is 8% [9]. Similar to IEEE 802.11ac signals, LTE-A signals are successfully transmitted with satisfactory performance. However, the performance relatively degrades with increasing carrier frequency because of fiber dispersion effects.

From these results, it is confirmed that RoF systems can provide satisfactory performance for emerging wireless standards. However, its performance can be greatly degraded because of nonlinear distortion and fiber dispersion effects, especially for signals in the high-frequency bands. This will limit its applications because high-frequency bands such as MMW are being considered as a key technology for 5G networks [10]. From these observations, further study and investigation should be conducted to promote this promising technology. Appropriate methods for nonlinear distortion compensation, especially for high carrier frequency signals, fiber dispersion mitigation methods, and mapping algorithms for aggregating multiple signals are among the open topics. Currently, standardization of RoF technology is being discussed at ITU S15/Q2. However, the focus is mainly on the digital and RoF systems for transmission of wireless signals in traditional microwave bands. Considering the potential of analog RoF systems, standardization activities focusing on this technology, especially for transmission of signals in high-frequency bands, should also be considered.

3.2. Intermediate frequency over fiber technology

3.2.1. Techology overview

As presented in the previous subsections, it is challenging to transmit high carrier frequency signals using both digital and analog photonic links. In this subsection, we present another technology, namely IFoF, for future mobile transport networks. In this system, radio signals at intermediate frequencies (IF) are transmitted over a photonic link to RRHs. At the RRHs, originally transmitted radio signals are recovered from optical signals and up-converted to a desired frequency before being transmitted into free space. With this configuration, the drawbacks of direct transmission of radio signals in high-frequency bands can be avoided. However, the inclusion of a local oscillator (LO) signal source at each RRH would increase system complexity and cost. A centralizing system in which an LO source is located at central stations (CSs) and shared with many small cells via fiber links would be preferable. This can be realized by an IFoF system using remote delivery of LO signals as shown in Fig. 3(a). In principle, it is similar to RoF systems; however, in addition to the IF signals, an LO signal is also transmitted to the RRHs. At the CSs, the LO signal is modulated on an optical signal and combined with the other optical signal that is modulated by IF signals, and transmitted over a fiber link to the RRHs. At the RRHs, the two optical signals are separated and recovered using optical band-pass filters (BPFs). One of the signals is used to recover the transmitted IF signals; the other is to recover the LO signal. If the frequency of the LO signal is too high, a lower-frequency synthesized signal can be transmitted from the CSs to the RRHs. At the RRHs, after being recovered, it can be up-converted to a desired LO signal using an electrical multiplier. The recovered LO and IF signals are then mixed by an electrical mixer.

3.2.2. Experiment demonstration

We assume that a mobile signal at very high frequency of 96 GHz must be transmitted from a BBU pool to RRHs. It is not easy to transmit such a signal over a fiber link directly as discussed previously. By using IFoF technology, we can transmit the mobile signal at a much lower frequency together with a LO signal, and at RRHs, a mobile signal at high frequency can be formed using signal up-conversion. To prove the concept, we transmitted an LTE-A signal at 2 GHz to-

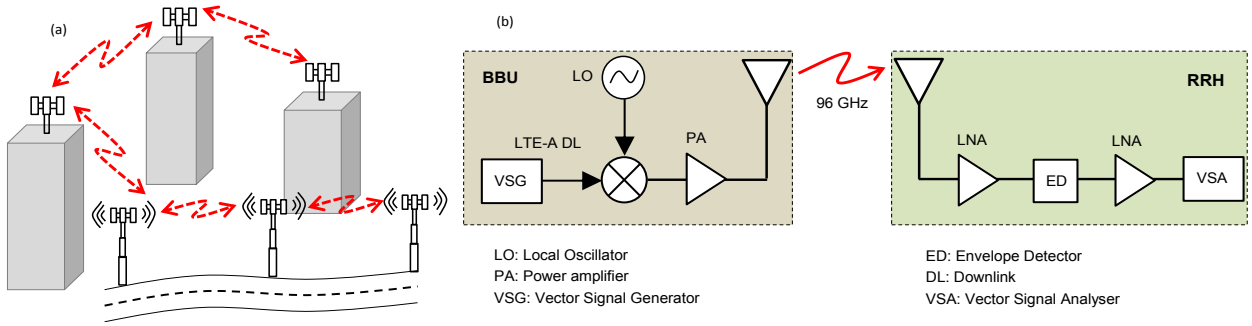

Figure 4: (a) Concept of using MMW links for mobile backhauling and fronthauling. (b) Experimental setup for RoR transmission.

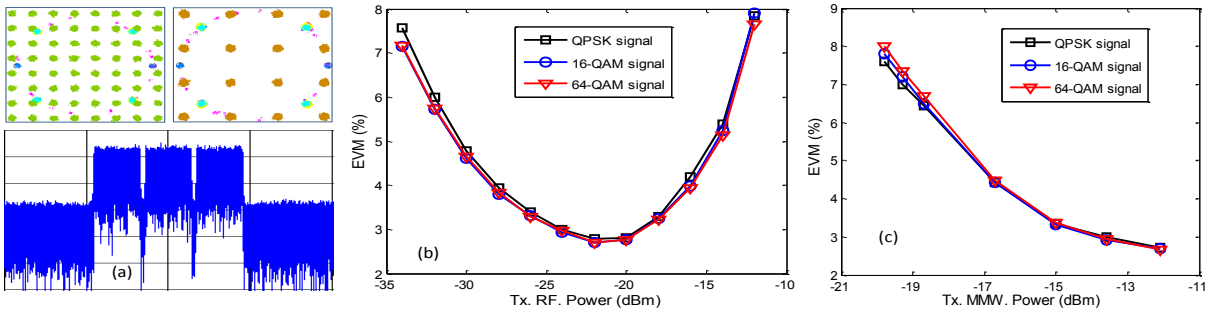

Figure 5: Performance of an LTE-A signal over the RoR system: (a) received spectrum and constellation; (b) versus transmitting power; (c) versus transmitting MMW power.

gether with a 12-GHz synthesized signal over the system. Because of the beating note between the first optical harmonics when modulating the synthesized signal at an optical modulator, at the RRH, a 24-GHz LO signal is generated instead of the originally transmitted 12-GHz signal [11]. This signal is input to a quadrupler for up-conversion to a 96-GHz signal. At the same time, the IF LTE-A signal is also recovered and mixed with the LO signal. This signal is input to an attenuator (ATT) before being down-converted to the original LTE-A signal using an envelope detector (ED). The received signal is then amplified by a low-noise amplifier (LNA) before being sent to a VSA for signal demodulation and analysis. The performance of a 64-QAM LTE-A signal after transmission over the system is shown in Fig. 3(b). Satisfactory performance even for a fiber length of 40 km is observed. The effect of fiber dispersion in this system is quite low. The obtained result confirms the potential of this technology for transmission of future mobile signals in the MMW band or beyond. It helps to improve performance, reduce system cost, and increase the spectral efficiency. Nevertheless, further studies and standardization activities are needed to promote this technology for use in future mobile and wireless networks. Among them, issues related to optical modulation methods and transmission of LO signals over photonic links are important. The recovered LO signal at the RRHs should have low phase noise, high signal-to-noise ratio, and narrow linewidth. The system should also be combined with other digital signal processing techniques to enhance performance.

3.3. Radio-on-radio transmission

3.3.1. Techology overview

In practice, it is not always feasible to use fiber cables. One of the examples is in ultra-dense urban areas where installation of fiber cables is not feasible or too expensive, as shown in Fig. 4(a). In this scenario, the use of fiber-like wireless communications in the MMW and terahertz (THz) bands is very attractive. Compared to fiber systems, wireless-based methods can provide a more flexible, resilient, fast, and low-cost solution. It can also be used for temporary uses or for connecting to remote rural areas where broadband fiber infrastructure is not available. Recently, the use of MMW communications for access and mobile backhaul links has garnered much research attention [12]. By using advanced wireless techniques such as high-order modulation, beamforming, and multiple antennas, a data rate of approximately 10 Gb/s can be achieved [13]. However, similar to the fiber transmissions, the data rate of a digital MMW link can be significantly increased because of the digitization process. For example, to transmit the current LTE-A signal using CA of up to five 20-MHz signals, 2×2 MIMO, and three directional sector antennas, a digital link can require a data rate of about 36.86 Gb/s [14]. This data rate imposes significant challenges to the MMW links. In contrast, if we transmit the LTE-A signal by mapping different signal components onto different IF components, the total required bandwidth can be reduced to approximately 2 GHz. This helps to greatly simplify the MMW links, and consequently reduce the cost,

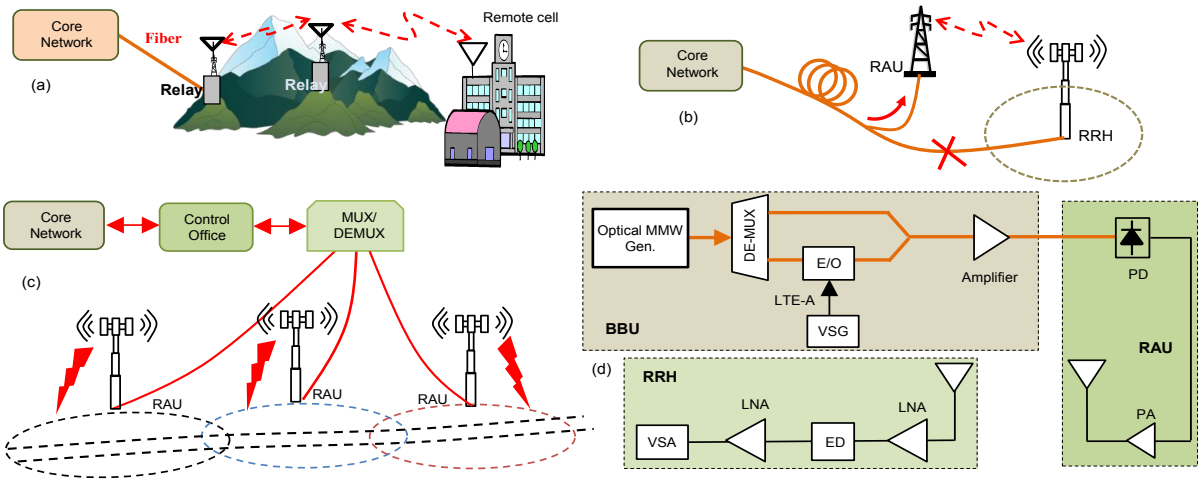

Figure 6: Fiber-MMW systems for (a) remote femto cells and (b) mobile backhaul/fronthaul recovery. (c) High-capacity system for high-speed trains. (d) Experimental setup for a seamless fiber-MMW system.

power consumption, and complexity. Furthermore, an analog waveform transmission helps to reduce the transmission latency and relax the requirement on transmission jitter. From these discussions, the analog waveform transmission of radio signals over MMW links, called RoR, is very promising.

3.3.2. Experiment demonstration

The RoR concept has been mentioned in previous research [15, 16]; however, an experimental investigation on signal performance is not yet available. Here, we present a simple demonstration on transmission of an LTE-A signal at 2 GHz over a 96-GHz link as shown in Fig. 4(b). The LTE-A signal is the same as those in the previous experiments, and the distance of the 96-GHz link is approximately 3 m. At the CS, the generated LTE-A signal is up-converted to 96 GHz using an electrical mixer, which is driven by an electrical LO signal at 96 GHz. The up-converted signal is amplified by a power amplifier (PA) before being fed to a 23-dBi horn antenna to transmit into free space. After transmission over free space, the signal is received by another horn antenna, amplified by an LNA, and down-converted to the originally transmitted LTE-A signal by an ED. The recovered signal is amplified by another LNA, sent to a VSA, and finally analyzed offline by VSA software. Examples of the received spectrum and constellations of 16-QAM and 64-QAM signals are shown in Fig. 5(a). We can observe clear spectrum and clusters with constellation points located at ideal positions. We measured the EVM performance, and the results for different transmission powers are shown in Fig. 5(b). Satisfactory performance is achieved with EVM values much better than the requirements. However, the performance also experiences some degradation when increasing the transmission power. This is caused by nonlinear distortion of the electrical components such as the mixer, PA, and ED.

We also measured the performance for different transmission powers of the MMW signal at the input of the transmitter antenna. This measurement is conducted using a variable attenuator inserted between the PA and the transmitter antenna. From these results, we confirm that a minimum power of approximately -19 dBm should be transmitted in order to recover the 64-QAM LTE-A signal successfully. Using the well-known Friss equation [17], we can estimate that the space loss after 3-m transmission is approximately 82 dB. This means that a minimum power of -55 dBm should be received. If we use high-gain antennas for the transmission, for example 50-dBi parabolic antennas, the distance of the MMW link can be increased to approximately 1.5 km.

Nevertheless, to further enhance the system performance and to promote this technology for practical use, many other issues should be further investigated and studied. Among these are techniques to compensate for nonlinear distortion at the electrical components. Development of a coherent detection method that can help to enhance the performance and increase the receiver sensitivity is another significant topic. In addition, development of integrated circuits that combine different components will also be important for reducing the system noise and complexity, and improve performance. Currently, topics related to 100-Gb/s wireless communication systems using MMW and THz bands are being discussed in IEEE 802.15. However, activities on precise techniques and high-performance systems for RoR transmission have not been considered. Considering the potential of the technology, we believe that it is worth involving it in some standards, such as ITU S15/Q2, or S13 for emerging technology.

3.4. Convergence of fiber and MMW systems

We have discussed the potential of fiber and wireless communications in high-frequency bands. However, in practice, it is not always feasible to use only one transmission medium. The first example is shown in Fig. 6(a), where a fiber cable cannot reach some underserved areas and MMW links are not long enough. In this context, a combination of fiber and MMW links can provide a more useful solution. A combina-

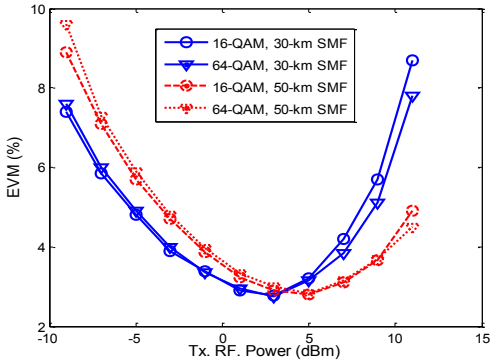

Figure 7: Performance of an LTE-A signal after transmission over a seamless fiber-MMW system.

tion of fiber and MMW systems can be also used in the event of a fiber cable cut due to disasters or accidents, as shown in Fig. 6(b). In this case, installation of new fiber cables can take several weeks or months, which delays service provision to users. In this case, a high-capacity wireless link can combine with the intact fiber span to form a complete system for fast recovery of services. The other major application is shown in Fig. 6(c). To provide high-speed communications to fast-moving vehicles such as high-speed trains, the use of a dual-hop configuration system in which antennas on the ground and antennas on the trains are connected by MMW links is an important approach [18]. In this configuration, an optical network should be used to connect different remote antenna units (RAUs) installed along the railway track with a central control office where all signal processing and control functions are located. By using this system, the number of handovers can be significantly reduced owing to the use of centralized control. From above examples, we can see the potential and importance of convergence of fiber and MMW systems. However, if the fiber and MMW links are connected via a wired -wireless media converter [19], the latency, power consumption, and complexity of the system, especially at the interface, will greatly increase. A photonic-based technology as shown in Fig. 6(d) is more promising for this convergence [20]. In this configuration, an optical MMW signal is first generated, consisting of two optical signals with a frequency difference equal the frequency of the MMW signal to be transmitted. The two optical signals can be separated by a de-multiplexer (DE-MUX). One of the signals is used for data modulation and the other is kept free to work as a reference signal to generate an MMW signal. These two optical signals are then combined again and transmitted via a fiber link to the receiver. An optical amplifier can be used to increase the power level when the transmission distance is long. At the receiver, the signal is input into a high-speed photo-detector (PD). Because of the beating note between the two optical signals at the PD, an electrical signal with a frequency equal to the frequency difference of the optical signals is generated. This generated signal can be fed directly to an antenna to transmit into free space without having to perform any signal conversion and processing. At the receiver, the signal is received, down-converted, and processed as in conventional fiber and wireless systems. Similar to fiber links, both digital and analog signals can be transmitted over the system. Fig. 7 presents an example of system performance for analog signal transmission. In this example, LTE-A signals are transmitted over a converged fiber and 92.5-GHz MMW system. The distance of the MMW link is 3 m. Satisfactory performance is achieved for 16-QAM and 64-QAM LTE-A signals. The fiber dispersion effect is negligible in this system. For digital signal transmission, high-order modulation formats such as M-QAM can be used with coherent detection at the receiver to increase the transmission data rate. This technology has attracted much interest recently, and many demonstrations have been reported [21, 22].

However, there are still many issues that need further study and investigation. Among the important ones are appropriate techniques for generating stable MMW signals with small frequency fluctuation, low phase noise, and narrow linewidth that can follow radio regulations. Development of efficient, compact, and low-power-consumption signal processing algorithms at the receiver site is another key topic. In addition, high-speed real-time systems are essential for applications to practice, especially for transmission of real-time services. Recently, this technology has been introduced in some standardization meetings of ASTAP as a possible solution for future access networks, especially for rural areas [19]. To be promoted as a widely accepted technology for future mobile and access networks, however, other activities on the system level and underlying technologies should be further considered, especially in broader organizations such as ITU.

In addition to the technologies discussed above, many other related topics can be further studied and investigated to develop an efficient transport network for future mobile networks, IoT, and smart cities, and to enhance the user experience and trust on the information and communication infrastructure. Convergence of fixed and mobile networks is one of the important issues to develop an efficient next-generation network. A co-design, co-operation, and co-optimization of fiber transport networks and RANs will help to achieve the targets of 5G as well as explore new capabilities. Photonic-based technologies such as optical beamforming, optical multi-point co-operation, full coherent fiber-wireless, and adaptive and co-operative transmission are among the possible methods that should be further investigated. Development of a new control protocol for the network convergence, and design of new interfaces and functional shift for the mobile fronthaul networks are other topics that need further study and standardization efforts.

4. CONCLUSION

Transport networks will play a vital role in the development of future mobile networks such as 5G and beyond. It should be constructed using a variety of technologies and network configurations, depending on the geographical areas, deployment models, and application scenarios. In addition, development of new broadband access networks that can be de-

ployed in undeserved areas cost-effectively and quickly is another important issue to achieve the goal of Connect 2020. In this paper, we presented several promising solutions that can be used to facilitate achieving the targets of 5G and Connect 2020. Analog RoF systems can provide low-latency and low-cost transmission of future mobile signals, especially in the high-frequency bands. IFoF is another promising solution for low-latency and high-spectrum-efficiency systems for transmission of mobile signals in the MMW band and beyond. RoR transmission can provide low cost, energy efficiency, and low latency for applications in ultra-dense urban or dead-zone areas. Finally, the convergence of fiber and MMW systems can provide solutions to many use cases, including fast recovery of services, broadband service provision to remote rural areas, or high-seed communications to fast moving vehicles. These technologies can be useful in many applications in future mobile and access networks. They should be the topics for further research and standardization efforts.

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A UNIFIED FRAMEWORK OF INTERNET ACCESS SPEED MEASUREMENTS

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ABSTRACT

The evolution of Internet access technologies, together with the wide diversity of customer devices, has led to a complex scenario where measuring basic metrics with accuracy has become a rather complicated task. Although nowadays there are a lot of tools to assess the rate of Internet speed, most of them share neither the methodology nor the infrastructure to produce comparable results.
In this regard, the development of a unified approach to measure the Internet speed would be beneficial for all ICT players. The establishment of such proposal would inspire better confidence in consumers through the provision of precise comparisons, and it would also be very useful to operators, regulators and providers. Towards this aim, the ITU-T has been working on the definition of a unified methodology and measurement framework to assess the rate of Internet speed.
This paper presents a detailed description of the work that is being done at present in the definition of the aforementioned framework.

***Keywords*—** Internet speed measurement, framework, bandwidth, access speed, latency.

1. INTRODUCTION

From the best-effort era of Internet to the immersion stage of technology in our daily lives, an important transition has occurred interfering in the way we interact with the world. Nowadays, users demand the best quality in terms of speed, ubiquity and full-time connectivity [1] and react with frustration when any interruption or malfunctioning of the contracted service is perceived [2], especially in mobile scenarios where network variability is still a challenge [3]. Aware of the potential impact in the market, many ICT players have seen the necessity for reliable methods to assess the compliance of customer's expectations to the contracted Service Level Agreement (SLA) [4].

As a result, many Quality of Service (QoS) measurement systems and tools [5-8] have emerged, focused on the most typical Internet metrics: download/upload transmission speed and latency. However, results comparison amongst them is not feasible due to several factors, including the purpose of the tests, the measurement infrastructures and the methodologies.

In this regard, it is crucial for the users of these tests to be well informed about the meaning and scope of the measured parameters. Internet users usually estimate their Internet access quality based on their experience in the Web navigation service. Hence, their judgment depends basically on their perception of the web pages loading times [9] and the download bit rate to an Internet resource. Measurement tools with servers in different countries [7-8] might be useful for the estimation of the *access speed to an Internet resource*, but not for verifying the compliance of the *access speed to the Internet* offered by the provider within the SLA. These two Internet speed concepts are often intermingled causing great confusion to users.

The underlying reality to this situation is that, despite the widespread use of Internet, there is still no regulation promoted by standardization bodies about how to perform speed measurements in order to avoid these concerns.

The ITU-T (International Telecommunication Union-Standardization Sector) has taken this challenge and is working on the definition of a new standard to fill the absence of a unified approach to Internet speed measurements (Q.Int_Speed_Test Recommendation [10]). In recent times, due to the complex task that has to be faced, the base draft of this recommendation has led to two different drafts. The first one attends to the definition of a framework for the standardized measurement of Internet speed (Q.FW_Int_sp_test [11]) and the second one, to the choice of the most adequate methodologies to be used within the defined framework (Q.TM_Int_sp_test [12]).

Several research centers, regulators and operators are participating in this work item [13], with the support of the ITU-T Conformity and Interoperability Group (C&I) [14] and the collaboration of the Organization for Economic Co-operation and Development (OECD) [15]. It should be remarked that an ITU academia member, the University of the Basque Country (UPV/EHU), is the editor of these two recommendations, which makes evident that the position of academia is taking hold in the ITU-T.

This paper aims to disseminate the work that is being done on the definition of the aforementioned framework.

2. BACKGROUND

2.1. Regulation on Internet access services

Different Internet speed measurement approaches have become the "de-facto mechanisms" and are being used by operators and regulators in the evaluation of the SLA. As stated in the 2014th OECD report on Access Network Speed Tests, 19 countries participate in official projects to measure QoS performance including Internet speed, and three more are planning future projects [16].

Table 1. OECD countries with official measurement projects

Country	Authority	Fixed or Unspecified broadband	Mobile broadband
Australia	Department of communications	EAM	EAM
Austria	RTR	EAM	EAM
Canada	CRTC	EDM	
Czech Republic	CTU		PSM-ISP, PSM for check
Denmark	Danish Business Authority	EAM	EAM
France	ARCEP	PSM-ISP	PSM
Germany	Bundesnetzagentur	PSM (-2013) EAM (2015-)	PSM (2012) EAM (2015-)
Greece	EETT	PSM & EAM	PSM & EAM
Italy	AGCOM	EAM, PSM for check	PSM
Korea	Ministry of Science, ICT and Future Planning	PSM and PSM-ISP	PSM
New Zealand	Commerce Commission	EDM	
Norway	Norwegian Communications Authority (Nkom)	EAM	EAM
Portugal	ANACOM	EAM	EAM
Slovenia	AKOS	EAM	
Spain	Ministry of Industry, Energy and Tourism (Minetur)	PSM-ISP	PSM-ISP
Turkey	Information and Communication Technologies Authority of Turkey	PSM-ISP	
United Kingdom	OFCOM	EDM	PSM

Table 1 summarizes the main alternatives used in both fixed and mobile broadband connections in different countries:

- **End-user Application Measurement (EAM):** This method requires the customer, on his will, to access the tests from a browser or an application under his control.
- **End-user Device Measurement (EDM):** The tests are carried out from a device installed in the users' network but controlled remotely by the project. In this case, the measurements are taken apart from the daily use of Internet by the customer.
- **Project Self Measurement (PSM):** This alternative does not require the client's network for the measurements. An entity, different to the ISP, defines a set of devices (probes) for the solely use of testing. If these tests are carried out by the ISPs themselves, this alternative is known as PSM-ISP.

A simple reading of the description of the three alternatives evidences quite a complexity when trying to correlate results that satisfy both users and operators. Tests driven by users from their own devices (EAM), do offer closer results to the navigational experience of the user, in particular when executed at application level.

However, operators require a deeper analysis of their access network, trying to avoid any dependency on the user's hardware and software, and thus requiring controlled measurement tests such as PSM or even EDM, which may differ from the conditions perceived by the customers.

In any case, and despite the adoption of any of these alternatives, the tests may *"not always provide the information needed to inform specific policy and regulatory goals"* [15].

Nowadays, existing standards define some basic guidelines for the measurement of Internet access speed [17], but most of them consider neither the multithreading capabilities of modern browsers nor any specific requirements of mobile networks. Also, the adoption of these standards by local regulators often includes additional considerations not contemplated in the guidelines.

Due to all these reasons, a standardized approach to define an Internet speed measurement may be really beneficial to all ICT players.

2.2. Scientific research

In recent times, there has been a significant amount of scientific proposals on the measurement of Internet QoS performance. Many authors have designed tools with important contributions to this topic, such as Pathload in 2003 [18], Traceband in 2010 [19] together with new models and methods, like AProbing [20]. Besides these techniques, other infrastructures for the QoS evaluation [21-22] have also been developed to provide an environment to bring in and execute any QoS measurement tool.

Many of the existing proposals are efficient in controlled environments and simulation. However, the heterogeneity of current networks may affect the accuracy of many of these contributions. As a conclusion, there is a need for further research in the design of measurement tools flexible to be adapted to multiple network conditions and different measurement scopes [23].

Meanwhile, Internet users have experienced higher speed connections and new data transmission services, unthinkable a few years back, such as high-definition video streaming and other cloud-based applications. Due to this wide range of offered services, users increasingly demand more quality of service at a higher rate than the providers can handle. As a result, operators and ISPs are displacing self developed projects in favor of publicly available Internet speed measurement tools, such as Ookla's SpeedTest [8]. Orange, Vodafone and Telefónica, three well known telecom operators, are good sample of this position [24].

On an institutional level, there are also measurement tools as the one developed by SamKnows [25]. This project counts with the support of several international institutions such as the European Commission and the USA's Federal Communications Commission (FCC). They have developed an EDM project to which customers freely sign up as volunteers to install a middlebox in their home network. This probe is set to monitor the Internet access quality through tests launched according to a defined schedule and a detailed report is provided to users on a monthly basis.

Nevertheless, and despite the existing range of tools and their benefits, there are still very important issues that need to be analyzed.

2.3. Issues to be faced

As a result of the different approaches and the diverse amount of the network segments used during a peer-to-peer testing, the results achieved by each of the measurement methods may be very different and no comparison is reliable enough to assure users conformance.

In addition, the results may not be accurate due to the existence of one or many of the following factors:

- Overload of the measured server and its capabilities.
- Dependency on hardware and performance of the customer's equipment.
- Dependency on the installed software (e.g. operating system, applications, etc.) and/or available performance of the user's terminal at the time of measurement.
- Existence of activated security software and/or hardware (e.g. firewalls, anti-virus, etc.) at the time of measurement.
- Network performance and the level of utilization of customer's interface connected to the Internet at the time of measurement.

In order to increase accuracy and minimize some of the previous factors, some existing methods drop around 40% of the measurement results, which, in the end, may also have influence in obtaining a reliable result [26].

Other methods collect additional data in order to identify specific network conditions (e.g. busy hour), yet this information is highly dependent on each operator and can only be offered as an orientative reference to users.

Finally, most of the measurement methods do not consider wireless or mobile environments. In such scenarios, any adjustment in the test parameters that was adequate on the available conditions at the beginning of the test might not be adequate during its execution. The huge dependency in coverage that a mobile device suffers, even being in a fixed place during the test, can invalidate the results.

To sum up, all these factors must be regarded thoroughly in both the definition of a standardized framework and the specification of the most adequate methodology for the measurement of Internet access speed.

3. THE FRAMEWORK

3.1. Scope of the framework

The future ITU-T Q.FW_Int_sp_test recommendation *"describes the framework of Internet speed quality measurement and specifies the requirements and architecture of the measurement system to be used for assessing the Internet speed connection"* [11].

Thus, the scope of this framework is to provide the architecture of the standard measurement scenarios, the measurement parameters, and the measurement procedure. In addition, it aims to describe the requirements for the measurement algorithm to be used on the fixed and mobile operators to estimate the access speed to the Internet resources. Under these considerations, a methodology or set of methodologies must be defined. These methodological procedures should converge into results comparability and provide more accurate information to both customers and operators on the compliance of the contracted SLAs.

Therefore, "*the framework is targeted at regulators, aiming to set up guiding principles regarding the establishment of the global standardized architecture to be used for the assessment of the Internet speed connection at the national level. The key goal of the framework is to provide transparent, trust-based approach which measurement results can be accepted by all ICT players (e.g. Regulator, Operator, ISP, customer, etc.)*". [11].

3.2. Measurement tests definition

The framework defines a dual testing based on the different points of view that customers and operators have on quality assessment [27]: Operators and regulators aim to evaluate Internet access speed within the barriers of the operator network to verify the level of compliance within the SLA, whereas customers usually evaluate the Internet access speed in terms of the Quality of Experience (QoE) [28] in the Web service.

As a result of this, two measurement tests are proposed for the estimation of Internet speed quality: The *Network Internet speed test* and the *Internet resource speed test*.

The first test considers the operator network itself and it may be used for SLA compliance monitoring and the second one considers the whole access speed to an Internet resource, since this measurement may be closer to the Internet speed quality as perceived by user.

The definitions of each measurement are next detailed (figure 1):

- **The Network Internet speed test:**

  This test has been defined to measure the absolute value of the end-to-end data transmission speed (bit rate) between the customer's Measurement Agent (MA) and an external interface of exchange point (peering point) ("A" in figure 1). This measurement should include the whole operator's network (access, transport, service control segments) up to the Exchange Point (EP) and should be measured on the output of a specific exchange point interface (i.e. the exchange point with the highest data volume exchange used by operator).

- **The Internet resource speed test:**

  This test has been defined to measure the absolute value of the end-to-end data transmission speed (bit rate) amongst the customer's Measurement Agent (MA) and a relevant Internet resource ("B" in figure 1). This measurement should include the whole network from the customer side to the relevant Internet Resource (IR).

In both cases, the measurement should be based on algorithms and protocols of the TCP/IP model and should be adaptable to the technologies that are used on the MA.

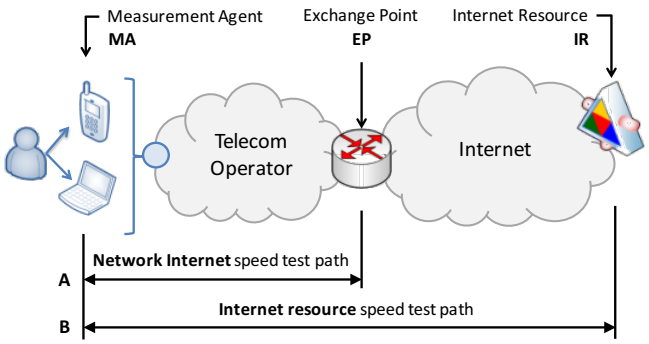

Figure 1. Global scenario and test definition

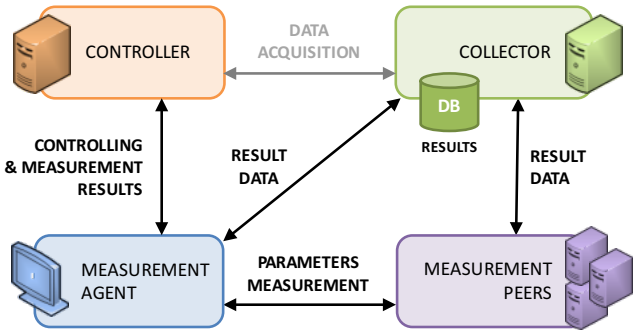

Figure 2. Test facilities defined in the Framework

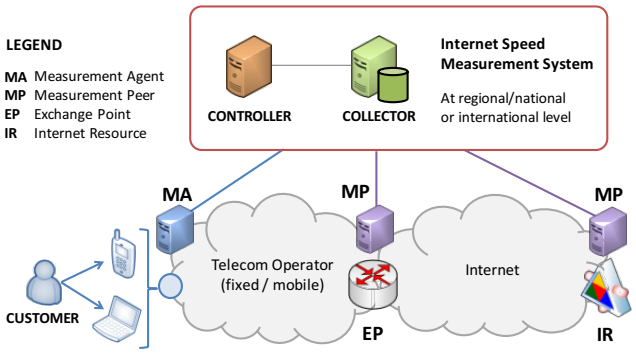

Figure 3. Internet speed measurement system architecture

3.3. Basic measurement principles

The measurement procedure should be based on a transparent approach which all ICT players can rely on. In this sense, regarding the location of the measurement system, two different options may be implemented:

- Outside operator's facilities (independent premises).
- On the existing operator's networks.

Also, the measurement system might be implemented at the national and/or international level. The implementation on the international level is a better solution for the assessment of the Internet resources access speed, due to the accuracy of measurements, the comprehensive analyses of user's hardware and software, the global visualization of measured results and some other aspects.

In spite of the location, all involved ICT players must have the comprehensive access to the features of the measurement system in accordance with their rights. At least, each of them should have guaranteed the access to the measurement data.

3.4. Test facilities

A measurement system has been defined for the two types of testing (Figure 2). This infrastructure will be composed of the following elements:

- *Controller:* Software and/or hardware tool to control testing procedures on a Measurement Agent (MA). The Controller should allow uploading test scripts on any MA and execute relevant test scenarios on it.
- *Collector:* Software and/or hardware tool to collect measurement and statistical data from all the Measurement Agents connected to the Controller.
- *Measurement Peer (MP):* Software and/or hardware to respond on testing messages sent from the MA.
- *Measurement Agent (MA):* Software and/or hardware that executes test scripts obtained from Controller. This equipment admits two different configurations: It can either be a single device owned by the user (Customer Equipment, CE), or involve a local measurement device, integrated in the CE or in the form of a middlebox (a probe). This layout has been considered for non user dependent measurements by operators and/or for the unwilling sacrifice of a hotspot limited resources [29].

3.5. Architecture of the measurement system

Figure 3 illustrates the architecture of the measurement system. Depending on which of the two testing is being executed, the location of the measurement peer differs:

- *Measurement Peer in the Network Internet speed test:* The peer should be placed on the output of the exchange point interface (peering point) that connects the operator's network to the rest of the Internet (figure 4, left). If any existing limitation implied that this location could not be contemplated, the operator is allowed to locate the MP within the operator's network, as close to the internal interface of the EP as possible, assuring guaranteed bandwidth on this direction.
- *Measurement Peer in the Internet resource speed test:* In this case, the MP should generally be located within the same domains of the Internet resource (figure 4, right). However, this option may depend on the objectives of the test methodology and therefore result as a non feasible alternative. The definition of a separate ITU-T Recommendation has been accorded for this matter.

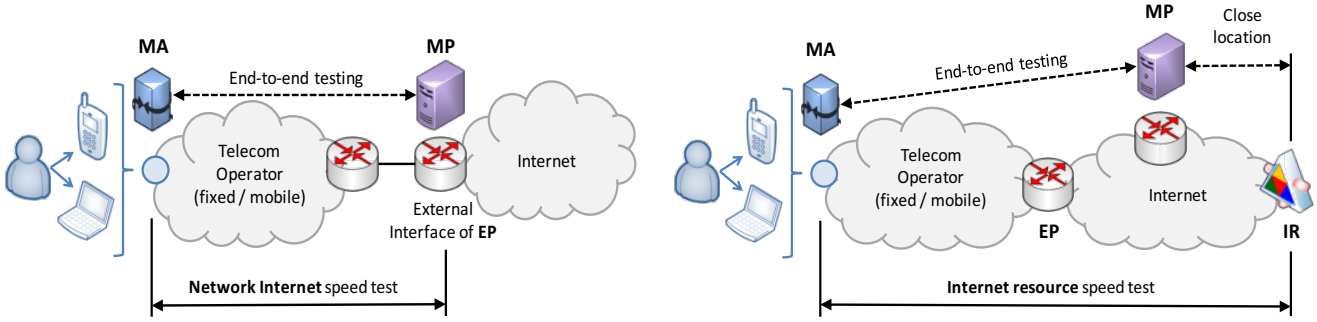

Figure 4. Network Internet speed test and Internet resource speed test schematics

5. TEST PROCEDURE

5.1. General description

For the execution of both measurement tests, several interactions amongst the test facilities and the measurement peers are required (figure 5):

- *Step 1. Test Initialization:* Users will have access to the measurement test scripts from their equipment throughout a web page or an application connected to the Controller. The test scripts will be uploaded from the Controller to the Measurement Agent. In case of complex MA with a detached measurement device configuration, the scripts are automatically downloaded to the middlebox without the user's interaction.
- *Step 2. Test Execution:* Once the test is accessed in the MA, it will be executed towards different measurement peers located in the exchange point or in the Internet resource as required by the customer or the middlebox scheduling. The test methodologies to be used at this step will be specified in the ITU-T Q.TM_Int_sp_test Recommendation [12].
- *Step 3. Test Finalization:* The measurement results will be collected in the Collector (which can coexist with the Controller). In addition, the results of the test execution can be sent either directly from the equipment to the Collector or throughout the Controller, considering security and/or privacy issues (dotted line in figure 5 represents this situation).

  When the test is accessed directly by end users, hardware and/or software information (browser, operating system) may be collected for better statistical results and data comparison. Also, when in mobile environments, additional information on connectivity, signal to noise ratio or signal strength during the test could be collected (amongst other parameters). The framework should be capable of the measurement and transmission of any valuable information, as required by the test methodology to be applied.

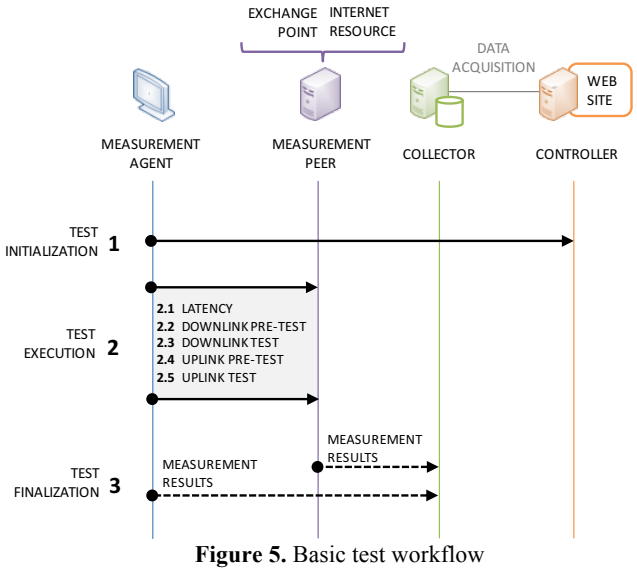

Figure 5. Basic test workflow

All collected data will be useful to detect unsuitable configurations and problems in the user's local network or equipment that may lead to unreliable measurements. This way, users can be warned their results may neither be conclusive nor binding to the real SLA values.

It must be taken into account that collecting user's information can be a sensitive issue since it could threaten the privacy of the user if some delicate information is collected (i.e. geolocation). This is still an open issue to be defined in future recommendation.

Once the statistics have been stored, all authorized users will have the possibility to display the available measurement results at a dedicated web page. If using the Controller for the outcome results comparison or reports presentation, a request path for data acquisition should be implemented between Controller and Collector.

Asides from this basic workflow, additional functionalities could be offered to clients with the aim of collecting further information. For instance, user's registration could be also available to facilitate users sharing and comparing their results and to access the historical of their measurements. User's registration would also help to collect general information for statistical data analysis (region and country averages, ISPs results information...). Nevertheless, registration should not be a requirement to use the test.

5.2. Test parameters

There are certain aspects of the Internet speed measurement methodology draft [12] that are also included in the framework recommendation [11] as high level headlines. That is the case of the proper parameters to be measured and the basic approach to the methodology itself.

There are three parameters that have been identified for both the Internet access speed test and the Internet resource access speed test:

- *Download data transmission speed:* The data transmission speed achieved in the downlink between the measurement agent and the correspondent measurement peer.
- *Upload data transmission speed:* The data transmission speed achieved in the uplink between the measurement agent and the correspondent measurement peer.
- *Two-way delay:* Also defined as the Round-Trip Time (RTT) delay, the two-way delay is twice "*the time required for a packet to traverse the network or a segment of the network*" (ITU-T Rec. G.1050 [30]).

5.3. Test methodology

Finally, this paper aims to introduce some open issues and considerations of the parallel methodology draft that are still under study. Prior to division of the Q.Int_Speed_Test draft [10] into the framework [11] and methodology [12] paths, four different alternatives had been considered for the basic Internet speed measurement procedure:

– Transmitting a fixed volume of data within a maximum timeout limit.

- Transmitting a finite but variable/adaptable volume of data within a timeout limit.
- Transmitting unlimited data continuously for a limited period of time.
- Transmitting an unlimited volume of data with no time limit until the speed measurement is stabilized.

The fourth alternative seems the most adequate in terms of accuracy, as required in section 4 of this paper. However, some limitations must be observed, since the unified methodology is meant to be accessible to customers and, at this moment, loading time seems to be the key factor for them when measuring Internet access speed [9], especially in mobile networks, where transmitting high volumes of data is also a matter to consider.

Multithreading capabilities of modern browsers and stability problems of wireless connections are also subject of study. Specifically in mobile networks, there is a dependency on user's location and movements, environmental conditions and other factors. Measurements taken in mobile networks can only show a situation at a particular time and place of testing. Therefore, in order to obtain the characterization of a particular area, a lot of results have to be gathered by launching multiple measurement tests in that specific coverage zone.

The study of these and other issues is paramount for the proper measurement methodology definition.

6. CONCLUSIONS

This paper introduces a novel unified framework for the measurement of Internet speed in both fixed and mobile networks. The ITU-T is carrying out the definition and standardization of this framework with the cooperation of research centers, regulators, operators, official telecom organizations and academia.

The framework draft is expected to be approved in December 2015, as an ITU-T Q series recommendation. Its aim is to set guidelines and principles for the estimation of Internet speed through a neutral and trust-based approach for both operators and users. As a result, operators will have a reliable tool to verify SLA compliance and users will have the chance to compare their results with the ones offered by other ISPs and operators.

Finally, the framework aims to improve the mobile access experience to customers by offering operators a mean to detect the strengths and weaknesses of their systems. In this regard, a global QoS observatory at a national or even international level could be established for the monitoring and evolution of Internet performance.

In fact, the test facilities architecture defined in this framework could serve in the evaluation of other Internet based services asides from the measurement of Internet speed, such as VoIP and video streaming services, or even new cloud based services. The inclusion of evaluation tests for these other services would definitely enrich the global QoS observatory for all ICT players of the sector.

7. ACKNOWLEDGEMENTS

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WHY WE STILL NEED STANDARDIZED INTERNET SPEED MEASUREMENT MECHANISMS FOR END USERS

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ABSTRACT

After several years of research towards sophisticated QoS measurement tools and methods, the results given to end-users by most commonly used on-line speed measurement tools are still far from being precise. In order to define a reliable Internet speed measurement methodology for end-users, the impact that the static and dynamic constraints of network nodes and TCP/IP implementations could impose must be first carefully analyzed. Such constraints will determine the measurement methodology to be defined in terms of measurement periods, number of concurrent connections and convergence time by deployment of controlled simulation/emulation environments and real world comparisons. This paper presents a detailed description of the works and leaves hints to be followed, aiming to get a full understanding of cross-layer effects during a speed test targeting end-user.

Index Terms— QoS, TCP, measurement, ns-3, DCE

1. INTRODUCTION

The continuous growth of smartphones, together with the increase of wired broadband access around the world, has led to a massive utilization of the network, with over 3 billion users [1]. As a side effect, this usage rise has helped to a better common understanding of communication technologies and computer networks among citizens. Due to this, nowadays, people are becoming aware of to which extent they are receiving the service they are paying for and feeling more comfortable with the technical terminology related to "Internet speed" .

As a result, many different tests are publicly available to measure the most relevant QoS parameters for end users, particularly those related with bandwidth and latency. However, after a quick look at the obtained results from such tests, huge differences appear leading to confusion and uncertainties for end users. In Figure 1, for the same network conditions and different realizations, Downlink and Uplink values obtained for most popular online tests are depicted (name of the tests hidden for privacy reason). Although different realizations for the same online test lead to quite equivalent values, differences appear in even one order of magnitude among tests. So, such differences between realizations could be at some point be provoked by transient network conditions but the reliability and comparability requirements are far from being met.

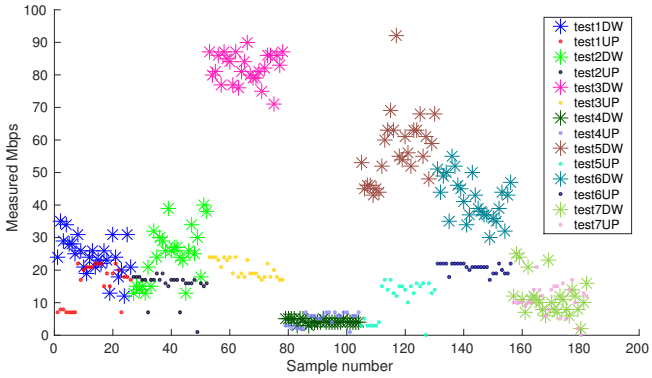


Figure 1: Results for common on-line "speed" tests

But, may this ambiguity be caused by technical constraints or by the lack of standardized measurement methodologies?. Latest research should be revisited in order to answer this question but, even before that, it is essential to carefully analyze the current different tests and which parameters are aimed at measuring. The estimated speed is usually represented in several different ways, without tests always specifying which particular metric they are referring to: ranging from link capacity [2] to available bandwidth (ABW) -the maximum bandwidth unused at certain point- or bulk transfer capacity (BTC) -the maximum achievable throughput by a TCP flow [3]- among others. Furthermore, there exist multiple measurement techniques for these indicators which researchers tend to classify into three different groups: active probing [4, 5], passive estimation [6] and mathematical model based [7].

However, such sophisticated techniques and tools turned out to be apparently useless, due to a poor estimation of the available bandwidth [8, 9], dependence on TCP flavour [10] or user equipment/network conditions requirements.

On the other hand, most of the online tests have not publicly released detailed technical descriptions of the measurement methodology in order to guarantee reliable enough results irrespective of different TCP/IP implementations or user equipment characteristics (apart from, for example, [11]).

Thirdly, most Standards Developing Organizations (SDOs) have their own and usually overlapping definitions of "speed" related Key Performance Indicators (KPIs) and measurement mechanisms but none of them have prevailed versus the users' "de facto" standard of most famous online tests.

Considering the cross–layer effects and dependance on underlying access and core technologies, a proper analysis of speed measurement methodologies should therefore learn from TCP's behaviour and patterns. It is crucial to have those mechanisms performing in different nowadays scenarios as to enable the definition of standardized measurement techniques and reducing aforementioned uncertainties.

For all those reasons, the purpose of this paper is manifold:

- To analyze standardization activities covering speed measurement mechanisms for end users.
- To describe how there exist several static and dynamic constraints in TCP behaviour that may affect the reliability of any tests and prevent their usability for comparison purposes.
- To provide real world evidences of the impact of these constraints into current networks, covering most of TCP flavours today.
- Provide basic guidelines to minimize such constraints and therefore, set the foundations for end users speed measurements standard development.

The structure of the paper is as follows: Section 2 describes the most representative aspects of TCP based speed measurement tests to take into account and associated relevant works. In order to clearly show the different points, the section has been divided into four subsections; TCP's multiple faces to underline different TCP flavours' behaviour, the impact of TCP parallelization techniques in nowadays tests, TCP's special events and effects, and finally, standardization status. Later, Section 3 describes the methodology followed to identify TCP's static and dynamic constraints and final comparison with live networks. Finally, based on the previous demonstrations, the paper will conclude (Section 4) summarizing major results and obtained conclusions. This way, the paper aims to encourage other researchers to join and follow the suggested path towards an unified methodology.

2. BACKGROUND

[12] and more recently [13] surveys provide a particularly comprehensive review of bandwidth estimation techniques, including a taxonomy and a brief analysis of pros and cons from a technical point of view. Unfortunately, regardless the achieved accuracy, most of them demand a set of requirements that prevent a widespread adoption, or at least, similar to that of web based speed test (just requiring a regular web browser and using HTTP/TCP/IP protocols). On the other hand, both aforementioned and other previous studies provide a good starting point to identify the different features to tackle, which will be described in the following subsections.

2.1. TCP's multiple faces

TCP has several flavours being the congestion control algorithm (CCA) an aspect to be particularly addressed due to its impact into the protocol performance. Considering different CCA's reactions to network conditions, an ideal measurement methodology should be capable of providing end users with as "accurate and CCA independent" as possible estimations. In order to further advance in the analysis of CCA caused bias, both theoretical [14] and simulation based studies [15] have been carried out. Figure 2 on the top shows the evolution of the congestion window (CWND) for different CCAs over the same scenario and conditions. Considering the relationship between CWND evolution and achieved speed it can be easily concluded how different flavours show a extremely different behaviour in terms of not only both maximum and average CWND but also its temporal evolution (i.e. time to reach the maximum and meaningful measurement period).

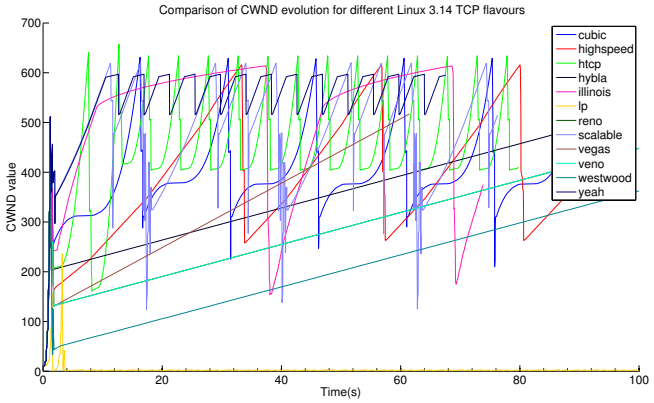


Figure 2: TCP flavours behaviour over the same conditions.

2.2. Multiple parallel TCP connection based tests

Even though some studies have shown that this technique is extremely invasive and uncontrollable [16], the use of more than one flow in order to fully *"fill the pipe"* is the most common trend nowadays.

If a single TCP flow is often unpredictable and highly flavour-dependent, multi-thread based measurement tools result therefore in a more challenging research task. To the original problem of differences for a single isolated connection due to TCP's implementation, friendliness and fairness aspects must be now added.

Figure 3 shows the aggregate congestion window of multiple flows for different flavours. Resulting apparent randomness makes it difficult to foresee a straightforward common criteria for required measurement intervals or even some kind of normalization between flavours.

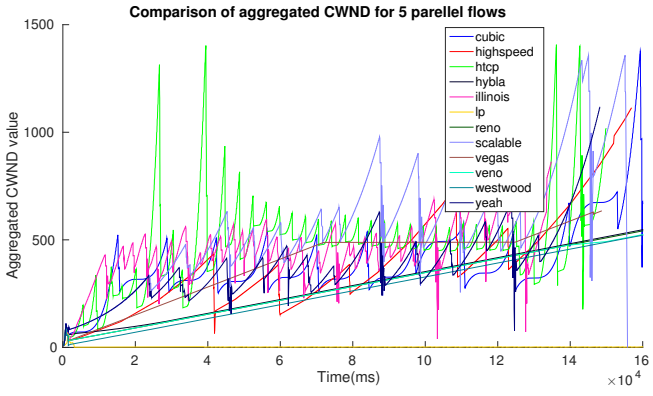


Figure 3: TCP flavours aggregated CWND in multi-thread tests.

2.3. TCP dynamics, bufferbloat and buffer size effects

Flow control and error recovery related feedback mechanism may result in idle times and inefficiency, specially in large Bandwidth-delay product (BDP) networks. Variable sliding window based reliable transport protocols such as TCP try to put in flight as many packets as possible in order to avoid such problems. Thus, a steady end-to-end flow of packets at the maximum rate demands that packets-in-flight must be enough to *"fill the pipe"* between sender and destination.

Resulting CWND growing mechanisms (as shown in Figure 2 and 3) and associated need for absorbing occasional packet bursts in variable capacity links, together with the reduction of RAM costs in network devices, has led to a remarkable increase in the buffer size both in the end and intermediate boxes.

That phenomenon is called bufferbloat [17] and, although achieves maximum performance in terms of throughput, also leads to a considerable packet delay increase and other undesirable effects in the competition between existing and new TCP flows. In fact, after so many year of TCP/IP networks, how to define transport protocols capable of using all available capacity while minimizing delay due to oversized buffers is still an active research area today (see [18, 19]). Thus, widespread CCA algorithms and queueing mechanisms in most current network equipment still suffer such effect (in terms of unacceptable delay [20]), therefore leading to the appearance of a new determinant factor affecting achievable maximum speed to be considered in the scope of our analysis.

2.4. Standardization activities status

Once the background of different open issues has been explained, it is crucial to review the standardization bodies and regulators work in progress in the area of Internet speed measurement tools for citizens.

The European Telecommunications Standards Institute (ETSI), through its draft STQ-219, is trying to define a methodology or framework to measure a certain user's QoS. In that sense, they have established different parameters such as measurement phases, durations and message exchange. However, no technical report providing a comprehensive explanation of the rationale of such selections has been released yet.

On the other hand, Standardization Sector of International Telecommunications Union (ITU-T) Study Group 11 (SG-11) [21] is working on an equivalent methodology targeting citizens' right for a common reliable way for assessing Internet access quality.

Regarding TCP' technical performance and insights, the Internet Engineering Task Force (IETF) has several contributions through Request for Comments (RFC). For instance, RFC5681(TCP Congestion Control) [22] defined TCP's basis such as slow start phase, congestion avoidance phase, fast retransmit, fast recovery and some loss recovery mechanisms. Afterwards, RFC7323 (TCP Extensions for High Performance) [23] was published to underline the impact of TCP timestamps and window scaling (WS) on the performance.

Across the IETF and their working groups (WG) [24], there are a couple of them defining related issues and concerns. RTP Media Congestion Avoidance Techniques (rmcat) are involved in establishing congestion avoidance techniques to improve the performance, bottleneck detection, impact of cross traffic, algorithms design and so forth. IP Performance Metrics (ippm) are working with passive, active and model-based methods to measure the bandwidth, even trying to establish their own *Model Based Metrics for Bulk Transport Capacity*. To get to that point, they have defined, at least briefly, most of the open issues regarding the measurement itself and cross layer effects.

In terms of available online tests, the Organisation for Economic Co-operation and Development (OECD) has compiled a repository of the most representative tools from each country, in order to enable citizens to access them easily in a common repository [25].

Last but not least, inside IETF's IRTF branch, there is a group called Internet Congestion Control Research Group (ICCRG) [26] working to also explain from research the nowadays network issues. They have underlined very interesting 7 main challenges still pending to be solved (RFC6077) and suggested a safe increase of the TCP's initial window using initial spreading to reduce latency in short-lived connections.

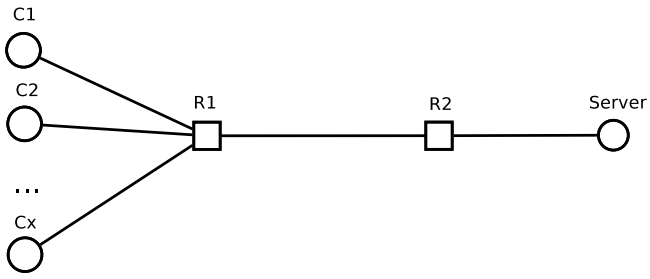
All these standardization efforts, however, have not yet resulted in an unified Internet Speed measurement methodology for end users. The process described in the following section aims at laying the foundation for a technically accurate definition of such estimator to be transpose into usable standard.

3. TCP FLAVOURS' IMPACT EVALUATION METHODOLOGY

A comprehensive set of simulations, both lab and real network tests, have been carried out in this study. The target: to evaluate to which extent the behaviour of existing TCP's different implementations entitle a obstacle to reliable speed measurement mechanism for end users in terms of a)

Size of the buffers and WS options b) time to reach maximum effective window size c) bufferbloat effect into goodput vs. CWND evolution behaviour and d) resulting needs in terms of number of concurrent connections and measurement interval. In this Section, the methodology is going to be presented, explaining which scenarios and targets have been used and followed. Figure 4 shows the two different scenarios that have been used in the different stages of this analysis, apart from lab network dump.

(a) Live tests



(b) NS-3 dumbbell scenario

Figure 4: Different scenarios.

One of the initial considerations for the design of the measurement methodology are the duration of the test and number of parallel connections. The ideal case would be that each measurement could be completed within few seconds even in "challenging" network conditions (i.e. high BDP). However, considering CWND' evolution first requirement must be ensuring that the test is long enough as to allow the maximum window size to be reached. This maximum window size can be limited by different static and dynamic factors regardless theoretical limit, therefore the value of this Maximum Effective Window Size (MEWS, involving both flow and congestion control mechanisms) will be also analyzed. In order to clarify the agents impacting on the MEWS, we decided to divide the research in the following different stages:

- Stage 1 - Static constraints: The main initial constraints to analyze are operating system (OS) dependent factors, usually configurable and with impact on flow control. These include transmission buffers sizes (in terms of maximum allocable window in both sender and receiver) and window scaling (WS, used to extend the 64 KB limit of flow control related advertised window field in TCP header) options. Since the OS buffer size is dependent on end users and servers equipment, we have focused on window scaling negotiation.
  The WS negotiation was obtained by capturing in a real network: the subnet of the research group located in the University of the Basque Country. The network dump took place without previous notification to our colleagues, to capture a normal day's traffic flows.

- Stage 2 - Dynamic constraints are linked with the behaviour of each TCP flavour under certain network conditions in terms of congestion and flow control mechanisms. In order to automate such analysis for as many up-to-date realistic TCP flavours, we deployed a hybrid simulation/emulation framework based on NS-3 network simulator. Figure 4b scenario shows the developed architecture, being a dumbbell topology with multiple clients and a single server and having the bottleneck between the routers (R1 and R2).
  The use of Direct Code Execution (DCE) instead of pure NS-3 simulated nodes allows the execution of a full Linux networking stack [27, 28]. and therefore all the settings of nowadays TCP implementations were available to be analyzed or changed. In this stage, we reproduced real world situations with cross traffic of different features for all TCP flavours available in the Linux kernel. Besides, we reproduced the bufferbloat effect to see and explain its impact into the measurement problem.

- Stage 3 - Real world comparison: The last step comprised verifying the obtained conclusions with real world performance, focusing on bufferbloat, goodput, TCP dynamics and latency. For that purpose, we carried out long transmissions during 3 complete days between deployed servers in Virginia (USA), Amsterdam (NL), Madrid and Bilbao (both in ES), see Figure 4a.

Once the scenarios have been explained, every stage results and outcome will be presented.

3.1. Stage 1: WS analysis

In order to establish a sensible measurement methodology, the WS has to be taken into account to decide the number of concurrent connections needed to achieve MEWS. The main goal of the real traffic dump was to capture every single TCP handshake (where the WS is negotiated) to have a perspective of nowadays WS range rates and resulting MEWS limitation since, once a negotiation is completely made, there is no room for reassigning (as stated in RFC7323).

The hourly results are shown in Figure 5, being on the top, the WS related to the clients (including most end users OS: Windows XP, 7 and 8, different GNU/Linux distributions and Mac OS X and Android, iOS and Windows Phone mobile OS), whereas on the bottom, the WS issued by the servers when researchers were browsing/accessing all over Internet.

Just looking briefly at the graph, a huge difference in the rate dispersion can be noticed. On one hand, clients have shown very scattered results, having multiple high and low WS. On the other hand, servers usually announce either very high values or no WS at all. Those results are consistent with our previous idea about the receiving buffer sizes.
This is, servers have usually bigger buffers than clients and this has a direct impact on the negotiation of WS, which reflects the available buffer size and foreseen needs for WS. The spread of clients graph would be related to the heterogeneity of our lab equipment and the buffer diverge capacity , which consists of laptops, desktop computers, probes, smartphones and so forth.
Anyway, the final conclusion is that in a non-negligible number of cases, either non-WS or WS 0 option were exchanged, resulting in the maximum capacity of the receiving buffer being 64 KB.
As can be seen in Table 1 such low value becomes a huge constraint in high BDP networks either not allowing to achieve the real maximum capacity or demanding an unrealistic number of parallel connections.
Additionally, the insertion of WS assessment in measurement tools should be recommended with a double purpose, to help in connections number decision and to check whether this constraints has prevent users from achieving maximum available bandwidth.

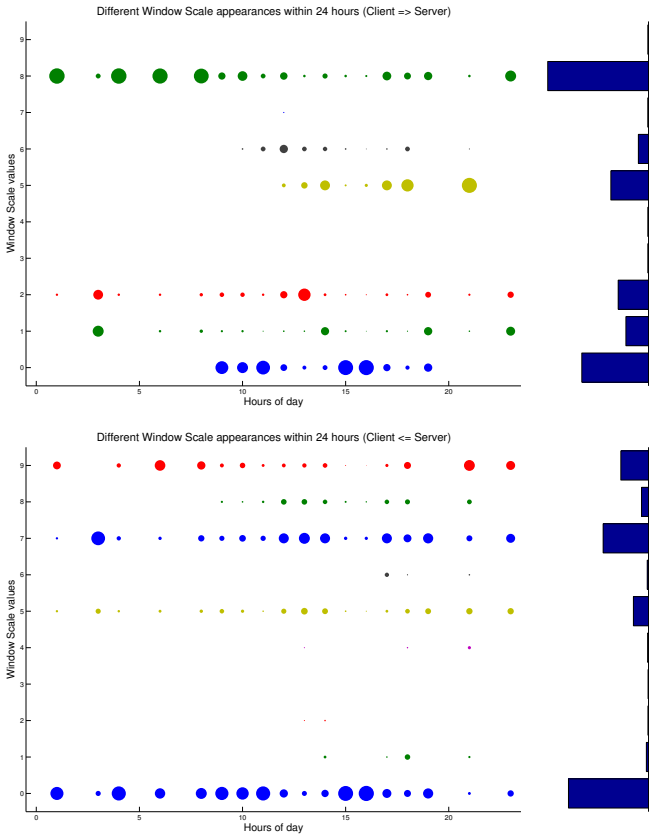


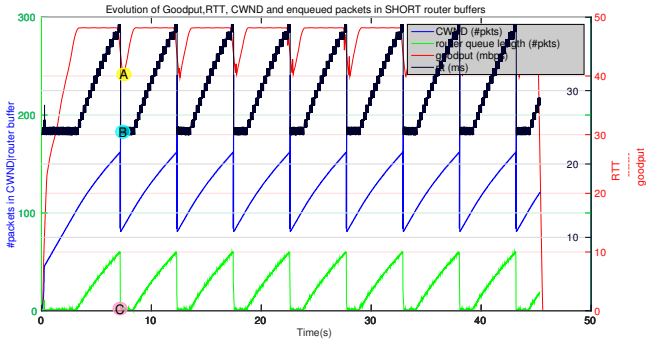
Figure 5: Window scaling negotiation.

	Achievable goodput (mbps)									
WS	1	2	3	6	10	20	50	100	150	200
0	1	1	1	2	3	6	15	29	43	58
1	1	1	1	1	2	3	8	15	22	29
2	1	1	1	1	1	2	4	8	11	15
3	1	1	1	1	1	1	2	4	6	8
4	1	1	1	1	1	1	1	2	3	4
5	1	1	1	1	1	1	1	1	2	2
6	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1

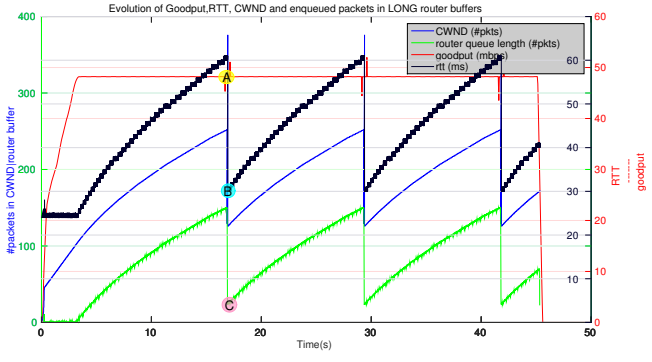
Table 1: Number of concurrent TCP connections needed (RTT=150ms)

3.2. Stage 2: evaluation of TCP dynamics in emulated scenario

In order to evaluate the actual impact on TCP's goodput of CCA mechanism under certain network conditions (w/wo bufferbloat) several tests were launched in the simulation tool. Figure 6 shows only two significant graphs for short and long buffer lengths for illustration purposes (Reno CCA is used). In green we can find the number of packets queued in each moment and in dark blue there is represented the round-trip delay time (RTT). Finally, goodput is drawn in red.



(a) Short Buffer



(b) Long Buffers (bufferbloat)

Figure 6: Impact of queue length

With short buffers (Figure 6a) resulting goodput is CWND dependant (point A). This is caused by intermediate node buffer's starvation (point C) letting enough time for the router

to dequeue every single packet. Another remarkable effect is RTT evolution, going back to transmission delay when queueing effect is removed (point B).

On the contrary, the the bottom graph of Figure 6 shows the overall performance under the same conditions but with long intermediate node queue size. In this case, we can find a couple of different effects due to no buffer starvation (see point C, the number of enqueued packets never drops to zero).
Firstly, since the buffer always has packets to transmit, goodput remains stable (point A) immediately after slow-start phase and regardless the CWND evolution. Therefore, the effect of CCA algorithm (and dependence on TCP flavour) is minimum. Secondly, RTT grows and falls following the CWND, but, it never falls back to base RTT due to queueing delay always taking place (point B).

Another important measurement set launched in this stage was related to the congestion epoch time (time between two mayor congestion events). An estimation of such interval for most currently available TCP flavours is crucial in order to the define a test stop criteria.

As seen before, in bufferbloat situations slow-start phase may be enough to maintain a stable goodput as soon as the intermediate oversized buffer is filled. However, such situation can not be assumed in all the cases. Instead, considering the periodic behaviour of TCP under static network conditions at least one of this periods should be considered. Considering current TCP implementations and the dependence on actual speed and RTT, there is no single expression available to calculate epoch times. In order to have a view of time scales to be considered in the standardized methodology we deployed a set of single flow tests with different RTTs and same capacity and calculated out of network traces the resulting epoch times.

Again, such time scales (ranging from 10s to 100s of seconds depending on TCP flavour and BDP) could prevent feasibility of on-line tests targeting end users. Then, a multi-connection approach was evaluated in order to try to reduce the time spent.

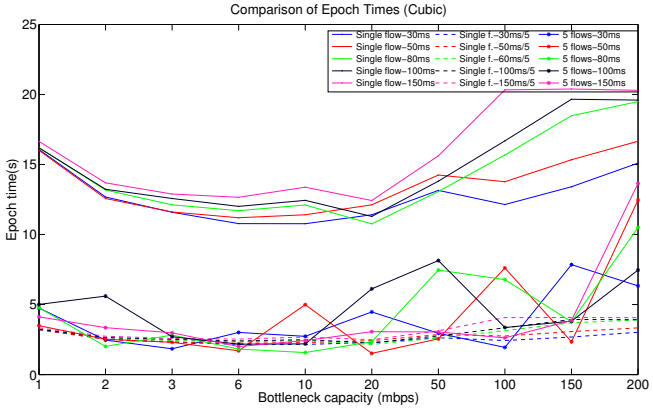


Figure 7: Epoch times - single flow Vs. multiflow.

As a demonstration of this approach, we launched identical measurements, but with 5 flows running in parallel from the same node.

The congestion epoch times for all those tests are shown in Figure 7. The graph presents the results of all the connections for one of the most representative CCA nowadays, Cubic (at least in the downlink, due to GNU/Linux predominance in the server market). The 5 lines on the top of the figure show the congestion epoch times for a single flow and different RTT in the bottleneck. Besides, below and in dashed lines we can find the theoretical results for multi-TCP connection based tests.
This is, the results obtained for single flow divided by the number of concurrent connections. In addition to all these measurements and also below, we have the results gathered from actual multi-threading assessments. Even though the results of multi-thread do not exactly fit theoretical measurements, it is remarkable the reduction of the congestion epoch durations when comparing with single flow ones.

As a conclusion it is clear that the use of parallel concurrent TCP connections reduces the “convergence time” for every considered BDP.

3.3. Stage 3: evidences in Real World traffic

In the last stage we measured in real world the TCP dynamics to understand the evolution and decide whether our previous statements were correlated with the overall performance. After 3 days of measurements, we have selected a pair of graphs to explain the two main cases regarding test behaviour. The first graph in Figure 8 shows the measurements between Amsterdam and Virginia through a whole day.

Every single sample’s obtained goodput (TCP level instantaneous speed) and the average are depicted. The obtained curves result show very clearly a non sustained goodput that follows the typical evolution of CWND. This may well be caused by no long enough intermediate or client/server buffers or the use of non-aggressive-enough TCP for this scenario, resulting in a non-filled intermediate buffer.
In addition to all those assumptions, the possibility of too many competing flows in the same bottleneck, increasing the RTT and having an impact on the final goodput can not be discarded. Anyway, the relevance of properly defining the measurement interval and its relationship with the epoch time is again remarked.

Finally, the graph below in Figure 8 is a result of a whole day measurements between Amsterdam and Bilbao (from 00:00 to 24:00). In this case the average value looks very stable once the pipe is filled, due to no buffer starvation and having a TCP flavour aggressive enough to continue *”feeding”* the network. In a situation like this one, even slow-start phase is almost enough to estimate the speed accurately and properly.

4. CONCLUSIONS

The title of the paper was a true declaration of intentions and the main conclusion is yes, we still need as technically accurate as possible standardized methodology to evaluate Internet speed, being end users the main target.

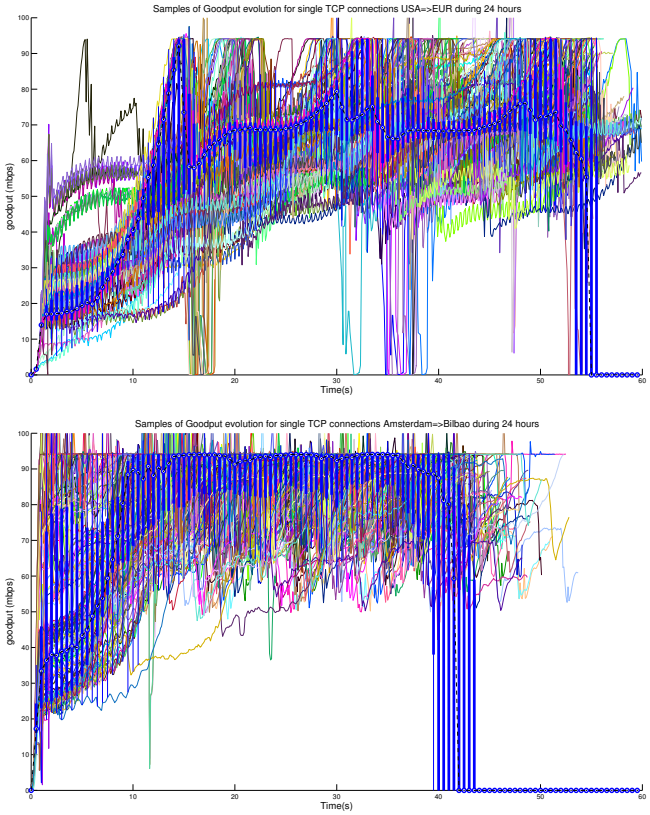


Figure 8: Goodput evolution in real world measurements.

Out of the proven divergence in the results of existing on-line tests (even "de-facto" standard ones) different aspects and constraints to be considered in the methodology have been identified.
The analysis of such obstacles not only illustrates the difficulty of defining a single estimator and explain some of the causes for aforementioned divergence but also aims at providing guidelines for future definition of most relevant parameters in the tests (i.e. duration, TCP implementation constraints, effect of buffers, etc..).

Firstly, the role of WS negotiation as a static constraint that may establish a ceiling in the maximum achievable effective window size (and therefore goodput) was shown. WS needs therefore to be considered in the future standard either as an essential parameter to establish a certain number of concurrent connections or to verify the reliability of final results. Secondly, it has been proved that in several cases slow-start phase may be enough to fill large enough bottleneck link queue, resulting in stable goodput from that point on. However in high BDP cases it is no longer true. Therefore, the necessity to consider congestion epoch times as a stop criteria to ensure the achievement of the maximum available capacity (and accuracy of the estimation) has been identified.

In order to shorten the test duration nowadays from 100s to 10s, the use of multi-thread has been suggested based on the different tests and measurements carried out. This research work shows the basic design guidelines a standardized Internet speed measurement tool for end users should follow.

In fact, stable network conditions have been assumed along the study in order to identify major limits. Randomness of current networks due to competing flows and, specially, variable capacity of wireless channels needs to be also incorporated to the analysis. As future work, we identify two main immediate targets. On one hand, the study of different features flows interaction, underlining the impact on the final measurement and the restrictions to adopt by developers. On the other hand, a deep study of the real deployments regarding the differences in software in terms of operating system and web browser/mobile app technology.

Finally, a comprehensive proposal of required signaling and statistical processing of the different samples of the test is mandatory. Such exchange of information and the data processing algorithm will aim at removing as much as possible TCP flavor dependence while assuring accurate enough estimation for end users.

5. ACKNOWLEDGEMENTS

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SESSION 7

TRUST BUT VERIFY!?

S7.1 Connecting the World through Trustable Internet of Things.*

S7.2 Is Regulation the Answer to the Rise of Over the Top (OTT) Services? An Exploratory Study of the Caribbean Market.*

CONNECTING THE WORLD THROUGH TRUSTABLE INTERNET OF THINGS

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ABSTRACT

The Internet of Things (IoT) is envisioned to connect things of the physical world and the cyber world to make humans ever smart by greatly improving their efficiency, safety, health, and comforts, as well as solving numerous challenges related with the environment, energy, urbanization, industry, logistic, transportation, to name a few. Consequently, the IoT has been an important topic of study in the International Telecommunications Union (ITU) for several years in different Study Groups. The new ITU-T Study Group 20 has just been established in June 2015 for further promoting coordinated progress of global IoT technologies, services and applications. In this paper, we review the IoT related activities being pursued in ITU by presenting the IoT reference model. We then describe a number of key requirements the IoT infrastructure should satisfy to make it economically and technologically deployable for useful services and applications. We present some prospective technologies, such as software-defined networking, information-centric networking, and ID-based communication, while pointing out to the related technologies that are worth further study in ITU.

***Keywords*—**Internet of things, machine-to-machine communication, trustable IoT, standardization,

1. INTRODUCTION

The Internet of Things (IoT) has a great potential to bring about revolution in the business and applications of information and communication technologies (ICT). Until now the devices, such as computers and smartphones, connected to the network are operated or used by humans. If only the handheld or human operated devices are connected to the network, there would be no need to develop network equipment with new technologies to expand the Internet because the number of connected devices has already exceeded the world human population. For example, besides the fixed computer devices connected to the Internet, there are more than 7 billion mobile cellular subscriptions, corresponding to a penetration rate of 97% of the world population of 7.4 billion in 2015 [1]. So, the exploration of new technologies to integrate *things* or *machines* into networks without human involvement for realizing innovative services and applications, and solving a myriad of social, economic, and environmental problems has been necessity for the continuous expansion of ICT business opportunities and innovations. Machine-to-machine (M2M) communication technologies requiring no human involvement in the communication loop have been thus considered as the base of the IoT platform. The IoT is considered as the major contributor of 50 billion devices that would get connected to the next generation (known as 5G) mobile networks in 2020 and beyond [2].

The IoT, by connecting things together to gather and process detail information about events and environments in the surrounding, would enable humans to effectively solve various challenges of modern society. It would thus make human lives safer, healthier, more efficient and comfortable. At the same time, it would create huge business opportunities for various vertical industries and social sectors such as automotive, energy and utilities, transport, logistics, healthcare, smart cities, fitness, sports, and public safety.

Recognizing the huge potential of the IoT in terms of its applications to address several global problems such as climate change, healthcare, urbanization, pollution, energy, food and water, the International Telecommunication Union (ITU) has been studying the IoT as an important topic for some years in the Telecommunication Standardization Sector (ITU-T). Several ITU-T Study Groups (SGs) have been involved in the study of different aspects of the IoT, such as requirements, capabilities, architectural framework, use cases and applications in different areas, e.g. smart sustainable cities and healthcare, Furthermore, as the potentials of the IoT to generate new business opportunities and innovation are getting clearer, a new ITU-T Study Group 20 (http://itu.int/ITU-T/go/sg20) has just been established in June 2015 for further consolidation of the IoT related activities. It would develop international standards for promoting coordinated progress of the global IoT technologies, with an initial focus on IoT applications in smart sustainable cities and communities.

In this paper, we first review the IoT related different activities currently being pursued in ITU-T by starting with the description of the IoT reference model. We observe that the majority of IoT related standards (i.e. Recommendations) produced or being developed in ITU-T are for the specification of requirements, frameworks, terminology, and collection of use cases. The detail technological specifications such as the functional architecture and protocol operations are still missing. Since the IoT is a broad area of study, encompassing various subjects in ICT such as big data, cloud computing, data mining, machine learning, sensing and actuating, visualization and augmented reality, in this paper we focus

on the communication related parts only. We therefore describe the communication network requirements and capabilities for building a reliable and trustable IoT infrastructure and review some prospective technologies, such as service-aware networking, data-aware networking, and ID-based communication, to fulfill these requirements. We explain about how these technologies would make the IoT infrastructure economically and technologically deployable for useful services and applications, while pointing out to some reference technologies that are worth further study in ITU.

The remainder of this paper is organized as follows. Section 2 reviews the IoT related activities being pursued in ITU and presents the IoT reference model. Section 3 lists the key IoT requirements, while Section 4 describes the prospective technologies. Section 5 concludes the paper.

2. REVIEW OF THE IOT ACTIVITIES IN ITU

Since ITU (formerly, CCIT and CCIR) came into existence 150 years ago in 1865, it has been leading the coordinated development of globally interoperable telecommunication technologies and policies. In the last decade, ITU-T has developed standards for the Next Generation Network (NGN) by importing the Internet Protocol (IP)-based packet switching and networking technologies into the telecommunication services. The NGN made the service-related functions independent of the underlying transport-related technologies of the converged fixed and mobile networks [3]. In this decade, ITU-T activities on the future networks, M2M, and IoT are noteworthy. ITU-T Study Group 13 has been collectively leading these activities and recently ITU-T Study Group 20 has been established for the exclusive study of the IoT related issues.

Approval of the ITU-T Recommendation Y.2060 "Overview of the Internet of Things" [4] in 2012 has been followed by the approval of a number of IoT related Recommendations on common requirements, framework, capabilities, and use cases. In ITU-T Y.2060, the *thing* has been defined as *an object of the physical world (physical thing) or the information world (virtual thing), which is capable of being identified and integrated into communication networks*. Similarly, the *IoT* has been defined as *a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies*. Similarly, the *device* has been defined as *a piece of equipment with the mandatory capabilities of communications and the optional capabilities of sensing, actuation, data capture, storage, and processing*. From the definitions, it is clear that the things are not only the physical devices but also information (virtual) objects that are capable of being identified and integrated into networks. The physical things are capable of being sensed, actuated and connected, while the virtual things (e.g. data object, multimedia content, application software) are capable of being stored, processes, and transmitted through the network. The physical things can also associate with (or represented by) virtual things in the information world through some mapping relationships, whereas some virtual things can also exist independently, i.e. without having any association with physical things.

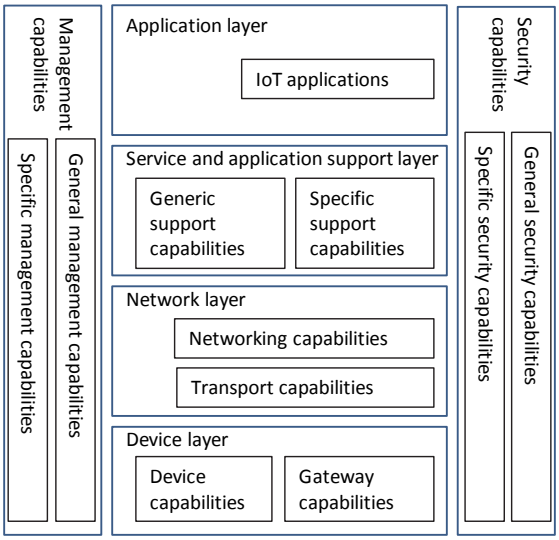

Figure 1. IoT reference model.

From the above definitions, it is also clear that the IoT is not a local infrastructure for interconnecting things only in a locality (e.g. a building, an enterprise, or a city) but a global infrastructure to connect things through interoperable underlying communication networks. In other words, ITU activities are focused on realizing a globally interoperable IoT infrastructure. The IoT adds a new fourth dimension of *anything* communication to ICT infrastructure besides the already existing three dimensions of *anytime*, *anyplace*, and *anybody* communications. In the IoT, devices communicate with other devices through the communication networks with or without a gateway. The devices can also communicate to each other directly, i.e. without going through a communication network.

2.1. IoT Reference Model

Figure 1 shows the IoT reference model referenced from ITU-T Y.2060 [4]. ITU-T has specified this layered reference model with the objectives of providing the universally common understanding of the crucial functions and capabilities of the IoT architecture, helping in reducing the implementation complexity, and promoting interoperability between the IoT applications as well as the communication technologies. It consists of four horizontal layers and the cross layer management and security capabilities associated with all of the four layers. The top layer is the application layer that contains various IoT applications, e.g. smart home, intelligent transport system, e-health, smart grid, etc. The second from the top layer is the service and application support layer, which includes the generic support capabilities as well as application specific support capabilities. As the name indicates the generic support capabilities are common capabilities applicable to many applications, whereas the application

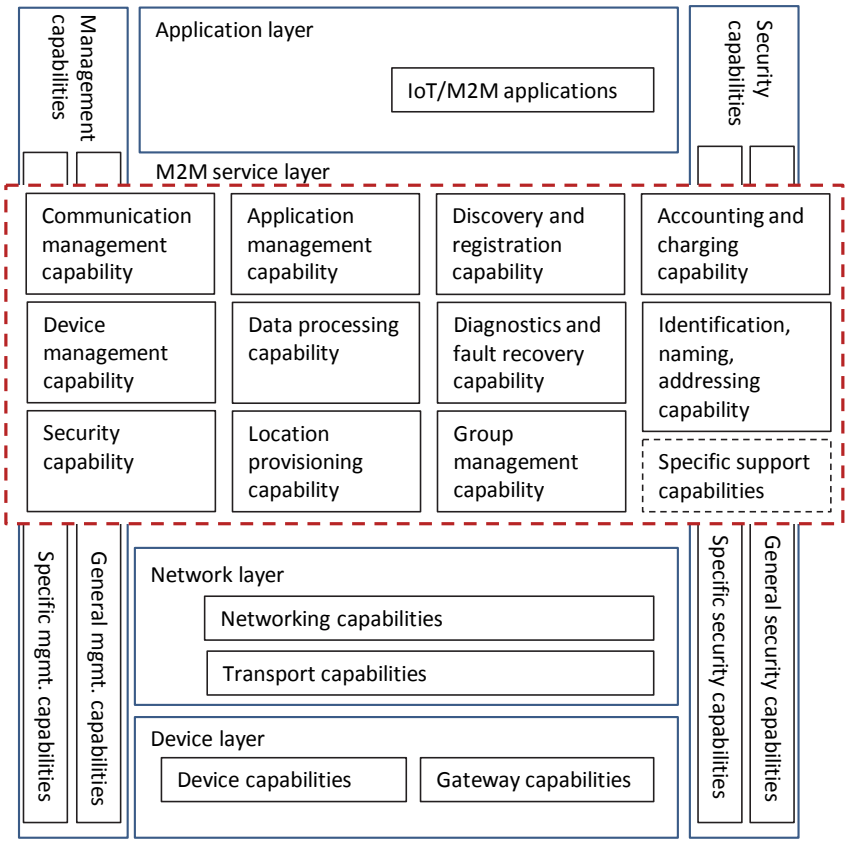

Figure 2. M2M service layer in the IoT reference model.

specific capabilities serve particular application requirements. The third layer from the top is the network layer, which includes the networking and transport capabilities. The networking capabilities come into action for connecting devices and things to the networks and maintaining the network connectivity. They include functions for access control, routing, mobility management, resource allocation, etc. Similarly the transport capabilities include functions for transporting data of IoT applications as well as control and management instructions. The bottom layer is the device layer which includes a collection of device capabilities and gateway capabilities. The device capabilities enable a device to interact with the network via a gateway or directly to transmit data it has generated by sensing the environment or events in the surrounding, or to receive control and management instructions from the network. They are composed of ubiquitous sensor networking functions. Similarly, the gateway capabilities enable the devices of diverse communication technology to connect with the network by performing protocol translation in the device layer and the network layer. The device layer technologies include ZigBee, Bluetooth, WiFi, etc., while the network layer technologies include PSTN, 2G, 3G, 4G networks, Ethernet, etc. Note that the network layer technologies of the IoT reference model are not only IPv4 and IPv6 protocols of the Internet.

Similarly, the management capabilities relevant to all the layers are also categorized into generic and specific capabilities. The generic capabilities include device management such as remote activation, status monitoring and control, software update, network topology management, traffic and congestion control, etc. The specific management capabilities satisfy particular application requirements such as e-health and smart grid. The security capabilities are also categorized into generic and specific classes. The generic security capabilities include access control, authorization, authentication, access control, privacy protection, confidentiality, integrity protection, etc.

2.2. ITU-T Focus Group on M2M Service Layer and Focus Group on IMT-2020

As mentioned earlier, M2M is a key enabler of the IoT applications and services. Consequently, the Focus Group on M2M Service Layer (FG M2M) was established in ITU-T in January 2012 to identify key requirements for a common M2M service layer by reviewing the related activities undertaken by various standards developing organizations (SDOs). As shown in Figure 2, FG M2M has specified an architectural framework of the M2M service layer that can be positioned between the application and network layers of the IoT reference model and covers a subset of different types of capabilities, including the service and application supporting generic and specific capabilities, as well as management and security capabilities of the IoT reference model [5]. These capabilities, such as discovery and registration,

identification, naming and addressing, group management, location provisioning, accounting and charging, are related with the devices, connectivity, data, and services. However, the key technologies supporting these capabilities are yet to be studied in ITU-T.

ITU-T has also established a new Focus Group on IMT-2020 in May 2015 to identify the network standardization requirements and analyze the technological gaps for the development of the next generation of International Mobile Telecommunications (IMT) or the 5G mobile networks that would go into deployment in 2020 and beyond (http://www.itu.int/en/ITU-T/focusgroups/imt-2020/). This Focus Group has been studying the standardization needs of the wireline elements of 5G networks that can smoothly integrate a massive number of M2M and IoT devices and services, satisfying their stringent requirements such as highly reliable connectivity, ultralow latency, and low power consumption.

2.3. ITU-T IoT-GSI and Study Group 20

The IoT is a topic of interest to various parties such as equipment manufacturers, telecommunication companies, vertical service industries and users. So, when the IoT activities were initiated in ITU-T, they fell in the work scopes of various Study Groups: SG2, SG3, SG9, SG11, SG13, SG16, and SG17. Therefore, to provide a common platform where the experts of these Study Groups can work together for the development of communication standards enabling the IoT in the global scale, the Global Standards Initiative on Internet of Things (IoT-GSI) (http://www.itu.int/en/ITU-T/gsi/iot/) has been established. The IoT-GSI also works in collaboration with other SDOs to harmonize the different approaches to the IoT and promote unified IoT standards development worldwide. Joint Coordination Activity on IoT (JCA-IoT) also exists to provide working guidelines to the IoT-GSI, as well as monitor and supervise its work.

To further strengthen the process of IoT standardization by carrying out exclusive studies of IoT technologies, services and applications in a single place, the new ITU-T Study Group 20 with the title of "IoT and its applications including smart cities and communities" has been established in June 2015 (http://itu.int/ITU-T/go/sg20). It has included the following work items under its scope:

- Framework and roadmaps for the harmonized and coordinated development of the IoT, including M2M, ubiquitous sensor networks, and smart sustainable cities and communities, in ITU-T and in close cooperation with ITU-D, ITU-R, and other regional and international SDOs and industry forums
- Requirements, capabilities, and use cases
- Definitions, terminology, and functional architecture
- User-centric networking and services
- Applications and services for smart sustainable cities and communities
- Guidelines, methodologies and best practices related to standards to help cities (including rural areas and villages) deliver services using the IoT, with an initial view to address city challenges
- High-layer protocols and middleware for IoT systems and applications
- Middleware for interoperability between IoT applications and components
- QoS, signaling, and end-to-end performance
- Security of IoT systems, services, and applications.

Since some of the above work items have already been pursued in other Study Groups, ITU-T Study Group 20 would take the responsibilities for the continuation of these items by distributing them to among its six initial Questions. For example Question 1 "Requirements and user cases of IoT and its capabilities" and Question 2 "Functional architectures for IoT" will continue the IoT work items formerly carried out by ITU-T Study Group 13 Questions 2 and 3, respectively. Similarly Question 3 "IoT applications and services" would take the IoT related work from ITU-T Study Group 16 Question 25. Question 5 "IoT in smart sustainable cities and communities" would continue part of work of ITU-T Study Group 5 Question 20 and Focus Group on Smart Sustainable Cities and Communities. Question 6 "Signaling and protocol architectures for IoT" will continue work items taken from ITU-T Study Group 11 Question 1 regarding interoperability aspects for IoT and its applications.

ITU-T Study Group 20 has also planned for close coordination with other Study Groups for the study of other aspects of IoT. For example, security considerations related with all the Questions will be studied in close collaboration with ITU-T Study Group 17. Similarly, requirements for identification, naming and addressing will be studied together with ITU-T Study Group 2, to ensure that either existing recommendations can meet the IoT requirements or new work items need to be initiated in ITU-T Study Group 2. Requirements for tariff and economic issues relating to the IoT and its applications including smart sustainable cities and communities will be studied in collaboration with ITU-T Study Group 3.

2.4. Work in Progress

The majority of IoT related standards produced or being studied in ITU-T Study Groups are on the requirements, frameworks, terminology, and collection of use cases. Detail technical specifications such as functional architectures, protocol operations, implementation guidelines, interoperability and standard compliance testing are still missing. Thus, ITU-T needs proposals and contributions for the development of technical standards on reliable and trustable IoT infrastructure on the basis of new technologies as well as optimal combination/extension of currently available component technologies. In the following sections, we first discuss some requirements and

capabilities for the IoT infrastructure and then discuss the prospective technologies.

3. KEY REQUIREMENTS OF THE IOT

The IoT infrastructure should satisfy a number of requirements to make it economically and technologically deployable for useful services and applications. ITU-T Y.2066 [6] lists several common requirements of the IoT. These requirements have been categorized in two groups: non-functional and functional requirements. The non-functional requirements are related with the implementation and operation, while the functional requirements are related with the applications support, service, communication, devices, data management, and security. However, ITU-T has not yet specified any technologies to fulfill these requirements. Therefore, below we reiterate some of the important requirements related with the IoT communication network such as trust, reliability, sharable, supporting different modes of communications (e.g. service-aware, data-aware, user-centric), location-independent ID-based communication, heterogeneous communication, naming, numbering and identification, open application programing interfaces, remotely configurable and controllable, and discuss the prospective technologies in the next section.

Sharable – The IoT infrastructure horizontally integrates various physical components, such as devices, communication networks, and cloud servers (data storages and computing), and it is likely that these components are deployed by different providers. For example, devices (sensors) may be deployed by local small providers, communication network by telecommunication companies, and the cloud servers by multi-national companies. The IoT infrastructure composed of these physical components should be vertically *sharable* among multiple types of application service providers or vertical industries so that the physical resources are optimally utilized at their full capacity while reducing the new service rollout time and cost.

Trustable and reliable – From the user's perspective, *trust* and *reliability* are two most important requirements for the dependable IoT infrastructure. Trust and reliability are directly linked with security and privacy protection. We are already highly dependent on the network for our business work, day-to-day family communication, education and entertainment. Moreover, various services we use daily such as public transportation, utility, and banking are also heavily dependent on communication networks for their operation. With the advent of the IoT, our network dependency would increase as several life-critical systems ranging from remote healthcare to traffic light control in the streets would be based on the network functionality.

Service-aware, data-aware, and user-centric – The IoT networks would not just provide dumb connectivity to enable things to interact with themselves or to transmit data to the cloud, but would be service-aware, data-aware and user-centric. The service-aware networking would enable the IoT to understand the service type, and carryout intelligent decision to allocate appropriate amount of network resources for automatic service provisioning so that the service requirements are optimally fulfilled. Similarly, the data-aware networking enables the IoT to capture and process (i.e. parse, classify, aggregate, cache, copy, analyze, discard, transmit, etc.) the data coming from the IoT devices, the service requests coming from the IoT users, or control instructions coming from the IoT service manager. Similarly, the user-centric networking should enable the IoT participants to have a complete control of their devices or data generated by their devices. Provisioning of different levels of security and privacy tools should exist to allow the users to choose the most suitable level for their requirements to be fulfilled.

Scalable naming and identification – By the definition of IoT, all things existing in both the physical world and the cyber world are required to be capable of *being identified and integrated into communication networks*. Given the volume and diversity in usages and capabilities of the things, there should exist scalable naming and identification schemes that can handle heterogeneous namespaces.

Location-independent heterogeneous communication – The IoT should be able to incorporate heterogeneous types of network layers such as IPv4, IPv6, cellular networks (2G, 3G, 4G, 5G), and PSTN, as well as the local area networking technologies such as ZigBee and Bluetooth. The devices should be able to smoothly move from one network to another among the heterogeneous networks. Moreover, devices located in one type of network should be able to communicate with other devices located in another type of network.

Automatic and remotely configurable and controllable – Since most devices in the IoT would perform M2M communications, they should possess automatic configurable and remote controllable features. The automatic configuration enables the devices to dynamically attach with (or form) a network, and the remote control and management enable status monitoring, software update, as well as configuration update.

Open application programming interfaces – To enable different types of applications and services on the shared IoT infrastructure, there should exist open application programming interfaces. They would enable sharing of the IoT infrastructure among numerous applications of different domains.

4. PROSPECTIVE TECHNOLOGIES FOR FURTHER STUDY IN ITU

In this section, we present a few prospective technologies that have potentials to satisfy the IoT requirements listed in the previous section and that are worth further study in ITU.

4.1. Software-Defined Networking

Developing the IoT infrastructure with software-defined networking (SDN) and network function virtualization

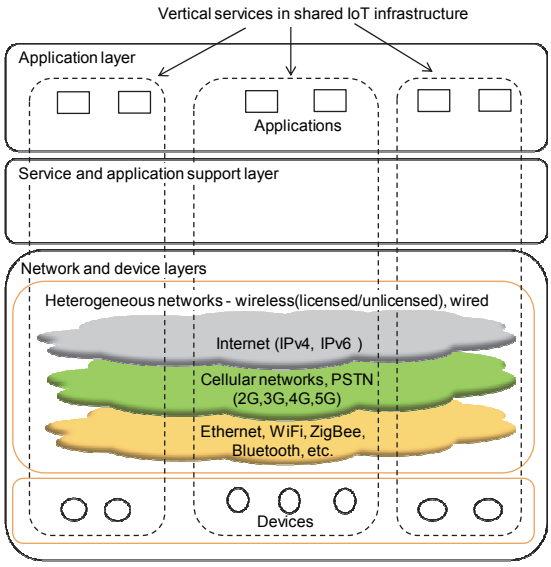

Figure 3. Vertical segmentation of sharable IoT infrastructure for various services and applications.

(NFV) capabilities would enable both the application service providers and the application subscribers to share the same infrastructure consisting of data servers, network switches, and communication links for different purposes. NFV allows segmentation of hardware (e.g. link bandwidth, computing, memory and storage) resources of network devices and isolation of the segments from each other so that each segment can be controlled, configured and deployed independently of others in a secure manner by an SDN control program remotely. The SDN support enables centralized control of virtualized network resources of different pieces of equipment for forming a network that would be most suitable for the given services. Figure 3 shows an example of how the network resources can be segmented vertically for different services in the shared IoT infrastructure.

The NFV and SDN framework specified by ITU-T Study Group 13 Question 14 in ITU-T Y.3011 [7] and Y.3300 [8], and other work in progress on functional architecture, requirements and use-cases are worth exploring more about their extension to the IoT.

4.2. Security and Privacy Protection

To make the IoT infrastructure trustable and reliable, it needs to be equipped with the capabilities of access control, authentication, authorization, device and data integrity protection, privacy protection, confidentiality, transaction auditing, etc. NFV is an important tool for enabling us to impose different levels of security requirements to match with the criticality of the services provided in each logically isolated network partitions (terminology used in ITU-T Y.3011 [7]). Similarly, the gateways can implement stringent security measures to isolate the user-premise network (e.g. body area network used for healthcare) from the untrusted outside domains. The gateways protect resource-constrained user devices such as body sensors from being unauthorized accessed and compromised by a malicious entity from outside [9]. Security requirements and framework specified in ITU-T X.1314 [10] and work in progress for the IoT security framework in ITU-T Study Group 17 Question 6 are relevant to this issue.

4.3. Network Softwarization, Information-Centric Networking

Network softwarization is a new networking platform that enables the data plane capabilities (e.g. protocols, resources) to be dynamically configured by software programs to meet with the given service requirements in terms of performance and security. It has been discussed in the ITU-T Focus Group on IMT-2020 (http://www.itu.int/en/ITU-T/focusgroups/imt-2020/) as a promising technology for the 5G networks.

The information-centric networking introduces the data-awareness property, enabling the network to handle enormous amount of data efficiently (i.e. without getting congested) in a distributed environment and the user applications to access desired data quickly, accurately, and securely irrespective of the locations of the data stores and the user applications. Data-aware networking introduces identification to each data object and employs in-network caching to make the network more efficient than the current Internet's host location-based communication for distributing data on demand to a huge number of mobile user applications. Introduction of data awareness to the IoT would require technologies for naming and addressing of the data objects, routing and resolution for finding the location of the data object matching with the user application requests (also known as *interests*), resource management for in-network caching, and key distribution for security and privacy protection. The identification framework for the future networks specified in ITU-T Y.3031 [11], and related Recommendations being developed in ITU-T Study Group 13 Question 15, such as ITU-T Y.3032 [12] for scalable name-to-address (or locator) mapping mechanism and ITU-T Y.3033 [13] for data-aware networking framework, are useful references for developing the IoT infrastructure possessing the data-awareness property.

4.4. Mobile Edge Computing

Mobile edge computing [16] is a new networking concept to bring the computing and storage facilities, as well as services from the centralized cloud servers to the edge of the network, i.e. closer to the mobile user applications. It would basically reduce the network latency required to convert the raw data produced by resource-constraint mobile devices and sensors into knowledge or actionable instructions. Thus, mobile edge computing can be considered as an extension of the data-awareness property by bringing not only the data but also the computing facility closer the IoT devices and applications.

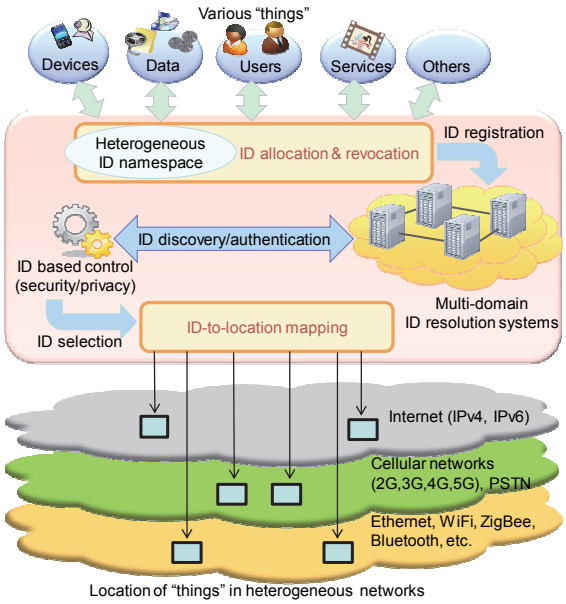

Figure 4. Identification framework for the IoT.

4.5. New Naming and Identification Schemes

The IoT requires naming and identification of both the physical and cyber things of various types and enormous quantity. It would be almost impossible to assign names to the billions of things of diverse features and usages from a single namespace such as the domain names used in the current Internet, or the international mobile subscription identities (IMSIs), which are at most 15-digit long (as specified in ITU-T E.212), used for the globally uniquely identification of mobile subscribers in the public land mobile networks. The IoT names can be both hierarchical and flat. Moreover, it is likely that not only the mobile carriers but also individual organizations having access to the Internet can provide network connectivity to the new IoT devices. Therefore, not only IMSIs but also different types of names/IDs would come into existence for the identification and discovery of devices in the IoT networks. The hierarchical names (e.g. domain names) are good for designing scalable name assignment and resolution mechanisms, while the flat names (e.g. one generated from public keys of public-private key cryptography) are good for using as self-certifying IDs.

ITU-T Y.3031 [11], which specifies an identification framework for future networks, is relevant to the IoT identification, but not sufficient. We propose to extend it as shown in Figure 4, so that it fits with the IoT requirements. IDs are assigned to various things such as devices, data or content, users, services, and others (e.g. application software, storage or computing resources). The major components of the IoT identification framework are ID allocation and revocation, multi-domain ID resolution, ID-based control for security and privacy, and ID-to-location mapping. The ID allocation function assigns IDs from the relevant ID namespaces to the things and the ID revocation function removes the IDs from the things and the ID-resolution system when the things no longer exist. The ID resolution systems deal with mapping the IDs with other information related with the things, such as the owner's name, lifetime, location and security parameters. Since there would coexist heterogeneous ID namespaces, there should exist an ID resolution system for each domain of IDs as well as their interworking mechanisms. The ID-based control functions use IDs not only for the identification of things, but also in myriad of networking functions, such as discovery, authentication, verification, registration, security, and privacy protection. The ID-to-location mapping works in conjunction with the ID-based control to find the most appropriate location of things in the underlying heterogeneous networks when the things do exist in multiple copies or associate with various networks.

4.6. ID-based Communication

The ID-based communication is helpful to achieve location-independent communication in heterogeneous networks, automatic and remote configuration and control of things, and network-independent open programming interfaces as described below.

The IoT requires location-independent communication in heterogeneous networks, which would be different from the current Internet's IP address-based, i.e. host location-based communication. Since an IP address is dependent on the IP protocol version (i.e. IPv4, IPv6) as well as on the subnet where the device is associated with, it cannot be used for end-to-end communication when two endpoints are not located in the IP networks of the same version or when one or both change the subnet frequently due to mobility or link switching in multihoming connections. Use of location-independent and network protocol-independent IDs for the identification of communication endpoints, connections, or data packets would help in seamless communication between networks of heterogeneous protocols. ITU-T Y.3034 [14], which specifies a mechanism for interworking of heterogeneous networks by leveraging the ID/locator split concept and protocol translation functions in gateways, and the paper on ID-based communication for a dynamic mobile sensor network platform presented at the ITU Kaleidoscope conference in 2014 [15] are the relevant component technologies for the development of a location-independent ID-based communication platform of the IoT.

The ID-based communication platform allows each device to possess a unique name/ID that would be independent of the network location. The IoT identification scheme provides security and other parameters related with the device ID from the ID resolution system. These parameters would be helpful for developing mechanisms for secure and dynamic network access by the devices wherever they move. Similarly, by leveraging the ID-resolution facility provided by the identification scheme, it would be easier to discover the current location and security parameters of mobile devices and establish secure connections for accessing data from them or remotely configuring and

controlling them as explained in [15]. Moreover, seamless integration of gateways in the ID-based communication platform and implementing advanced capabilities in the gateways would be helpful for the enforcement of secure access, remote configuration and control of the resource-constrained devices in the IoT.

Tagging each device with a location-independent ID and using the ID in the identification functions of the communication services and applications would enable us to develop open application programming interfaces (APIs). The APIs would be made independent of the network protocols so that the same applications could be installed on various types of user devices located in the heterogeneous networks. However, since the IoT has already been a hot topic of discussion in different SDOs and consortiums, it is likely that they create their own APIs suitable for the service scenarios and use cases that fall in their focus. Therefore, it is necessary for ITU to promote the development of global standard APIs through liaisons with the related SDOs and consortiums. ITU-T Study Group 20 can lead this work.

6. CONCLUSION

The IoT brings both opportunity and challenges. The opportunities are that it creates a new wave of innovations in ICT applications and business opportunities to make human life more comfortable, deliver services more efficiently, and manage scare resources (both natural and human-created) more effectively, while increasing productivity. The challenges are that it requires a more trustable and reliable network platform to connect a huge number of heterogeneous devices, ranging from resource-constraint tiny sensors to big data servers.

As a contribution to help in generating new work items for the IoT standardization in ITU, this paper presented some prospective technologies, such as software-defined networking, information-centric networking, mobile edge computing, network softwarization, and ID-based communication, and mentioned about how they can be integrated into the communication network to create a trustable and reliable IoT infrastructure that would be economically and technologically deployable for proving various services and applications.

This paper presented the review of IoT related technologies mainly focusing on the ITU activities. Because of the space limitation, it could not include the review of related work in other standards developing organizations or academic research projects. In future work, the authors will continuously research the IoT related network technologies in more detail and try to bring the research outcomes to ITU for the IoT standardization.

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IS REGULATION THE ANSWER TO THE RISE OF OVER THE TOP (OTT) SERVICES? AN EXPLORATORY STUDY OF THE CARIBBEAN MARKET

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ABSTRACT

Over the Top (OTT) content has seen unprecedented growth in recent years that has disrupted the traditional telecommunication business model. As a consequence, countries have offered different regulatory responses. The Caribbean market has seen similar evolution in OTT content which has transformed the telecommunication market and has influenced the growth in access to technology. An analysis of this market has seen fractured regulatory responses with the telecommunication providers chiefly driving the process. It is argued that such an approach may result in an unbalanced ecosystem, limited consumer protection with privacy and security concerns. The purpose of this paper is to report on the regulatory responses in key countries in the Caribbean and propose a regulatory framework that may aid in the effective management of OTT services and its evolution in the region. The framework considers the perspectives of the multiple stakeholders including regulatory agencies, telecos and customers and includes domain understanding, OTT understanding, regulatory process understanding, regulatory design and development, evaluation, implementation and review and monitoring stages.

Keywords *– OTT services, telecommunications, regulation, Caribbean.*

1. INTRODUCTION

OTT services refer to the delivery of multimedia services i.e. audio, video and messaging services over the Internet [1]. This solution has rivaled telecommunication providers' video, voice and messaging services through improved options including increased accessibility, customer-centric pricing and multiple social features. With the explosion of Voice over Internet Protocol (VoIP) and OTT services coupled with a largely unregulated market, many countries including those in the Caribbean are left to grapple with finding the most appropriate policy and regulatory framework to manage the proliferation of what some consider "disruptive technology". A review of the global responses has seen varied responses which indicate divergence to whether regulation is the answer to the OTT phenomenon. The Telecommunications Regulation Handbook[1] conveyed that the need for regulation depends on the conditions of the marketplace. While the debate ensues, the discourse has been largely outside of the academic sphere. The opportunity to examine the regulatory conditions of the growing Caribbean market and recommend a more structured regulatory management is therefore presented.

The purpose of this study is two-fold:

1) To examine and report on the current forms of regulatory responses to OTT services in the Caribbean; and
2) To introduce a regulatory framework that supports multi-stakeholder objectives and multi-dimensional issues that is representative of the realities of the conditions of the marketplace and technological landscape.

Since 2014 the local regional headlines have been dominated by the rift between Digicel, the leading telecommunications provider in the Caribbean, and Viber, a key global OTT player, where Digicel has blocked or has threaten to block Viber and other OTT providers such as NimBuzz and Tango on its network. Digicel argued that these providers are engaging in bypass operations as they do not pay for routing their traffic over Digicel's network and are putting pressure on bandwidth which negatively impacts the customers' data usage experience [3]. The immediate responses from the regulators were varied. Haiti and Trinidad regulators (i.e. Conatel (Comision Nacional de Telecomunicaciones) and Telecommunications Authority of Trinidad and Tobago (TATT) respectively) have intervened and have asked the telephone/telecommunications companies (telecos) to restore services or to put the block on hold at least until additional information is received. On the other hand, Jamaica's Office of Utilities Regulation (OUR), the regulatory body responsible for oversight, instead have decided to engage in talks with both local telecos providers (Digicel & LIME) before making a decision to the blocking of the services. Such a stance may be viewed as yielding to the telecos, albeit temporarily. Since then there has been little regulatory development since there is no known formal enactment or measures to manage the continued growth of OTT services and the telecos' reactions. Fast forward to the introduction of the Whatsapp call feature in early 2015 and Digicel has continued its stance and have prevented voice calling on its network.

It is premised that given the complexity and multi-dimensional issues that may be taken into consideration to manage the growth of the OTT services, some levels of regulation and government intervention may be necessary in the future. And the future is now. An examination of the domain revealed that some of the key issues to consider include legal definition of VoIP and OTT services, consumer protection, fair competition and anti-trust, net neutrality, security and innovation.

2. OVERVIEW OF OTT SERVICES

The proliferation of access and use of the Internet has also seen the development of certain innovations that are aimed at meeting the changing needs of users who constantly demand instant *access anytime anywhere* to audio, text, video and other services. VoIP and OTT services and applications are two key developments that have help changed the landscape. Following this, the last decade has seen significant growth in VoIP subscribers worldwide and it is expected to reach 348.5 million in 2020 with revenue of USD 136.16 million [2]. Similarly, there has been significant growth in OTT subscribers and it is reasonably projected that the number of OTT subscribers will continue to grow in 2015 and beyond.

OTT services are generally considered synonymous with VoIP based on some trade articles, however there is a distinction where OTT services refer to any application or service that provides product/service over the Internet and bypasses the traditional distributor i.e. the ISP. In short, the telecos are not used to deliver the content. OTT content is one of the many Internet applications and is normally in the form of audio, video, and other media. The application or service may be broadly categorized into OTT communication (voice/video and messaging) and OTT media (user generated content, production content, audio/video and gaming)[1]. OTT communication refers to services whose primary applications rely on the use of the Internet as the medium for communication instead of the traditional or legacy telephony infrastructure. OTT media is distinct from IPTV (which uses dedicated IP channels for content) and includes content being streamed over the Internet. According to reports, OTT growth is enabled by the "delayering of the industry", i.e. content or applications are no longer network specific and there convergence in the network and service layers[3].

Some of the popular OTTs include Skype, Viber, Whatsapp, Facetime, Blackberry Messenger which provide predominantly chat, voice and telephone services. The creation of OTT has led to conflicts between companies that offer services or overlapping services that has impacted the revenue of traditional telecos. Currently the Voice OTT services (e.g. Viber, Skype and Facetime) have provided the most obvious threats to the telecos where they have experienced significant reduction in revenues as users are relying on these OTT services to communicate within their social networks instead of using fee services such as SMS. Since the start of 2014, Viber has grown to over 300 million users globally [4] and allows free calling between its users. Similarly, Skype also has over 300 million subscribers and allows free calling between its users and relatively low costs for calls made to telephones. These figures are expected to continue to rise in 2015 and beyond as a result of customer demand and technological advances. This shift in demand has had significant implications for competition in the local and international markets.

Examples of the shift in subscriber demand(s) as a result of the growth of OTT are [5]:

- Email replacing post;
- Hulu or Netflix replacing regular TV or cable providers;
- Facetime, Skype, replacing long distance telephone providers;
- Youtube replacing videos, music television broadcasters;
- Chat services including Whatsapp, Viber replacing SMS.

Blocking of Content

The rate of growth of global IP traffic has continued to grow exponentially resulting in the increased significance of traffic management. Cisco reports that by 2018, global mobile IP traffic will reach an annual run rate of 190 exabytes, up from less than 18 exabytes in 2013 [6]. As a result, there have been many traffic management techniques applied by ISPs to manage IP traffic, including blocking.

Blocking is where end users are prevented from using or accessing a particular website or a type of content. The blocking of VoIP traffic on a mobile data network is one common example. This is one of the current approaches being employed by local regional providers such as Digicel and LIME. Blocking may be implemented to [7]:

a) Block unlawful or undesirable content, such as child abuse, viruses or spam;
b) Hinder competition, particularly if the access provider offers a service that competes with the service being blocked; and
c) Manage costs, particularly where the cost of carrying a particular service or type of service places a disproportionate burden on the access provider's network.

The choice of a traffic management strategy has implications for net neutrality, competition and possibly the viability of the open Internet. The importance of traffic management cannot be overstated as it is critical for the proper functioning of the Internet; however it can also be misused by an ISP to create unfair access or use of the Internet [7].

Net Neutrality

The concept of "net neutrality" is still developing and as such there is no settled definition to date. With closer attention being paid to the governance of the Internet, net neutrality is becoming even more important. The different viewpoints nevertheless underline equality in the treatment of content and freedom from discrimination. Tim Berners-Lee [8] describes net neutrality as keeping the Internet free from political or commercial discrimination. It is also described as the principle that all electronic communication passing through a network is treated equally [7]. This means that all communication is treated as independent of (i) content, (ii) application, (iii) service, (iv) device, (v) sender address, and (vi) receiver address. Net neutrality is further defined as a network design principle where it is suggested that a useful public information network aspires to treat all content, sites, and platforms equally [9]. It is argued that the broad definitions of net neutrality are being challenged by the reality of an Internet where traffic management is critical to ensure efficient operation for all users and to prevent degradation of service [7].

Proponents of net neutrality have argued for increased protection and regulations because ISPs have a natural tendency to engage in discriminatory practices in the use of their networks [10]. On the other hand, opponents of net neutrality argue that there is no evidence of widespread abuse and the proposal to have an open unregulated Internet is a Pandora's box which can lead to a reduction in the access providers' ability to offer innovative packages of services [10]. While the debate rages on, it is important for policy makers to play a leading role in ensuring that discriminatory practices are minimized, consumers are protected and competition is nurtured.

3. REGULATORY LANDSCAPE

The regulatory issues relating to the VoIP/OTT market are not monolithic. According to a report from the International Telecommunication Union (ITU) [1], the issues may be categorized based on the maturity of the VoIP/OTT market in the respective country: early; maturing and mature [1]. The issue of illegal termination and bypass is consistent across all types of market and quality of service is significant to both early and maturing markets. Some of the other issues identified at the early stage include defining VoIP and considering its legality, licensing, numbering and quality of service (QoS). At the maturing stage issues of regulatory capture, universal service, number portability and access to emergency service numbers are considered. At the mature VoIP market, security of transmission, net neutrality and blocking, consumer protection, location correspondence and anti-competition issues are underlined.

Currently OTT services worldwide are predominantly unregulated. A global scan shows that countries generally adopt four main approaches to combat OTT: a full ban, in places such as China and the Middle East; operator restrictions, such as what currently exist in Jamaica; primarily unregulated such as environment that exists in Canada and USA; and a commercial approach where there is support and creation of commercial versions. Reports from ITU revealed that the incidences of the banning of VoIP services have been steadily declining although no formal update since 2009.

USA

The Federal Communications Commission (FCC) has sought to adopt what is considered a "light regulatory touch" with regards to VoIP and OTT services. The FCC does not consider VoIP a traditional telephone service, but a computer-based 'information service', that is relatively unregulated. The Telecommunications Act 1996 governs telecommunication and broadcasting services where Title 1 governs telecommunication and Title 2 governs broadcasting under which information services fall.

Per the Telecommunications Act 1996, USA:

The term `information service' means the offering of a capability for generating, acquiring, storing, transforming, processing, retrieving, utilizing, or making available information via telecommunications, and includes electronic publishing, but does not include any use of any such capability for the management, control, or operation of a telecommunications system or the management of a telecommunications service.

The term `telecommunications service' means the offering of telecommunications for a fee directly to the public, or to such classes of users as to be effectively available directly to the public, regardless of the facilities used.

The FCC believes that competition instead of regulation is the best strategy for these developments since it promotes innovation [11]. According to the FCC Chairman:

"…Our mantra at the FCC is "Competition, Competition, Competition.". We believe that competition is better than regulation at stimulating innovation and protecting consumers. I recognize that the broadcasting industry is subject to competition – more, in fact, today than ever before. And I recognize that more is coming..."

Currently there are no licensing requirements, but a Universal Service contribution is required with respect to OTT Voice Providers. Additionally, a January 2014 Release from the FCC [12] outlined that there is a requirement that text services provide support for emergency services.

Canada

Canada through its regulatory agency, the Canadian Radio-television and Telecommunications Commission (CRTC) has stated in that it has no immediate plans to impose any regulatory obligations on OTT providers[13]. It went further and stated that it also has no plans to reduce the obligations of regulated broadcasters and distributors in response to growing competition [13]. An analysis of events in 2014 revealed that not much has changed; however, the CRTC is still engaging stakeholders to determine the best course of action to the question of regulation in the face of continued competition from a wide spectrum of OTT media services [14].

Europe/Middle East

Licences are not necessary but individual countries, e.g. in France and Spain, OTT providers have been blocked when offering voice services that connect with PSTN. The argument is that the OTT is behaving like a telco and should therefore fulfill the obligations of a telco, such as paying USO and offering emergency services.

Some countries still have outright bans of VoIP and OTT services, particularly in the Middle East. The reasons range from an issue of revenue to the risk of corruption of the culture or plain censorship. Saudi Arabia has banned OTT services such as Viber which according to an ITU report is due to legal intercept problems. In Vietnam for example, Prime Minister Nguyen Tan Dung has outlined plans to regulate use of OTT messaging services in that country. This is attributed to the harm done to mobile operators by the free messaging services since there is a risk of loss in revenue [15]. Other regions have less blatant restrictions, where for example in the UK the operators cripple the OTT services by either slowing it down, raising the data costs, or by blocking it entirely , which may occur due to that being a part of the consumer contract [16].

The Caribbean

Jamaica

In Jamaica, OTT services although unregulated are currently treated by the telecos as bypass. Consequently, there have been different ranges of blocking undertaken by the telecos, such as the blocking of whole services (e.g. Viber in 2014) or blocking of specific services or features (e.g. Whatsapp call feature in 2015).

Section 9(1)(d) of the Telecommunication Act, 2000 stipulates that a person shall not engage in bypass operations. The Act under section defines bypass operations and voice services where voice services may include VoIP:

"bypass operations" means operations that circumvent the international network of a licensed international voice carrier in the provisions of international voice services; and

"voice service" means -

(a) the provision to or from any customer of a specified service comprising wholly or partly of real time or near real time audio communications, and for the purpose of this paragraph, the reference to real time communications is not limited to a circuit switched service;

(b) a service determined by the Office to be a voice service within the provisions of section 52, and includes services referred to as voice over the Internet and voice over IP.

Section 52 further states:

"(1) The Office may, where it considers necessary, decide that a particular service should be treated as a voice service and notice of that decision shall be published in such manner as the Office considers appropriate.

(2) In making a decision under this section, the Office shall have regard to such factors as may be prescribed."

Section 2 of the Act defines telecommunication service and telecommunications network as follows:

telecommunications service is "a service provided by means of a telecommunications network to any person for the transmission of intelligence from, to or within Jamaica without change in the content or form and includes any two way or interactive service that is provided in connection with a broadcasting service or subscriber television service"; and

telecommunications network as "a system or any part thereof, whereby a person or thing can send or receive intelligence to or from any point in Jamaica, in connection with the provision of a specified service to any person".

Currently, there is no news as to the direction the government is going in relation to VoIP/OTT services. In June 2014, the regulatory body has stated that it has requested additional information from LIME and Digicel on their decision to block certain providers of VoIP services on their network and expected to get necessary information to move forward[17]. Since 2015, there has been no public update on the matter or information available on its website. This situation further underlined the challenges in the regulatory process and relatively delayed responses to changes in the telecommunications environment.

Trinidad & Haiti

Both countries' regulators have requested that the telecommunication providers not ban users from using the OTT services, at least until they have received additional information. The Telecommunications Act of Trinidad & Tobago does not have a definition of bypass or any

explicit mention of bypass or voice service. However section 21 of their Act states that no person shall operate a public telecommunications network, provide a public telecommunications service or broadcasting service without concession granted by the minister.

Section 2 of Telecommunications Act, 2001 defines the following:

"telecommunications service" includes a closed user group service, a private telecommunications service, a public telecommunications service;

"public telecommunications network" means a telecommunications network used to provide a public telecommunications service;

"public telecommunications service" means a telecommunications service, including a public telephone service, offered to members of the general public, whereby one user can communicate with any other user in real time, regardless of the technology used to provide such service;

In Haiti, CONATEL in accordance with Articles of the Decree of 12 October 1977 and 10 June 1987 [18] has given directive to Digicel that it is the only body responsible for suspending or suppressing users' services and therefore any ban should be lifted. Therefore, Haiti's regulatory oversight seems to be much clearer in who is responsible for management of telecommunication services and who should have access to it.

4. THE CASE FOR REGULATION

It is therefore evident that there are numerous and varied strategies that have been adopted by countries to deal with VoIP/OTT services. However, they can be reduced to two general categories namely: regulation or non-regulation dependent on such issues as the promotion of competition, innovation, consumer protection, security and governance. There are different viewpoints in making the case for regulation. Regulation has the prospect of bringing structure and improved coordination to the marketplace. Alternatively, it is argued that the Internet has largely remained unregulated which has helped fueled its growth and this may be hindered with regulation of OTT services and applications such as OTT content. Secondly, regulation runs counter to the principles of net neutrality. Despite this, regulation is important for many reasons such as to avoid market failure, foster effective competition, protect consumer interest and increase access to technology and services [1].

The current environment scan shows a fiercely competitive market between the OTT service providers and telecos, and this is not forecasted to change soon. According to Bhawan and Maarg [19], the current situation has led to regulatory imbalances because the telecos bear the costs for the infrastructure, spectrum management and licensing fees while having to adhere to Universal Service and other regulatory obligations. On the other hand, the OTT service providers are not obliged to adhere to any regulatory obligations and do not bear any infrastructural or spectrum costs.

It is proposed that there are benefits to be gained from some form of regulation in the Caribbean. Whether regulation is the answer for countries in the Caribbean will depend however on the individual government's vision for its respective Telecommunications/ICT market and the need for affordable broadband access for its citizens. In any event, a clear understanding of the multi-dimensional nature of VOIP and the issues raised by OTTs is required and it is imperative that we act quickly so that we do not lose the benefits that new emerging technologies offer.

Some the key issues to consider:

1) Redefinition of bypass operation especially in the context of the dramatic shift in how services are delivered to the customer as a result of the delayering and convergence of the networks. Many of the Telecommunications Acts in the Caribbean were passed before this new shift in delivery of services and have not been updated to reflect changes in the telecommunications environment;

2) The necessity of a definition of voice services within the context of the pervasive development and use of multiple OTT services where the provision of a distinction between telecommunication and information services, similar to the US approach may be required and the determination of whether these types of services are voice or data services.

3) The provision of clear distinction between VoIP and OTT services especially in the context of current global developments;

4) The issue of net neutrality, open internet and their implications for stakeholders in the telecommunications industry;

5) The rights of the consumer in terms of access to services and competition in a dynamic environment.

6) The balance of revenue and market protection versus competition and innovation. Due consideration should be given on how to protect the revenues of the licensed telecos while promoting innovation, competition and consumer access and protection.

7) The continued development of telecommunications infrastructure and improved access to Internet services, particularly where there is still inequality of access and quality of services issues in countries in the Caribbean;

8) The movement towards development of new business models in response to changing markets as a result of technological developments.

5. TOWARDS AN OTT REGULATORY FRAMEWORK FOR THE CARIBBEAN

The important features of an effective regulatory framework include a clear decision-making process, accountability, consumer protection, dispute resolution and enforcement process [1]. This may be facilitated by a clear structured process of activities. Motivated by these guidelines, a generic regulatory framework to manage OTT services is proposed, figure 1. The principles of CyberLeg-DPM [20] are adapted to the regulatory environment for OTT services in the Caribbean. The CyberLeg-DPM is a process model that includes steps that are representative of the lifecycle of legislative development and implementation [20]. The model is aimed at improving the efficiency and effectiveness of legislative process and therefore it is envisioned that similar benefits may result in the regulatory context. CyberLeg-DPM also embodies the principles of frugal innovation to address the current limitations in successfully applying a disciplined approach to developing and implementing new legislations. It promotes the effective use of resources and improvement in several legislative processes through defined steps and improved transparency to bring beneficial value to the legislative development value chain. It is argued that this view can also result in significant cost-savings to government, legislative and enforcement stakeholders, and others through a comprehensive process-oriented approach to designing and implementing cybercrime legislations. The CyberLeg-DPM specifies in logical order the set of key resources and procedures necessary in developing and implementing cybercrime legislation at the state or regional level. These characteristics are adopted within the regulatory development setting.

The steps are adapted to include:

- Stage 1: Domain/market understanding
- Stage 2: Field/OTT understanding
- Stage 3: Regulatory process understanding
- Stage 4: Regulatory design and development
- Stage 5: Evaluation
- Stage 6: Implementation
- Stage 7: Review and monitor

Stage 1 - Domain understanding – refers to identification and accounting for the diverse stakeholders' requirements in the telecommunications, VoIP and OTT domains. It involves due consideration of the issues relevant to the stakeholders including analysis of the relevant Acts and policies to identify gaps, limitations such as redefinition of bypass operation, OTT and VOIP services. Situation and feasibility assessment is done to account for the resource requirements and risk management. The regulatory development project design is the key outcome of this stage.

Stage 2 - Field/OTT understanding - refers to a detailed examination of existing and related regulations and legislations at different levels such as globally, regionally, and locally. Relatedness accounts for any legislation, regulation or policy that can or may impact the telecommunications regulation. These related laws and rules can be closely connected such as the cybercrime laws. With growing trends, the interconnected network of related legislations and regulations will continue to grow and will require formal coordination and management. This stage also involves understanding of technical knowledge component of network and telecommunications, the types of likely actions and other technical competencies. The key output of this stage is the result of comparative legislative and regulatory frameworks that will aid in guiding the development of the relevant regulations.

Stage 3 - Regulatory process understanding - sets the framework for building knowledge on and about the regulatory process for the specific country and the set of supporting processes that will facilitate all areas working in concert for an effective regulatory design and implementation with an efficient supportive environment. Each country may have specific set of processes/activities in developing regulatory process such as parliamentary approval. This process will also require involvement from multiple agencies and expertise from within the legal and regulatory fraternities for example. The key output at this stage includes a clear outline of the set of steps necessary in making, approving and implementing regulations, dependencies, and lines of accountabilities and governance structure.

Stage 4 - Regulatory design and development – involves the process of developing the regulation and developing/refining the regulatory process. The results of the previous stages are used to inform the actual creation of the regulatory artifact, including any process changes based on analysis. The processes identified in the

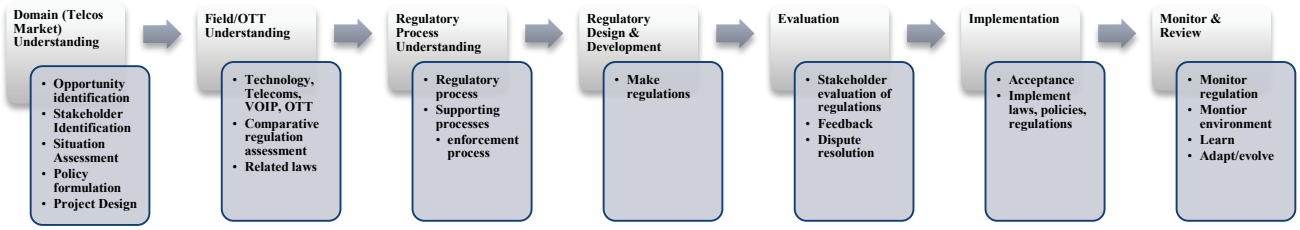

Figure 1: OTT Regulatory Framework (Generic)

previous step are further examined to determine how (i) the regulation can best fit into the current process and/or (ii) regulatory process guide on process improvements are provided to inform the relevant groups. The draft regulation is the key output at this stage supported by any revised processes.

Stage 5 – Evaluation – includes a comprehensive review of the regulation and any new supporting processes. This is done by key stakeholder groups including regulators, government, telecommunications and OTT providers, and customers. A clear consultative process supports the evaluation activities. The domain, market and regulatory objectives are also examined with the identified success criteria to assure completeness. In essence, the achievements of the objectives and evaluation of achievements of success criteria provided at the onset are examined at this stage. The refined regulation and know-how of the integration of the regulatory processes and the newly drafted regulation are the key outputs of this stage.

Stage 6 – Implementation – refers to the acceptance, implementation or enactment stage of the regulatory development process. This step is associated with the approval or passing of the regulation, the steps taken for it to become law, and the associated processes to put the new rules into operation. The key output therefore is the enacted regulation.

Stage 7 - Review and monitor – involves continuous analysis of the regulation, the general environment to help identify any opportunities for enhancement. This is crucial given the dynamism of the market and prolific evolution of technology. Critical to this step is instituting formal methods to assess the success of the new regulations and the supporting process in the context of adoption and use by its constituents. Key output of this stage is the results of review and monitoring process and key lessons.

6. CONCLUSION

This research is still at the preliminary stage and involves legal technology, telecommunications and policy considerations. Despite the nascent nature of the study, it offers several benefits and potential contributions. The study reports on the current regulatory environment in the Caribbean with respect to OTT services. The findings highlight that there is little or no regulation and underline that there are opportunities for regulation particularly where the legislations are not keeping pace with the technological development. While there may be salient arguments for no regulation, the nature of the Caribbean market may require a more structured path, i.e. some level of regulation to better monitor the telecos' activities, help protect customers while fostering innovation and promote rights and access to global services. As a consequence there needs to be a structured rethinking of formally addressing the concerns of the market and its key stakeholders including customers to protect their interests. The research also adapts a legislative process framework (CyberLeg-DPM) [20] to the regulatory environment in the Caribbean that can be applied in the examination and management of the OTT services. These findings are intended to add to the current dialogue on the policy considerations for OTTs.

The study is situated within the Caribbean context which is currently under-represented in both the academic and industry dialogue on this topic. Future work includes examining other countries in the Caribbean, expand the analysis to other countries, further explication, refinement and evaluation of the efficacy of the proposed regulatory framework in various market contexts.

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SESSION 8

ESTABLISHING TRUST FOR NETWORKED THINGS

S8.1 Invited Paper: A Required Security and Privacy Framework for Smart Objects.

S8.2 Smart Doorbell: an ICT Solution to Enhance Inclusion of Disabled People.

A REQUIRED SECURITY AND PRIVACY FRAMEWORK FOR SMART OBJECTS

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ABSTRACT

The large scale deployment of the Internet of Things (IoT) increases the urgency to adequately address trust, security and privacy issues. We need to see the IoT as a collection of smart and interoperable objects that are part of our personal environment. These objects may be shared among or borrowed from users. In general, they will have only temporal associations with their users and their personal identities. These temporary associations need to be considered while at the same time taking into account security and privacy aspects. In this work, we discuss a selection of cur- rent activities being carried out by different standardization bodies for the development of suitable technologies to be deployed in IoT environments. Based on such technologies, we propose an integrated design to manage security and privacy concerns through the lifecycle of smart objects. The presented approach is framed within our ARM-compliant security framework, which is intended to promote the design and development of secure and privacy-aware IoT-enabled services

Keywords— Internet of Things, Security, Privacy, Trust

1. INTRODUCTION

The application of security mechanisms to manage the life cycle of smart objects has received an increasing attention from the research community. Millions of interconnected constrained devices are starting to set up open and dynamic environments, which are difficult to be managed directly by humans. Indeed, this trend is expected to have increased in the coming years to reach between 50 and 100 billion of de- vices by 2020 [1]. In these environments, traditional operational procedures for bootstrapping, authentication and authorization are becoming obsolete, since they were not de- signed to deal with the inherent requirements of IoT ecosystems, in terms of scalability, heterogeneity, flexibility and us- ability.

The extension of technology to everyday devices implies the extension of identity management foundations to the physical world, in order to foster the deployment of Machine- to-Machine (M2M) communications [2] in which smart objects will be able to interact with each other, as an integral part of the IoT paradigm. In this sense, the IoT will require more lightweight, decentralized and end-to-end verification and authentication of the new devices deployed in a network, and, on the other hand, extension of the trust domain to such de- vices. This drives the need of new self-managing models to allow IoT smart objects to establish trust relationships among each other, while dealing with the new security and privacy concerns, which are inherent in these uncontrolled environments.

To this means, this work proposes the design of an integral approach for managing security and privacy concerns throughout the life cycle of a smart object. The design of the proposed approach is framed within our security frame-work [3] that is based on the *Architectural Reference Model* (ARM) [4], in order to realize the M2M vision of the IoT paradigm, while security and privacy are preserved. Specifically, in this work, we consider the use of the Handle System [5] as distributed information system for identification and resolution purposes of smart objects, an approach that is being currently considered by the ITU. Furthermore, we base our proposal on the use of the *Protocol for Carrying Authentication for Network Access* (PANA) [6], which is being currently used by ZigBee Alliance and ETSI M2M as IoT boot-strapping protocol. Moreover, we propose the use of partial identities as mechanism in order to conceal and minimize the private information revealed on a daily basis operation. The partial identities are implemented by applying anonymous credential systems (e.g. Idemix [7]), which allow to prove a subset of the attributes associated to the whole identity. Such privacy-preserving identity management mechanism could be integrated with other recent proposals, such as our *Distributed Capability-based Access Control* (DCap-BAC) [8] approach, in order to establish the notions of a se cure and privacy-preserving M2M-enabled IoT.

The remainder of this work is organized as follows: Section 2 provides a general overview of concepts related to identity management in IoT. Section 3 introduces some of the main security and privacy challenges of the life cycle of smart objects, and an overview of the main interactions of our security framework to cope with such concerns. Subsequently, section 4 proposes the use of different candidate technologies that are currently considered by standardization bodies to cope with security issues in IoT environments. Furthermore, Section 5 focuses on the

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privacy-preserving mechanisms that are envisioned to support secure and privacy-aware M2M communications. Finally, Section 6 concludes the paper with some remarks and an outlook of our future work in this area.

2. IDENTIFICATION AND IDENTITY FOR SUPPORTING SECURITY

2.1. Identities and Partial Identities in IoT

In the IoT ecosystem, identity management foundations must be extended to consider smart objects as entities with communication capabilities. While such smart objects may have different networking identifiers, they have also to possess their own identity to be distinguished from other devices. This identity could make reference a core identifier but also to specific features or attributes that point to the object. Furthermore, smart objects could act on behalf of a user. These objects could then be aware of the identity of their owners disclosing sensitive information to other devices. The identity management should be distributed in order to authenticate objects between each other but, at the same time, centralized enough to be able to establish a hierarchical approach where identity credentials could be issued and authenticated securely enabling a global digital trust environment.

Privacy concerns are also of paramount importance in IoT, where mechanisms for anonymity making use of partial identities are required. A partial identity is a subset of the attributes that comprise the complete or real identity of the user. Thus, an identity of a particular user or object may be composed of different partial identities. Each of these partial identities can be used to identify the user or the object in different circumstances according to the context or social situation. The real identity is the union of all the attributes of the partial identities of the user or object. Partial identities may comprise not only traditional user personal attribute values like names, identifiers, and addresses, but also object at- tributes, such as hardware features or software version. Thus, IoT ecosystems require suitable identity management solutions to cope with new challenges due to inherent nature and requirements of IoT, where the identities of a huge amount of heterogeneous smart objects need to be properly managed.

2.2. Object Naming, Resolution, Networking and Addressing

In order to achieve a real IoT, an essential feature is to give support to finding smart objects in order to be addressable, named, and finally discovered. In the IoT paradigm, smart objects cannot be configured with respect to a fixed set of services. This is mainly due to the underlying dynamics of the IoT system resulting from the mobility of such devices, as well as the changing availability of services due to constraints on the underlying resources and devices. Therefore, a real need exists for a suitable infrastructure to be in place that allows addressing, naming and discovery of IoT services:

- IoT Addressing: an IoT address refers to an identifier of a smart object and/or its virtual representation. This feature entails the assignment and management of ad- dresses/identifiers for smart objects.

- IoT Naming: it refers to mechanisms and techniques for assigning names to objects and supporting their resolution/mapping to IoT addresses. IoT Naming pro- vides the means to identify smart objects through a resolution mechanism of a name according to a naming system. Additionally, names can be organized according to taxonomies or classifications in a hierarchical fashion and according to a well-defined naming system.

- IoT Discovery: it refers to the process of locating and retrieving IoT resources in the scope of a large and complex space of smart objects.

Previous concepts are closely related, given that the adherence to certain choices and solutions (e.g., standards, mechanisms, algorithms, tools) for one area (e.g., choice of addresses/identifiers) can directly affect the respective choices and solutions in the other areas (e.g., naming system used). As a consequence, the consideration of solutions for one area cannot be seen as isolated from the others.

2.3. Handle and Identifiers

The realization of the concepts described in the previous section implies the need for suitable infrastructures to enable addressing, naming and discovery procedures for the IoT ecosystem. Indeed, currently there are different proposed Internet identifier services addressing some of these aspects. X.500 [9] is the OSI Directory Standard defined by the ISO and the ITU. It defines a hierarchical data model with a set of protocols to allow global name lookup and search. In the same direction, The Lightweight Directory Access Protocol (LDAP) [10] was developed as a more lightweight alternative, but bringing different problems related to the hierarchical data model, as well as to the complex search/query process. Addressing some of these main concerns, the Handle System (HS)[1] is a general purpose distributed information system that provides efficient, extensible, and secure identifier and resolution services for use on networks, such as the Internet [5]. While X.500 or LDAP could also be used, HS provides additional features, outperforming previous approaches due to its flexibility to enrich the resolution infrastructure with security aspects. Furthermore, HS could be used in tandem with LDAP providing efficient name resolution service, and extended search capabilities, respectively [11]. It is part of the Digital Object Architecture (DOA). A Digital

[1] www.handle.net

Object (DO) has a machine and platform independent structure that allows it to be identified, accessed and protected.

The HS was developed initially with digital documents in mind, but it has evolved into a generic implementation of the DOA, supporting multiple object types, not just 'digital documents'. It is being taken into account by the ITU under ITU-T Recommendation X.125. The HS incorporates an operational security system based on both private/public key pairs and passwords. It allows for the storage and resolution of a set of attributes to a particular identifier, including an infrastructure for authentication, signing, integrity checking, public key operations as well as an authorization mechanism to restrict the access to the attributes. A handle consists of a prefix and a local identifier. The syntax of the DO is a set of pairs (type, value). As with the Domain Name Sys- tem (DNS) with its DNS Resource Directory (DNS-RD), the Handle Resolver (i.e. handle server) will provide a set of such pairs, some of which include well-known data types, like URIs, INET HOST addresses, etc. The pairs can be hierarchic, so that a DO contains descriptions and identifiers of other DOs in its parameters. Clearly, some of the parameters may contain IPv6 addresses, but there may be several such addresses depending on different views of the parameters.

The attributes managed by Handle and associated to an identifier can be exploited by an identity management system in order to allow the usage of partial identities associated to such attributes. A claim-based anonymous credential system, e.g. Idemix [7], can interact with Handle to generate credentials based on the attributes associated with the smart object. Subsequently, the smart object can derive partial identities from such a credential to operate against other smart objects in a privacy-preserving way. Specifically, we envision the use of Handle for three main purposes:

- Restricting the access to Handle attributes to authorized smart objects, based on a public key infrastructure through the use of X.509 certificates.
- Anonymous credential provisioning and partial identity management based on the attributes that are registered in the HS.
- Generation of authorization credentials to enable M2M secure communications, based on handle attributes to make access control decisions.

3. TOWARDS A SECURITY FRAMEWORK FOR SMART OBJET LIFE CYCLE

The secure management of the life cycle of IoT smart objects imposes the need for considering architectural approaches, taking into account the inherent requirements of the application of security and privacy-preserving mechanisms on IoT scenarios. Towards this end, IoT-A [4] was a large-scale European project focusing on the design of an *Architectural Reference Model* (ARM), in order to optimize the interoperability among isolated IoT domains. Based on ARM, our security framework [3] [12] is intended to address security and privacy concerns in the IoT paradigm, by instantiating and extending the security functional group of ARM. Consequently, such framework promotes its applicability and inter- operability in a wide range of IoT scenarios, in which security and privacy are required.in capital and lower case letters. Papers with multiple authors and affiliations may require two or more lines for this information.

Under the complete view of our IoT security framework, as well as the main stages of the life cycle of smart objects [13], below we provide an overview of the main interactions that are required to address security and privacy concerns through such phases. It should be pointed out that, while it has been proposed in our framework, for the sake of clarity, the interactions of the Group Manager functional component are not addressed in this work [14]. Figure 1 shows the required interactions to manage security during the smart objects life cycle. The description of these interactions is split according to the main stages of it. In particular, the life cycle begins when a smart object is installed and commissioned during the bootstrapping process. We propose to extend this phase so the smart object is also registered (Bootstrapping and registration), and consequently, it can be discovered by other smart objects. This discovery process is shown in the figure through the Discovery and provisioning stage, in which a smart object additionally tries to obtain the required security credentials for a secure and protected access. In case this process is successfully completed, both devices can communicate with each other during the Operation stage, in which a smart object tries to get access to the discovered device by using the credentials previously obtained.

At this point, note that, while it is not shown, we assume smart objects are supplied with statically configured cryptographic material (e.g. symmetric keys or X.509 certificates) before the bootstrapping process. Such cryptographic material can be configured by the manufacturer (or the device's owner), and it can be considered as the *root identity* that is employed for bootstrapping procedures. During this stage, the smart object is commissioned and connected to the net- work, which implies an authentication and authorization process that is required before starting the sending or receiving of data. Specifically, the purpose of this process is twofold. On the one hand, the smart object can be registered in or- der to be discovered by other smart objects to communicate with each other. This functionality is already considered by the ARM through the IoT Service Resolution functional component, and it can be carried out by an infrastructure entity (e.g. based on Handle). On the other hand, a success authentication and authorization process could derive other cryptographic material to be employed by the smart object during its operation. In particular, we

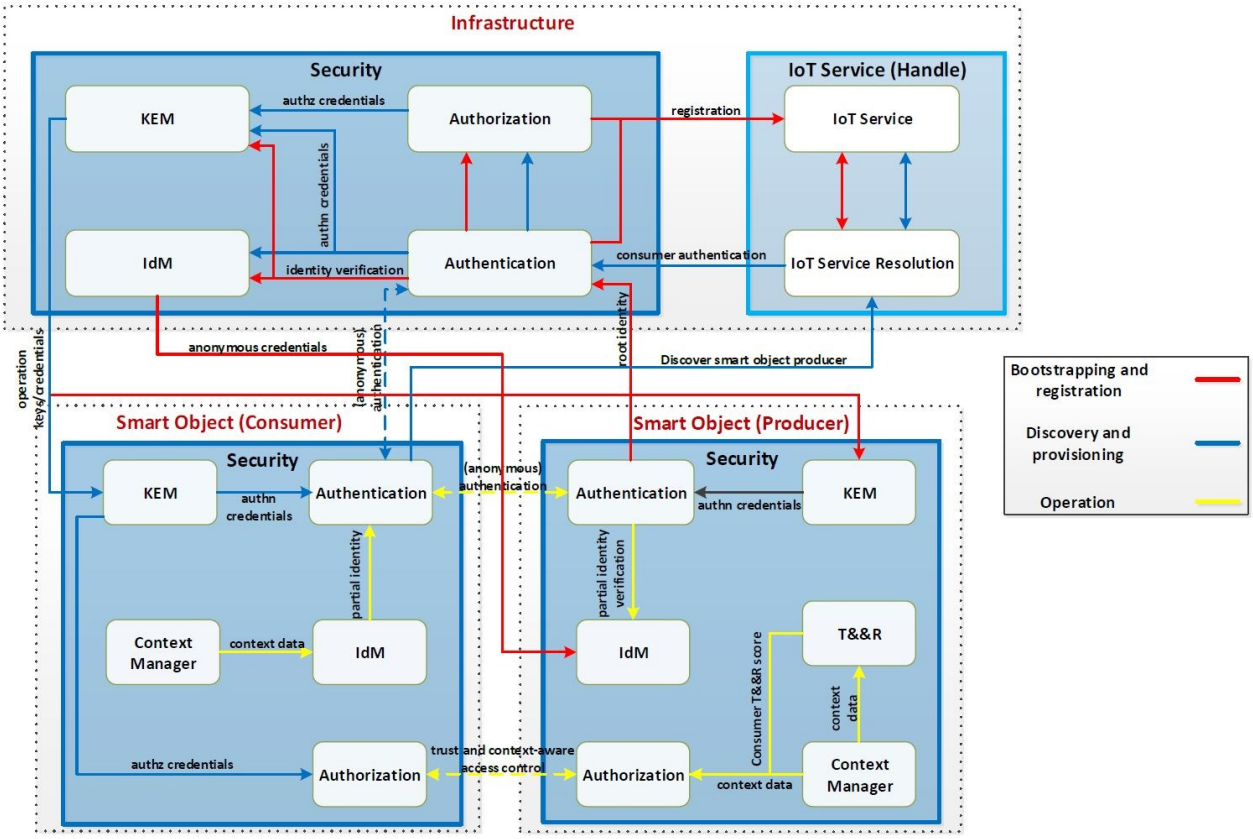

Figure 1. Overview of the security framework interactions for Smart Objects Life cycle

envision that anonymous credentials (e.g. based on Idemix) associated with identity attributes that are demonstrated during the boot- strapping, could be supplied during this process. However, while smart objects could use such credentials for privacy-preserving communications, the creation of an anonymous credential would be linked to the root identity of the smart object. This process is intended to preserve the accountability of the anonymity condition, in order to avoid the misuse or abuse of it.

After the smart object has been successfully bootstrapped, it enters the operation phase by providing (or trying to get access to) the services for which it has been manufactured. At operational level, security guarantees that only trusted and legitimate smart objects can communicate with each other. Consequently, the application of security and privacy-preserving mechanisms is crucial to ensure a proper and effective operation of the smart object. For these interactions, we assume the existence of two smart objects acting as a producer (providing a service), and a consumer (trying to get access to such service). In addition, we assume that these smart objects have already carried out the process previously described. Before starting the operation stage, the consumer initiates a discovery process to know the services being pro- vided by the producer. This step involves authentication and authorization procedures, in order to determine whether the consumer is authorized to find that service or not. Further- more, such authentication mechanism can consider privacy concerns of the consumer through the use of partial identities, which can be derived from the anonymous credential. Furthermore, we envision the extension of the discovery step in order that the consumer, in the case of a successful authentication and authorization process, can get the required credentials for a secure M2M communication with the producer smart object. Once this process is completed, such credentials are used by consumers to access a resource being hosted by the producer. On the one hand, from a consumer perspective, the operation stage can take into account privacy concerns through the selection of a different partial identity (or pseudonym), according to contextual information being sensed. On the other hand, from the producer perspective, the evaluation of authorization credentials presented by the consumer could consider additional information, such as trust and reputation scores associated to the requesting smart object [15].

4. LIGHTWEIGHT SECURITY MECHANISMS FOR IOT ENVIRONMENTS

Having highlighted the main required interactions of our IoT security framework have been highlighted, below we give an overview of candidate technologies being currently considered by different standardization bodies, and how they can be integrated to achieve the functionality previously described. The integration of these mechanisms is intended to provide a holistic view to support security and privacy

aspects, which can be leveraged by smart objects during their life cycle.

4.1. Security Bootstrapping

The bootstrapping process usually consists of a set of procedures in which a node is installed and commissioned within a network. Optionally, this stage can include authentication and access control mechanisms to get security parameters for trusted operation. For a successful and secure bootstrapping process, well-known mechanisms need to be on the basis. Additionally, in the context of IoT constrained scenarios, the application of such procedures needs to be analysed due to implicit requirements of these environments. Towards this end, [16] provides some design considerations that must be taken into account in the design of an appropriate IoT boot- strapping protocol. In addition, [17] presented three main alternatives for the security bootstrapping of IoT devices: *Host Identity Protocol Diet EXchange* (HIP-DEX) [18], PANA [6] and 802.1X.

Currently, PANA is widely accepted as the main candidate for IoT security bootstrapping, and it is being employed by ZigBee Alliance in conjunction with EAP-TLS as authentication protocols. In this work, we consider that smart objects are initially equipped with an identity certificate (e.g. a X.509 certificate), which contains a set of attributes associated with the smart object (e.g. manufacturer or hardware features). Then, we propose the use of PANA as a signaling protocol enabling smart objects, in an on-demand way, to make smart objects to apply for security credentials that can be used for secure M2M communications during their operation.

4.2. Operational Security

At operational level, security guarantees that only trusted and legitimate instances of an application running in the IoT can communicate with each other, through the use of the corresponding security mechanisms at the application layer. Specifically, CoAP [19] defines a security binding to DTLS [20] through the use of pre-shared keys, raw public keys or certificates. However, it does not cover the use of authorization and access control mechanisms at the application level. Towards this end, our *Distributed Capability-Based Access Control* model (Capac) has been postulated as a realis- tic approach to be used on IoT scenarios [8]. This approach is based on linking access privileges or capabilities to smart objects, which are identified by their public key. Capac is based on the use of authorization tokens, containing capability that were previously granted to the holder, as well as a set of access conditions to be locally verified by the end de- vice when the token is presented. Specifically, it makes use of the *JavaScript Object Notation* (JSON) [21] as representation format for the capability token, which is attached in access requests by using the *Constrained Application Protocol* (CoAP) [19].

In addition to the main authentication and authorization for communication between two smart objects, given the global scale of the IoT, it is likely that smart objects often operate as groups of entities (e.g. interacting or collaborating for a common purpose). Indeed, we consider the concept of group as essential in the IoT to cope with environments with a high number of smart objects interacting with each other, and the application of security mechanisms involving groups of devices with dynamic and ephemeral relation- ships as a challenging aspect. In this sense, the *Ciphertext-Policy Attribute-Based Encryption* (CP-ABE) [22] has been recently proposed as a highly flexible cryptographic scheme, which provides the ability to define groups and subgroups of smart objects according to different combinations of identity attributes. Indeed, unlike the use of symmetric key cryptography, in which groups of entities must be preconfigured, a smart object could encrypt each piece of data under a different combination of attributes, allowing for the creation of dynamic groups or subgroups. For example, a smart object could encrypt information so that only the set of objects from the same manufacturer or the same owner could decrypt the information. The application of CP-ABE for IoT scenarios is currently considered in our framework, through the design of our proposed Group Manager functional component, as well as the interactions with other security components.

4.3. Supporting Security and Privacy features in the Life Cycle of Smart Objects

After the overview of the main security and privacy technologies addressing different aspects of the life cycle of smart objects, this section shows an overview of how some of the above mentioned technologies previously described could be integrated into addressing such requirements.

According to the main stages described in the previous section, the life cycle of a smart object begins with *the boot-strapping/registration* phase. For this stage, we consider the use of PANA due to its flexibility enabling the execution of different authentication mechanisms or EAP *methods*. Once the smart object is successfully authenticated through its root identity (for example, by using a X.509 certificate), we pro-pose to extend this phase so the smart object is registered through the use of the Handle infrastructure to be discovered by other smart objects. This process may involve the registration of attributes or additional information that is contained in the smart object's certificate. After this process, the device could try to obtain an Idemix credential that is associated with the information previously registered in the Handle server. Indeed, it can use the issuance Idemix protocol as specified in [7].

In the *discovery and operation* stages, a smart object (acting as a *consumer*) tries to access a resource being hosted by another (acting as a *producer*). For this purpose, firstly, it discovers the device by querying the Handle server. It should

be pointed out that this process may require authentication and authorization procedures according to the information that was registered during the bootstrapping and registration stage of the smart object producer. In addition to the discovery, the consumer tries to obtain the credentials that are required for a secure and M2M operation. In this case, we propose to extend the semantics of PANA notification messages so that a device can apply for DCapBAC tokens to get access to a resource being hosted by another device. Obtaining these credentials implies an authorization process driven by infrastructure components, which are responsible for generating DCapBAC tokens to authorized smart objects. For this purpose, we propose the use of CoAP/DTLS or HTTPS as communication protocols, and the *eXtensible Access Control Markup Language* (XACML) [23] as standard access control technology. Finally, after the smart object consumer obtains the required DCapBAC token, it can make use of a CoAP-DTLS exchange attaching the credential for a secure and protected M2M communication.

5. PRIVACY-PRESERVING M2M SUPPORT

The realization of the IoT ecosystem implies moving towards automated and self-managing security mechanisms, which allow IoT devices to set up trust relationships with each other with a low degree of human intervention. Furthermore, given the M2M nature of these emerging scenarios, the application of current privacy-preserving technologies needs to be reconsidered and adapted to be deployed in such global ecosystem, addressing aspects such as *Privacy by Design* (PbD) [24], in order to give people maximum control over their personal data. As already mentioned, privacy-enhancing technologies provide means to achieve anonymity, data minimization, unlinkability as well as other techniques to provide confidentiality and integrity of sensitive data. In this regard, the usage of partial identities as privacy-preserving identity management scheme, allows users to define a subset of the personal attributes, from their real identity, in order to identify them in a given context. In order to realize this vision, some solutions rely on the notion of Anonymous Credential Systems [25] to deal with privacy concerns. Through the use of these technologies, a consumer smart object could try to get access to a producer device by proving a subset of identity attributes from their whole identity, without the involvement of an on- line Trusted Third Party (TTP) in charge of authenticating the subject.

The use of partial identities and anonymous credential systems, which has been previously proposed, could be combined with authorization mechanisms, such as our DCapBAC approach [8]. Specifically, in the original DCapBAC proposal privacy aspects are not considered, since it is based on the use of X.509 certificates, which are used to identify smart objects making use of authorization tokens. These considerations were addressed in our recent work [26] by enhancing DCapBAC with anonymity features, in order to deal with privacy concerns through the integration with Idemix [7].

Specifically, with this approach, the smart object (acting as a producer) could use its Idemix credential obtained during the bootstrapping/registration phase to get an Anonymous DCapBAC token from the Capability Manager (the entity that is responsible for generating these credentials) in a privacy-preserving-way. Specifically, the Idemix proof generated by the producer could be associated with a particular partial identity (i.e. a subset of identity attributes), which could be used for authorization purposes by the Capability Manager and the PDP. Such proof should also contain a pseudonym generated by the smart object to be specified in the token. Then, the smart object can make use of such anonymous token, to get access to the producer smart object through the Idemix proving protocol. This process allows the consumer to prove it is the entity associated with the token while concealing any other identity attributes. The integration of this mechanism to the scenario proposed in the previous section is being currently designed and implemented, and it represents part of our ongoing work in this area.

6. CONCLUSIONS AND FUTURE WORK

The realization of IoT scenarios imposes significant security and privacy concerns due to the extension of Information Technology to our everyday lives. These aspects must be addressed by considering the whole picture of this paradigm, so the enormous envisioned potential can be leveraged by the society in the context of the future Smart Cities. Physical objects of our surrounding environment are being enabled with intelligence and communication abilities transforming them into smart objects. In this work, we have reviewed the main security and privacy challenges that are inherent in an IoT ecosystem. These implications are considered crossing all the stages of the life cycle of a smart object. We claim the need to consider architectural approaches to cope with these challenges in order to design appropriate mechanisms for emerging environments. By considering our previous work in this area, and some promising technologies that are currently being contemplated for deployment in IoT scenarios, we have provided the design of an integrated approach in order to capture such requirements. This scenario is being developed under our ARM-compliant security framework, with the aim of providing a holistic security approach as a step forward to realizing the vision of a secure and privacy- preserving IoT.

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SMART DOORBELL: AN ICT SOLUTION TO ENHANCE INCLUSION OF DISABLED PEOPLE

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ABSTRACT

In daily life, people have the need to know the identity of a visitor who comes to their homes, regardless of whether they are there at that time. This need is even greater for people who suffer from some kind of disability that prevents them from meeting the visitor. To provide a solution in this sense, this paper proposes a smart model that performs the task of a doorbell, which should recognize the visitor and alert the user. To achieve that, this proposal incorporates technologies for facial recognition of people, notifications to users and management of their responses. The process to solve the problem was divided into interrelated stages and standardization issues are discussed later. Finally, to test the effectiveness of the model, three scenarios were simulated; each one was composed by different households over which the recognition of known and unknown individuals was analyzed.

***Keywords*—** Smart Doorbell, Social Inclusion, Internet of Things, Face Detection and Recognition.

1. INTRODUCTION

Today, the world population is over seven billion people and more than one billion people live with some form of disability. International Telecommunication Union is working in this sense to give equal opportunities for people with disabilities and create accessibility guidelines for the elder [1].

Argentina has a population of 40,117,096 inhabitants, where the 12.9% present a disability or permanent limitation (each province of the Argentinian North East is above the national average). Of the total population, 10.2% are 65 years or more, group in which the percentage of permanent disability grows to 40.9% [2]. Regarding the use of information and communication technologies (ICT) within the country, it is known that 47% of households have a personal computer and in 86% of them there is at least one cell phone [2]. It should be noted that internet penetration scales up to 62%, the third highest in South America [3][4].

People with disabilities are constantly facing problems of different complexity when they perform their daily tasks, like opening the door to someone or finding out who is outside their house. Innovative technologies can be leveraged to assist individuals in these tasks or provide tools to do so.

In this paper we present a model for a smart doorbell which, through the use of a camera and image recognition software, can identify the visitor and send a notification with his/her information to the owner of the house. This notification is sent to the user's mobile device, from where he can respond by video or voice.

The development of this smart doorbell model is originated within the framework of a continuous advancement of information systems over all kinds of tools, updating them and contributing with improvements for greater comfort for its users, also aiding in increasing life quality by solving everyday problems.

The theoretical aspect of the proposed model is based in the concept of Internet of Things (IoT) [5], for which smart technologies are a key enabler [6]. The objective under IoT is to provide intelligence and interconnectivity to daily things in order to obtain social or economic benefits. Furthermore, the model uses facial recognition through Nearest Neighbour classifiers [7] to accomplish the core functionality.

The proposed model is a progress in Things-to-Humans collaboration; this kind of solutions are expected to be usual from 2020 onwards [8], being it a key part in the development of IoT.

Different domains have been proposed to classify IoT applications; the model described in this paper aims to two of them. The first is the "smart home" domain and the second refers to "independent living" domain [9]. Combining those domains we have a home automation IoT application oriented for the elderly and disabled.

This paper is structured as follows: Section 2 describes the problem addressed with more detail and background. Then, Section 3 presents the specifications for the proposed model. Section 4 exposes some challenges to the model and the standards. Section 5 shows simulations which intent to probe the effectivity and reliability of the proposed system, and finally, Section 6 concludes with a discussion about the model and future work.

2. PROBLEMATIC SITUATION AND BACKGROUND

For most people, answering the door when someone is knocking is a simple and daily situation. However, for

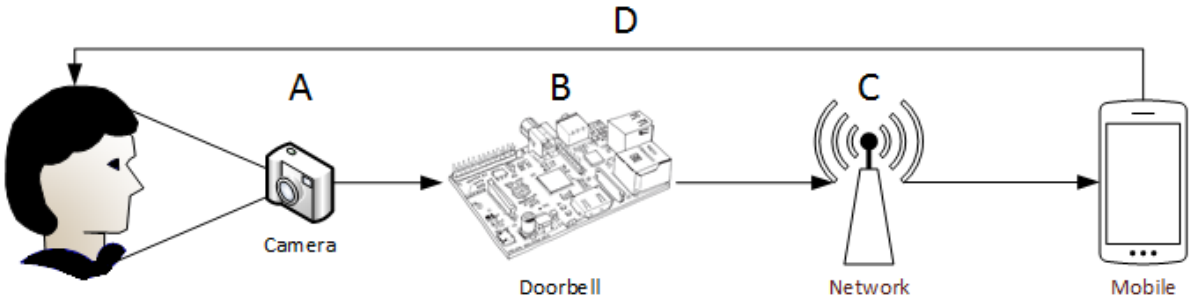

Figure 1. Proposed stages for the model

elderly people or a person with physical, visual, hearing or mental disabilities this task can be uncomfortable and complex. For these individuals, moving to the point where there is a conventional intercom buzzer can take a long time and the person who visits could have retired by then.

In these situations, a notification system can avoid the unnecessary displacement to the door to meet an unimportant or unwanted visitor and would allow a much faster response to the person outside.

In elderly people's situation, the comfort of answering the door immediately and without the need of movement is desirable. Moreover a system that notifies to a mobile device can be useful for security concerns in older people living alone, either because nobody lives with them or because they are temporally left alone in the house; in this case the elder (or a relative somewhere else) can monitor the visitors arriving and be aware of any unknown or doubtful caller, preventing in this way any scam or dangerous situation for the elder.

For a person with visual impairments, recognition of the visitor can be a problem. Recognizing someone by his or her voice can be very difficult if there is not a daily contact with that person. Given this situation, a doorbell able to recognize those who visit provides an important assistance.

Anyone with hearing disabilities can have, among others, two problems: the first is the warning bell since they cannot hear its sound. This situation is usually solved by wiring the conventional doorbell to at least one light in every room in the house so when a person rings the doorbell the lights blink; the second problem which arises is the recognition of the individual who rings the doorbell; a person who suffers from hearing impairment must, inevitably, go to the door to see who is there. Under these circumstances, it would be desirable to have a system that identifies the visitor and sends a notification to a mobile device making it vibrate and alerting the owner, thus avoiding the wiring of flashing lights.

The importance of information technologies to contribute to the social development is not subject of doubt. The United Nations has issued documents where member states are urged to take accessibility as an integral part of their ICT programs and projects [10], and more specifically, the Secretariat for the Convention on the Rights of Persons with Disabilities has referred to the issue of improving life quality through the use of information technologies [11].

There is a rich history of information and communication technologies applied in order to improve the quality of life and solve various problems of people with disabilities, to name a few: a project in Stockholm called SmartBo had the goal to adapt a home using ICT to enhance the independence of people with disabilities [12]; a system to control the computer's mouse through head movements designed for a quadriplegic user [13]. Also, products that were not produced with inclusiveness in mind can be taken to help the disabled, for example a remote door locking system via Internet [14].

There are also records of systems related to the solution presented in this work; Argus is a product that uses facial recognition of individuals entering a building to, subsequently, deliver notifications to people interested in the arriving person [15], or systems using similar hardware and software to detect persons through image processing to issue notifications with their position [16].

3. PROPOSED MODEL

To solve these problems a smart doorbell which has the ability to recognize the person who triggers it and then notify the user in his mobile phone was devised.

The following four stages represent the basic operations of the system (see Figure 1):

- Stage 1. Capture (Figure 1.A): The visitor presents himself in front of the door and when he presses the doorbell button, the camera captures an image of his face.
- Stage 2. Processing (Figure 1.B): The captured image is sent to the doorbell server, where it is processed to recognize the visitor.
- Stage 3. Notification (Figure 1.C): Once the person is recognized or not, a notification is generated and sent through the network to the user's mobile device.
- Stage 4. Response (Figure 1.D): Once the notification is received, the user can choose to answer by starting a conversation, as in a conventional bell, or to ignore it.

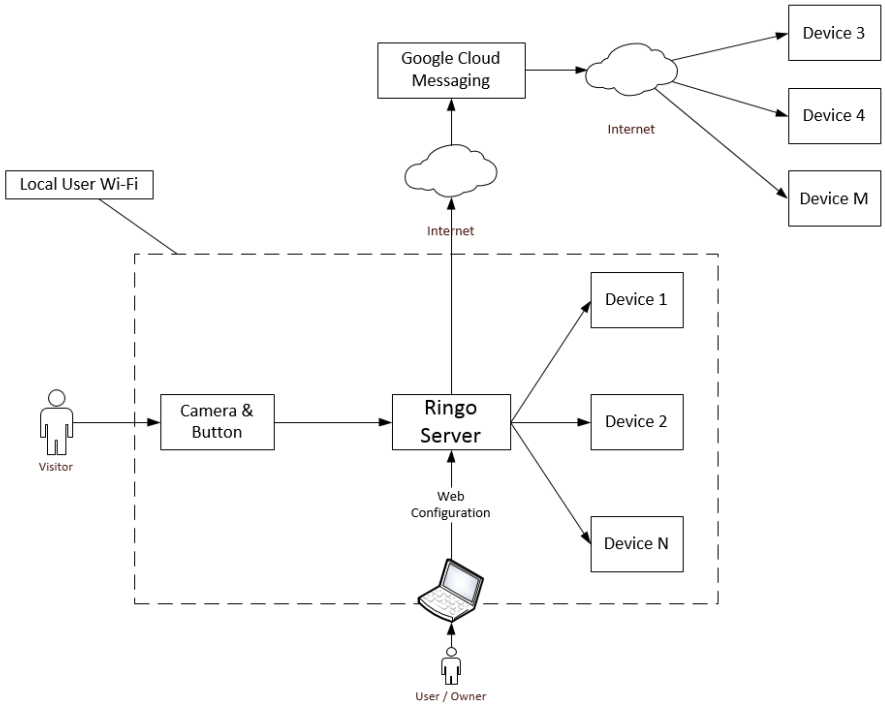

Figure 2. Simplified operation diagram of the model

Besides this main feature, this doorbell has other helpful characteristics: (i) leave messages recorded for predefined visitors: if the user have to go out, he can leave a prerecorded message to be reproduced if the selected person rings the doorbell; after the visitor is recognized in stage 2, the bell will play the prerecorded message for that person; (ii) allow visitors to leave messages: when there is no response to the notifications sent in stage 3, the visitor will be allowed to leave a voice message to the user.

On the other hand there are management software features: (i) allows the creation of lists of unwanted people, who the doorbell will ignore; (ii) keep a log of visits; (iii) enable and disable the doorbell since the user may not want to have it activated at certain times.

This system aids in solving the problem presented earlier for people with disabilities of any kind, making the task of answering the door easier. People with mobility problems will not have to move to do so; those with visual problems will be notified audibly of whom is outside, and for those with hearing problems their mobile phone will vibrate with the notification. The system also provides greater comfort and safety for users in general.

Essential aspects of the system's components and its operation are described in detail in the following sections.

3.1. Model's Hardware Description

The hardware required for the system consists of a Single Board Computer (SBC) Raspberry Pi. This computer has a relatively low cost and has a 700 MHz Broadcom System on Chip (SoC) (depending on model) with ARMk6 architecture, a Graphics Processing Unit (GPU), main memory (RAM) of 512 megabytes and secondary storage on Secure Digital (SD) or Secure Digital High-Capacity (SDHC) memory cards.

In addition, a high definition infrared camera PiNoir and an infrared LED illuminator are required to improve visibility in night conditions. These peripherals are easily connected to the board and accessed through standard software interfaces. To connect the device to the network, a Wi-Fi 802.11 g/n USB adapter is required. Finally, it is necessary a push-button directly connected to the General Purpose Input and Output (GPIO) pins of the board, which works as a trigger button.

3.2. Model's Software Description

The frontend is composed of a web interface for managing the doorbell settings and an Android application where the notifications are received and from which certain system functions can be adjusted, such as enabling or disabling the bell, silencing notifications, setting the "out of home" mode, answering the doorbell with audio and video and leaving messages for specific visitors.

The web interface is developed mostly using AngularJS and Bootstrap, JavaScript libraries to easily create dynamic websites. It communicates with the backend, which exposes a Representational State Transfer (REST) interface for queries and data modifications.

The backend is divided into four subsystems: detection service, recognition server, XMPP server [17] and configuration server. All backend subsystems, schematized as "Ringo Server", are illustrated in Figure 2.

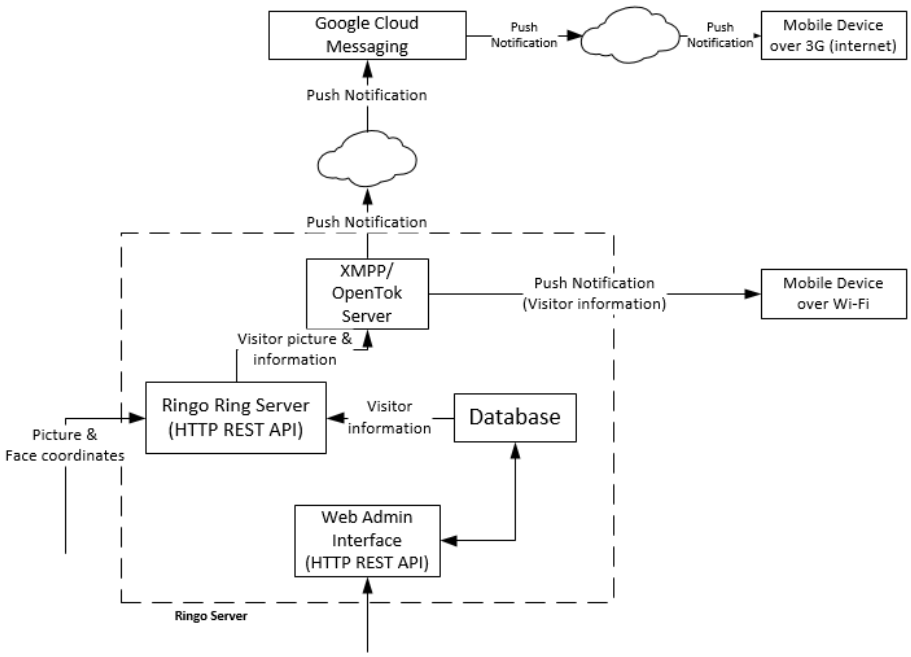

Figure 3. Ringo Server component diagram

The mobile application is developed using the Android Software Development Kit (SDK) [18], Smack [19] a Java library to communicate with Extensible Messaging and Presence Protocol (XMPP) servers, and for local area networks service discovery JmDNS [20] is used.

The event flow begins when a visitor activates the push-button. At this time, the detection service begins capturing images using the camera to detect the coordinates of possible faces, stage 1. These results are sent to the recognition server, which attempts to recognize or match to any face pictures stored in the database, stage 2. Then, the visitor information is sent with the photo (or only the picture in case of no match) to the XMPP service, which distributes the message as a notification to all mobile devices connected at that moment, stage 3.

In case the user sets the "out of home" mode, the notification is sent without charge through Google Cloud Messaging (GCM) service [21]. This service allows the device not to keep a persistent connection to a server for receiving alerts, optimizing the use of battery and processor (Figure 3). GCM imposes a limit of 4 KB of data per notification, enough to send a small image and a person's information (i.e. name, lists to which he belongs, etc.). On the other hand, devices connected to the local network can use VoIP to establish a communication with the outside visitor outside, stage 4.

Last, the configuration server provides a web interface for administration and adjustment of the doorbell by the user.

The backend is developed using Django [22], a framework written in Python for database-driven websites and Django Rest Framework [23] to ease the development of the REST interface. Face detection and recognition is performed using Open Computer Vision (OpenCV) [24], a library created by Intel and maintained by the community through their open source license. Detection is achieved through two algorithms incorporated in OpenCV: Local Binary Patterns (LBP) [25] and Haar Cascades. LBP is also used for recognition. Information about visitors is collected progressively at different times when they arrive. This means that the database starts empty and as people arrive, their picture is saved and the user can later set the names and other information concerning the visitors. Because of this, on their first visit, each person is not recognized by the system and the notification sent to the user will lack any information other than the picture from the camera.

The XMPP service is a separate process running as a daemon in the server and listening for TCP connections on port 5222. The application chosen for this purpose is ejabberd [26] for its ease of installation and configuration. The connection and the sending of the visitor's data are performed with SleekXMPP [27], a XMPP library written in Python.

The recognition and configuration subsystems run on the Apache web server with a Web Server Gateway Interface (WSGI) for applications [28]. The chosen database server is PostgreSQL.

The backend runs on a Raspbian operating system in the Raspberry Pi computer.

4. CHALLENGES TO THE MODEL AND STANDARDS

Confidence is critical in applications as the one described in this paper so the user can first, rely on the notifications he is getting from the system and second, be sure that all the information stored and processed is safe as it moves through different networks. The success or failure of the model is subject to the trust it can inspire in the user. In order to build this trust, it has to be grounded over strong

recognition software and standards that empower security and privacy.

The recognition software of the model is described and tested in this paper. As for the standards, the ITU-T has published many recommendations regarding IoT applications. In Recommendation Y.2060 [5] are expressed many security capabilities that IoT applications should have. In the Recommendation F.748.0 [29] the ITU-T describes as a fundamental characteristic that "IoT applications are required to support privacy protection during data transmission, aggregation, storage, mining and processing". Recommendation Y.2066 [30] addresses again the issue of security and privacy protection over the use of the application. To comply with this, the presented model uses well known and well tested software and software libraries, and all communications between the server and the different devices are protected with Transport Layer Security (TLS).

But not only is the success of this model tied to trust, the only way IoT will grow and accomplish its full potential is through trust. IoT will empower the Information Society only if it is trustworthy. In order to allow IoT expansion, the challenge of upcoming standards is the explicit assurance of security and privacy.

5. SIMULATIONS

To evaluate the performance of the proposed system a series of simulations have been developed, where the reliability of face recognition is tested in a laboratory environment using the AT&T database of faces [31], which contains 10 different facial images of each of 40 distinct subjects.

There are two groups of interest in the analysis of arriving people: a group of known visitors and a group of unknown visitors. For the known visitors group, the system may identify correctly or fall into one of two error types: identify the visitor as another person (false positive) or not recognize him, labeling the visitor as a stranger (false unknown). For the unknown visitors group, the system may correctly label a person as stranger, or it could make a mistake and identify him as a known visitor.

5.1. Procedure

In order to achieve the goal of this section, the use of the system is simulated in three different houses, each with a definite number of people loaded in the system (i.e. known visitors). To do this, a portion of the available images of every subject is used to train the system and the remaining is used for testing. This experiment simulates an individual ringing the doorbell. For example, a person with 6 images used for training has rung the bell 6 times. Another group of individuals is used as a group of strangers.

Three different experiments are performed with the three houses:

- First experience: 5 people are assigned to House A, 10 people to House B and 15 people to House C. 6 pictures of each subject are used to train the system and the remaining 4 are used for testing, making a total of 20 tests per known visitor on House A, 40 on House B and 60 on House C.
- Second experience: after the previous experiment, 20% more individuals are added to each house, having now House A with 7 known visitors, House B with 14 and House C with 21. The amount of images is maintained: 6 are used for training and the remaining 4 are used for testing, making a total of 28 tests for House A, 56 for House B and 84 for House C.
- Third experience: the amount of subjects and images per subject are maintained, but the number of images used for training is lowered to half, leaving 3 images for each known person.

In all the experiments, a fixed set of images of unknown individuals are used for testing: 4 tests for House A, 7 tests for House B and 10 tests for House C.

5.2. Results

The three experiments were performed as discussed before. The percentage of hits obtained for the different homes in every experience when known and unknown visitors arrived are summarized in Table 1.

Regarding the first experience, the amount of positive recognitions obtained were no less than 80%. For House A, 16 of 20 tests were recognized correctly, the wrong results were due to misclassification of individuals as strangers. Regarding the test with strangers, a correct classification was obtained in 100% of cases. For House B, 38 of 40 tests were recognized correctly, equaling to 95% of cases, being the two errors a false positive and a false unknown. The tests with strangers yielded a success rate of 71.43%. For House C, in 90% of the tests, the subjects were recognized correctly. There were 6 errors due to two false positives, and the others due to false unknowns. As to strangers testing, 8 out of 10 subjects were correctly classified. The average of successful recognition obtained in the three homes was 88.33%.

In the second experience, when increasing the amount of known individuals in each home, the recognition rate

Table 1. Hit rate summary

	Experience 1			Experience 2			Experience 3		
	House A	House B	House C	House A	House B	House C	House A	House B	House C
True Known Positive (%)	80.00	95.00	90.00	85.71	96.43	88.10	82.14	85.71	72.62
True Unknown Positive (%)	100.00	71.43	80.00	100.00	71.43	80.00	100.00	71.43	80.00
Overall True Positive (%)	83.33	91.49	88.57	87.50	93.65	87.23	84.38	84.13	73.40

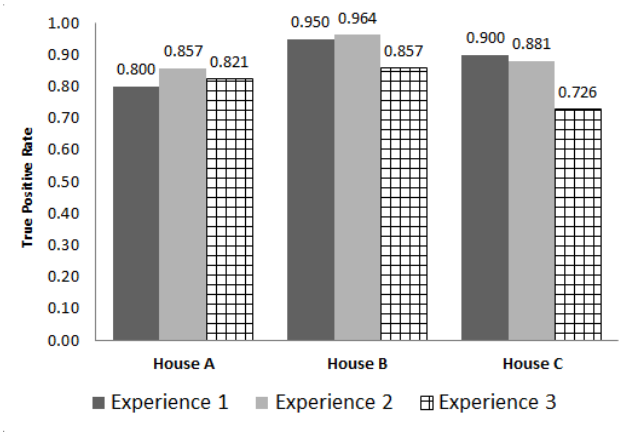

Figure 4. Variation in the rate of correct recognition

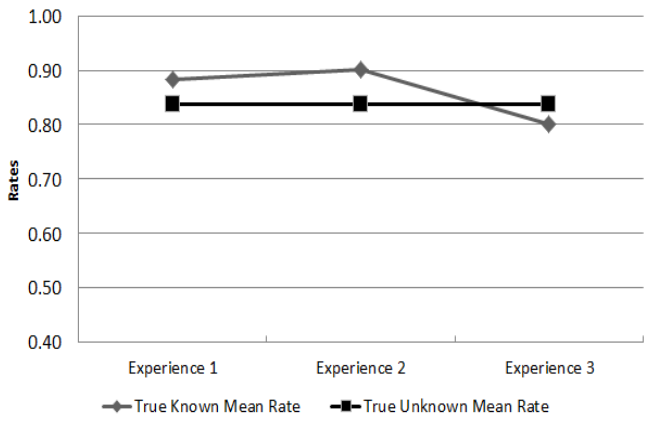

Figure 5. Evolution of the average rate of correct recognitions

improves for the first two homes but not for the third one, which has more subjects stored. Classification errors for House A account for 14.29%, where there are one false positive and three false unknown of a total of 28 tests. For the second home, two errors were detected, reducing the error rate to 3.57%. For House C, the percentage of correct classifications got reduced to 88.10% because of 10 errors which include 5 false positives. In this experience, the average of successful recognitions in the three homes increased to 90.08%.

In the third experience, reducing the number of training images produced a decline in the rate of hits for every home having lower rates in homes with a higher number of known individuals. Figure 4 shows how the ratio of correct recognition varies in each home for each experience. For House A, 23 of 28 tests were classified correctly, accounting for 82.14%, the 5 errors made were due to false unknowns. For House B, the rate of hits was 85.71% of 56 tests, with 8 errors where half of these were false positives and the other half were false unknowns. The tests for House C had the lowest performance, recognizing only 61 of 84 tests, accounting for 72.62% where 9 of the errors were false positives and 14 were false unknowns. The average of correct recognitions obtained for this experience was 80.16%.

For tests with unknown individuals, the results of the first experiment were repeated, both in the second and in the third experiment, with 100% right identifications of unknown subjects for House A, 5 correct out of 7 tests for House B and 8 of 10 for the third home.

The evolution of the average rate of correct recognitions for each kind of test, for both known and unknown people, in the three experiences is shown in Figure 5.

The errors committed by the system can be manually corrected by the user as visitors arrive and are misclassified. This way, it is expected for system to perform better over time and to improve recognition rate. Because of this, the errors shown are a starting point for the system for they will be reduced by the increase of knowledge and training.

6. CONCLUSIONS AND FUTURE WORK

The Smart Doorbell introduced in this paper is able to recognize previously stored individuals who knock on the door, to later notify the user, through the network, to his or her mobile device. As future work, the need to reduce the error rate in the classification stands out, so as to increase the confidence in the system, and improve recognition so that its quality is maintained with an increasing number of visitors in the database.

One possible approach to improve the model is to implement fingerprint recognition as a backup and validation method to identify the visitor. The implementation and viability details of this approach are left to be investigated.

Another thing about improving confidence in this kind of systems is related to the standards. It is imperative that future standards provide the mechanisms to guarantee the security and privacy of Internet of Things applications in order to build trust.

This system aims to promote social inclusion by solving a set of problematic situations for people who suffer some kind of disability, but also seeks to ease people's daily activities. This is an example of how ICTs are a means to both technological and social progress, making clear the need for solutions of this kind.

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POSTER SESSION

MUNIQUE: MULTIVIEW NO-REFERENCE IMAGE QUALITY EVALUATION

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ABSTRACT

This paper presents a novel no-reference objective algorithm for stereoscopic image quality assessment, called MUNIQUE, which is based on the estimation of both two-dimensional and stereoscopic features of images, namely local estimations of blockiness and blurriness and the disparity weighting technique. Applications of stereoscopic image and video quality assessment in surveillance systems are discussed. Simulation results using LIVE 3D Image Quality Database Phase I, which includes Gaussian blur and fast fading degraded images, are presented and a comparison of performance of MUNIQUE with several state of the art algorithms is made. Correlation coefficients between subjective and predicted scores indicate a superior performance of the proposed algorithm, when it is compared with others no-reference algorithms. An implementation of the proposed algorithm coded in C# programming language is publicly available at: https://sites.google.com/site/jvmircas/home/munique

Index Terms— Stereoscopic Image, Objective Algorithms, No-Reference, Multiview Surveillance, Disparity

1. INTRODUCTION

Smart video is an essential technology in the Information Society. It has been used in a wide variety of applications in smart cities, from public safety to personal connectivity. However, the image quality of those applications is still an important concern. Almost every technique designed to process multimedia sources, and transmit, store, or visualize the files, cause impairments that usually degrade the quality of content and finally compromise the Quality of Experience (QoE). Common artifacts in digital images are blurring and blocking, mainly due to coding, compression, and transmission. Hence, evaluation, in quantitative and qualitative ways, of a particular degradation is a fundamental step which enables one to monitor, classify, compare, and improve multimedia services and processing techniques.

In effect, models and algorithms for Image Quality Assessment (IQA) play a key role for industry, companies, and image/video applications, to establish the performance of systems and to obtain optimal parameters to maintain the QoE in specified conditions [1–3]. In practice, such adjustment is performed according to technical requirements that have a significant impact on consumer electronics parameters, namely, bandwidth, bit-rate, storage capacity, and power consumption.

Therefore, it is necessary to evaluate the quality of stereoscopic image signals in a fast, accurate, and reliable way. An alternative is to use successful *full reference* objective algorithms that were developed along the past decade to evaluate 2D image/video quality [1]. Several publications have shown that the performance of objective image/video quality assessment algorithms may be increased, taking into account the effect of perceptual characteristics, such as visual attention [4–9]. However, this approach has two main limitations for the stereoscopic image/video scenario, namely: 1) stereoscopic images contain a disparity information, which is an inter-view relation that must to be considered for designing of objective algorithms [10, 11]; 2) original stereoscopic image signal is usually not available to be compared with the degraded signal (which is a requirement for full-reference algorithms). *No-reference* algorithms, on the other hand, evaluate the degraded image without any knowledge about the original signal.

Hence, this paper presents a novel *no-reference* objective algorithm for stereoscopic image quality assessment, called MUNIQUE (MUltiview No-reference Image QUality Evaluation). MUNIQUE combines a technique for estimation of blockiness and blurriness features, which was firstly developed by Wang *et. al.* [12], with the disparity weighting technique developed by Regis *et. al.* [11], which has been shown to effectively capture the relevant visual information obtained by the human visual system from the stereoscopic image. Also, MUNIQUE uses the fact that the visual importance of a region in a stereoscopic image, assigned by the human visual system, is directly related to the disparity information [10].

The performance of the proposed objective algorithm was evaluated using the subjective results provided by LIVE 3D Image Quality Database Phase I [13]. Several statistical inference methods were applied to compare the performance of the objective algorithms. Confidence intervals and hypothesis testing for Pearson correlation coefficients are also presented.

The authors would like to state their gratitude to the Institute of Advanced Studies on Communications (Iecom) and to the National Counsel of Technological and Scientific Development (CNPq), Brazil, for funding this research project.

The remaining of the paper is organized as follows. Section II discusses the impact and applications of multiview image quality assessment in video surveillance systems. Section III briefly presents Wang's 2D no-reference framework, on which the proposed algorithm is based. Section IV details the underlying mathematical model of the proposed no-reference algorithm for multiview images. The experiments necessary for the validation of the proposed algorithm are presented in Section V. Section VI presents the criteria under that the performance of the algorithms were compared and analysis the simulation results. Finally, Section VII states the conclusions and future directions.

2. MULTI-VIEW IMAGE QUALITY AND SECURITY APPLICATIONS

Video surveillance is a fundamental technology to smart cities, either used for public safety or for intelligent applications such as object tracking and recognition. However, the achievement of high quality for multi -view video surveillance applications is still a challenging task. Specifically, some requirements for surveillance systems are: it should provide a sufficient level of image detail (resolution); it should perform well in extreme low light scenarios; also, users would like a consistent (high) image quality, but at low bandwidth consumption. Those requirements lead to a very close relationship between image quality and systems functionality. For instance, in case of object tracking or recognition, video surveillance systems should provide a minimum image quality necessary such that those systems will still be able to effectively and accurately track or recognize a specified object.

Multiview images have been suitable for a variety of security applications, even despite their high hardware cost. Black et. al. [14], for instance, proposes a multiview image surveillance and tracking system based on the use of overlapping and non-overlapping camera views. The proposed system operates as a framework that allows the integration of image-tracking information from multiple sources. Moreover, it uses intelligent cameras, which provides a background subtraction, jointly with 2D and 3D implementations of Kalman filters in order to simultaneously detect moving objects within each camera view, and finally combine them to obtain a prediction of the 3D location of desired objects. In Fleck *et. al.* [15], a network of smart cameras for 3D real time tracking and visualization, for both indoor and outdoor scenarios, is proposed. The described system includes an arbitrary number of camera nodes, a server node, and a visualization node. Maaloouf et. al. [16] discuss the underlying issues about the definition of standards for 2D video security and 2D video-surveillance systems to achieve complete interoperability. But they also state that image quality issues, even for 2D video-surveillance systems, are still not addressed appropriately. Finally, they proposed an offline system for image quality evaluation, which consists in algorithms for tracking, for no-reference image quality evaluation, and for super-resolution image reconstruction.

It has been noted that those systems need a figure of merit to accurately describe the multiview image quality in real time, which is being provided for the end user; and for a standardization of the quality issues in image/video surveillance systems. Therefore, since multiview image quality is a constraint for those systems, algorithms for multiview image quality assessment must provide a reliable and accurate measurement, in a reasonable amount of time, in order to contribute for the achieving of optimality criteria in multiview video surveillance systems. Additionally, no-reference algorithms are notably the only alternative in scenarios of real time tracking, for each there is none original image available.

3. NO-REFERENCE IMAGE QUALITY ASSESSMENT

Wang *et al*. [12] proposed a *no-reference* image quality algorithm based on estimations of blurring and blocking effects. The features of blurring and blocking are extracted using the differences of luminance in horizontal and vertical directions, calculated as

$$\mathrm{d}^x_{h_L}(x,y) = h_L(x+1,y) - h_L(x,y), \;\; x \in [1, X-1], \quad (1)$$

in which $\mathrm{d}^x_{h_L}(x,y)$ is the difference of the luminance of the signal h_L along of the x-axis.

Blockiness is estimated as the average of $\mathrm{d}^x_{h_L}(x,y)$ for block boundaries, i. e.,

$$\mathrm{B}^x_{h_L} = \frac{1}{Y\left(\lfloor \frac{X}{8} \rfloor - 1\right)} \sum_{y=1}^{Y} \sum_{x=1}^{\lfloor \frac{X}{8} \rfloor - 1} |\mathrm{d}^x_{h_L}(8x,y)|. \quad (2)$$

The blurring is characterized by a reduction in the signal standard deviation, called signal activity. The signal activity is estimated as follows

$$\mathrm{A}^x_{h_L} = -\frac{1}{7}\left[\mathrm{B}^x_{h_L} - \frac{8}{Y(X-1)} \sum_{y=1}^{Y} \sum_{x=1}^{X-1} |\mathrm{d}^x_{h_L}(x,y)|\right]. \quad (3)$$

The Zero Crossing Rate (ZCR) is calculated as

$$\zeta^x_{h_L}(x,y) = \mathrm{sign}\left(\mathrm{d}^x_{h_L}(x,y) \cdot \mathrm{d}^x_{h_L}(x+1,y)\right), x \in [1, X-2] \quad (4)$$

in which $\mathrm{sign}(\cdot)$ is the *signum* function,

$$\mathrm{zcr}^x_{h_L}(x,y) = \begin{cases} 1, \; \zeta^x_{h_L}(x,y) = -1, \\ 0, \; \zeta^x_{h_L}(x,y) = 1. \end{cases} \quad (5)$$

$$\mathrm{ZCR}^x_{h_L} = \frac{1}{Y(X-2)} \sum_{y=1}^{Y} \sum_{x=1}^{X-2} \mathrm{zcr}^x_{h_L}(x,y). \quad (6)$$

The vertical features for the left and right views are computed

with similar methods. Finally, the overall features are

$$\mathrm{B}_H = \frac{1}{2}\left(\frac{\mathrm{B}^y_{h_L} + \mathrm{B}^x_{h_L}}{2} + \frac{\mathrm{B}^y_{h_R} + \mathrm{B}^x_{h_R}}{2}\right), \quad (7)$$

$$\mathrm{A}_H = \frac{1}{2}\left(\frac{\mathrm{A}^y_{h_L} + \mathrm{A}^x_{h_L}}{2} + \frac{\mathrm{A}^y_{h_R} + \mathrm{A}^x_{h_R}}{2}\right), \quad (8)$$

$$\mathrm{ZCR}_H = \frac{1}{2}\left(\frac{\mathrm{ZCR}^y_{h_L} + \mathrm{ZCR}^x_{h_L}}{2} + \frac{\mathrm{ZCR}^y_{h_R} + \mathrm{ZCR}^x_{h_R}}{2}\right). \quad (9)$$

The NR score is computed as

$$\mathrm{NRS}(H) = \alpha + \beta \mathrm{B}_H^{\gamma_1} \mathrm{A}_H^{\gamma_2} \mathrm{ZCR}_H^{\gamma_3}, \quad (10)$$

in which, $\alpha = -245.8909$, $\beta = 261.9373$, $\gamma_1 = -0.02398886$, $\gamma_2 = 0.01601664$, $\gamma_3 = 0.00642859$ [12].

4. PROPOSED NO-REFERENCE ALGORITHM

In this section, two no-reference algorithms, based on the algorithms of Wang [12] and Regis [11], are proposed. Initially, a modification in Wang's algorithm is made regarding the computation of the zero crossing rate, i. e., the Equation (4) is modified as

$$\hat{\zeta}^x_{h_L}(x,y) = \mathrm{sign}\left\{\mathrm{d}^x_{h_L}(x,y) \cdot [h_L(x+2,y) - h_L(x,y)]\right\}, \quad (11)$$

after some mathematical manipulations,

$$\hat{\zeta}^x_{h_L}(x,y) = \mathrm{sign}\left\{\left[\mathrm{d}^x_{h_L}(x,y)\right]^2 + \mathrm{d}^x_{h_L}(x,y) \cdot \mathrm{d}^x_{h_L}(x+1,y)\right\}. \quad (12)$$

From Formula 12, two conditions must be satisfied for the existence of a zero-crossing, namely

$$\begin{cases} \mathrm{sign}\left\{\mathrm{d}^x_{h_L}(x,y) \cdot \mathrm{d}^x_{h_L}(x+1,y)\right\} = -1 \\ |\mathrm{d}^x_{h_L}(x+1,y)| > |\mathrm{d}^x_{h_L}(x,y)|. \end{cases} \quad (13)$$

It can be seen that this proposed algorithm includes the original condition of Equation (4), and the second condition ensures that only relevant zero crossings are computed. Finally, the proposed NRS is computed as

$$\mathrm{NRS}^*(H) = \alpha + \beta \mathrm{B}_H^{\gamma_1} \mathrm{A}_H^{\gamma_2} \mathrm{ZCR}^{*\gamma_3}_H. \quad (14)$$

The main contribution of this paper, called MUNIQUE, introduces the disparity weighting technique in the blockiness and blurriness estimation as follows

$$\mathrm{DB}^x_{h_L} = \frac{\sum_{y=1}^{Y} \sum_{x=1}^{\lfloor \frac{X}{8} \rfloor - 1} |\mathrm{d}^x_{h_L}(8x,y)| \cdot \mathrm{D}(H(8x,y))}{\sum_{y=1}^{Y} \sum_{x=1}^{\lfloor \frac{X}{8} \rfloor - 1} \mathrm{D}(H(8x,y))}. \quad (15)$$

$$\mathrm{DA}^x_{h_L} = \frac{1}{7}\left[\frac{8\sum_{y=1}^{Y}\sum_{x=1}^{X-1} |\mathrm{d}^x_{h_L}(x,y)| \cdot \mathrm{D}(H(x,y))}{\sum_{y=1}^{Y}\sum_{x=1}^{X-1} \mathrm{D}(H(x,y))} - \mathrm{DB}^x_{h_L}\right]. \quad (16)$$

Finally, MUNIQUE is computed as

$$\mathrm{MUNIQUE}(H) = \alpha + \beta \mathrm{DB}_H^{\gamma_1} \mathrm{DA}_H^{\gamma_2}. \quad (17)$$

5. VALIDATION SCENARIO

The statistical measures used to compare the performance of the objective algorithms were: Pearson Linear Correlation Coefficient (PLCC), Spearman Rank-Order Correlation Coefficient (SROCC), and Root Mean Square Error (RMSE). In practice, PLCC evaluates accuracy, SROCC evaluates monotonicity and RMSE measures consistency of an objective model.

The statistical figures of merit were computed after performing a non-linear regression on the objective measures using a logistic function to fit the objective prediction to the subjective quality scores. The logistic model used is as follows

$$\mathrm{DMOS}^p_l = \beta_1 \cdot \left(\frac{1}{2} - \frac{1}{1 + \exp\left(\beta_2 \cdot (Q_l - \beta_3)\right)}\right) + \beta_4 \cdot Q_l + \beta_5 \quad (18)$$

in which Q_l represents the quality that an objective algorithm predicts for the l-th stereoscopic image signal. Nonlinear least squares optimization was performed using the MATLAB®function `nlinfit` to find the optimal coefficients β that minimizes the least squares error between the subjective scores (DMOS_l) and the fitted objective scores (DMOS^p_l). The MATLAB function `nlpredci` was used to obtain the DMOS predicted scores after the least squares optimization. The initial conditions used for the fitting procedure were: $\beta_1 = \max\{\mathrm{DMOS}_l\}$, $\beta_2 = \min(Q_L)$, $\beta_3 = \frac{1}{L}\sum_{l=1}^{L} Q_l$, $\beta_4 = 1.0$, and $\beta_5 = 0.1$.

5.1. LIVE 3D Image Quality Database Phase I

The LIVE 3D Image Quality Database Phase I [13] was used to validate the performance of the objective algorithms. This database is publicly available and provides original and distorted stereoscopic image signals (left and right views), as well as the correspondent subjective score (DMOS). Two distortion scenarios were considered in this research: Gaussian blur and Rayleigh fading, with 45 image signals corrupted using Gaussian blur and 80 image signals impaired by Rayleigh fading.

6. NUMERICAL RESULTS

Tables 1a and **1b** present values of PLCC, SROCC, and RMSE obtained by several objective algorithms, for the scenarios of Gaussian Blur and Fast Fading, respectively. Objective algorithms were compared according to their classes,

namely, full-reference (FR) 2D, no-reference (NR) 2D, full-reference 3D, and no-reference 3D.

Among the NR algorithms, it can be seen that MUNIQUE presented the best performance for Gaussian blur scenario, while BIQI [17] presented the best results for images subject to Fast Fading. Even so, MUNIQUE presented a performance comparable to FR 3D algorithms for the Fast fading scenario. Comparing the results between NRS* and NRS, it is also clearly seen that the modification on the NRS algorithm has improved its performance considerably. Finally, **Figure 1** presents the scatter plots of the proposed algorithms.

6.1. Hypothesis Test for ρ

A statistical analysis was performed under the following hypothesis

$$\begin{cases} \mathcal{H}_0 : \rho = \rho_0, \\ \mathcal{H}_1 : \rho > \rho_0, \end{cases} \tag{19}$$

in order to verify if the Pearson correlation coefficients (ρ) increased significantly.

The procedure uses Fisher's transformation

$$Z = \frac{1}{2}\log_e\left(\frac{1+r}{1-r}\right) = \text{arctanh}(r), \tag{20}$$

in which r is the sample correlation coefficient (PLCC). Indeed, Z follows approximately the Normal distribution $N(\mu_Z, \sigma_Z)$ with

$$\mu_Z = \text{arctanh}(\rho_0), \quad \sigma_Z^2 = \frac{1}{\mathcal{N}_s - 3}. \tag{21}$$

The Critical Region (CR) for Z, for the significance level of 95%, is

$$\text{CR} = \{Z : Z > \mu_Z + 1.654 \cdot \sigma_Z\} = \{Z : Z > Z_{CR}\}. \tag{22}$$

For each sample Pearson correlation coefficient (r), shown in **Tables 1a** and **1b**, CR and Z_0 were computed using Formulas (22) and (20). If $Z_0 \notin$ CR, the hypothesis $\mathcal{H}_0$ is accepted, i.e., there is not evidence that the Pearson correlation coefficient has increased, otherwise the hypothesis $\mathcal{H}_1$ is accepted, which means that the Pearson correlation coefficient has increased, with a confidence level of 95%.

For example, let be $\rho_0 = 0.6521$ (PLCC for NRS* in Fast fading scenario), then Z_{CR} is computed according to the Formula (22). The next step is to transform the other Pearson correlation coefficients into Z_i (the index i meaning the i-th algorithm) according the Formula (20). If $Z_i > Z_{CR}$ then the i-th algorithm presents a more significant PLCC than ρ_0, with a confidence level of 95%.

In **Table 2** the values '0' and '1' mean that one of the hypothesis $\mathcal{H}_0$ or $\mathcal{H}_1$ was accepted, respectively. In practice, a symbol value of '1' indicates that the statistical performance of the objective algorithm in the row is superior to that of the objective algorithm in the column. On the other hand, a symbol value of '0' suggests that the statistical performance of the objective algorithm in the row is equivalent to that of the objective in the column. The sequence of the values in a cell corresponds to the hypothesis test for Gaussian blur and Fast fading scenarios, respectively.

6.2. Confidence Interval for ρ

Figure 2 presents a 95% confidence interval for ρ in the Gaussian Blur and Fast Fading scenarios under the hypothesis $\mathcal{H}_0 : \rho = 0$, $\mathcal{H}_1 : \rho \neq 0$. The Z Fisher's transformation was applied to the sample Pearson correlation coefficient (r) to produce the confidence interval.

Under that hypothesis, Z follows the Normal distribution with zero mean and with variance given by Formula (19). The confidence interval for this random variable is defined as

$$\text{IC}(z, 1-\alpha) = (Z - z_{1-\alpha} \cdot \sigma_Z, Z + z_{1-\alpha} \cdot \sigma_Z). \tag{23}$$

For $\alpha = 0.05$, i.e., a confidence interval of 95%, $z_{0.95} = 1.96$, and Formula (23) is rewritten as

$$\text{IC}(z, 0.95) = (Z - 1.96 \cdot \sigma_Z, Z + 1.96 \cdot \sigma_Z). \tag{24}$$

The inverse of the Z Fisher's transformation is

$$r = \frac{e^{2z} - 1}{e^{2z} + 1} = \tanh(z), \tag{25}$$

and the confidence interval in terms of r is defined as,

$$\text{IC}(r, 0.95) = \left(\frac{e^{2\cdot(Z-1.96\cdot\sigma_Z)} - 1}{e^{2\cdot(Z-1.96\cdot\sigma_Z)} + 1}, \frac{e^{2\cdot(Z+1.96\cdot\sigma_Z)} - 1}{e^{2\cdot(Z+1.96\cdot\sigma_Z)} + 1}\right). \tag{26}$$

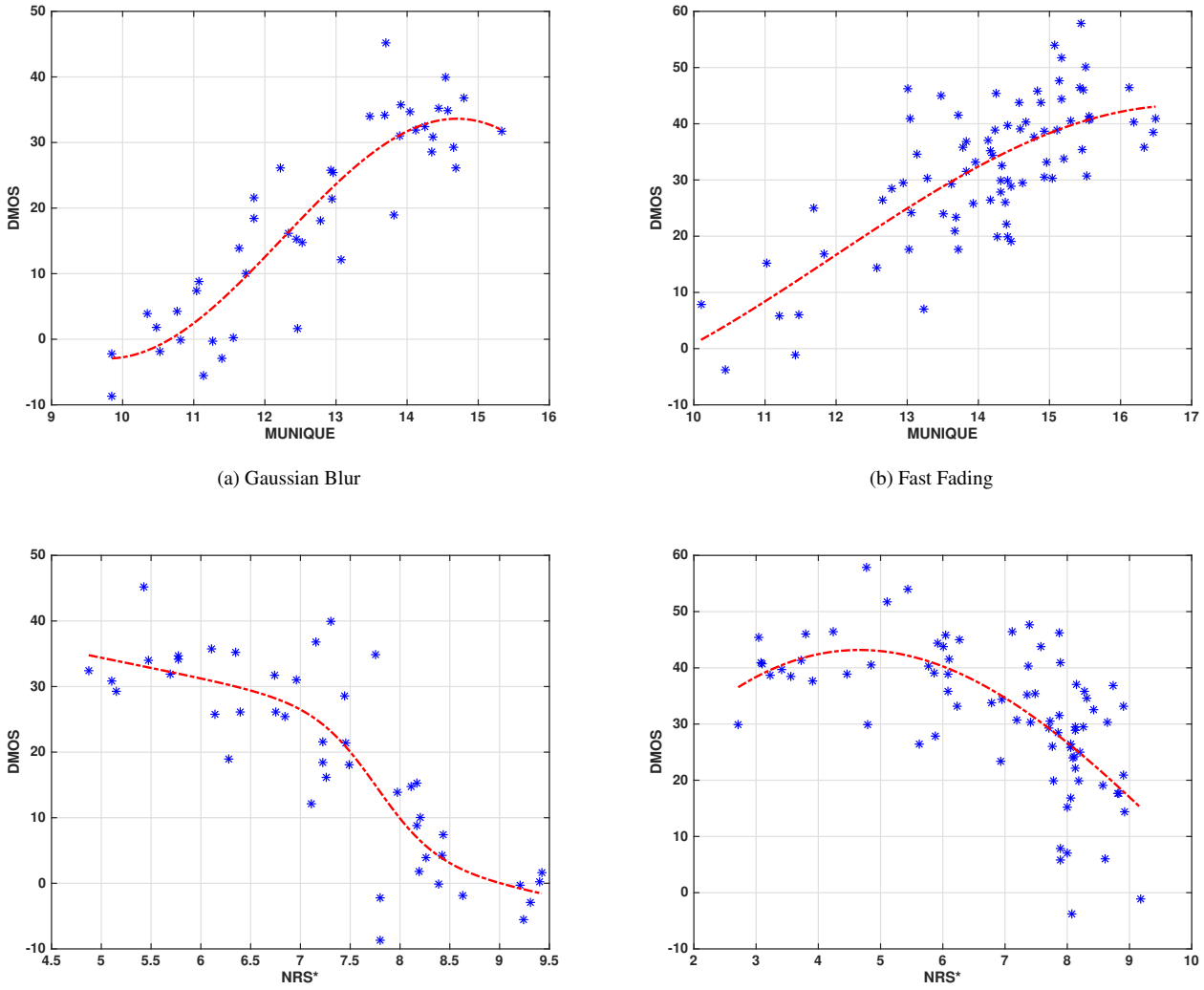
Figure 2 suggests that, along with an increase in the correlation coefficient, there is a reduction in uncertainty, which is represented by the length of the PLCC confidence interval, for the NRS* algorithm, compared with the its original version, NRS.

It is also clear that MUNIQUE presented a better performance than Akhter's 3D no-reference algorithm for all statistical inferences used. Surprisingly, MUNIQUE was also superior to You's 3D full-reference algorithm for the fast fading scenario. MUNIQUE showed a good performance even if when it is compared to Benoit's 3D full-reference algorithm.

7. DISCUSSION AND CONCLUSIONS

A novel no-reference objective algorithm for stereoscopic image quality assessment was proposed, called MUNIQUE. It is based on a combination of blockiness and blurriness feature estimation and disparity weighting.

Stereoscopic image signals impaired with Fast Fading and Gaussian Blur, provided by LIVE, were used on the validation experiments. The numerical results indicate an improved performance for MUNIQUE in relation to the NRS



(a) Gaussian Blur

(b) Fast Fading

(c) Gaussian Blur

(d) Fast Fading

Figure 1: Scatter plots for LIVE 3D IQA Database.

Table 1: Performance measures of the NR objective algorithms for the LIVE 3D IQA Database.

(a) Gaussian Blur

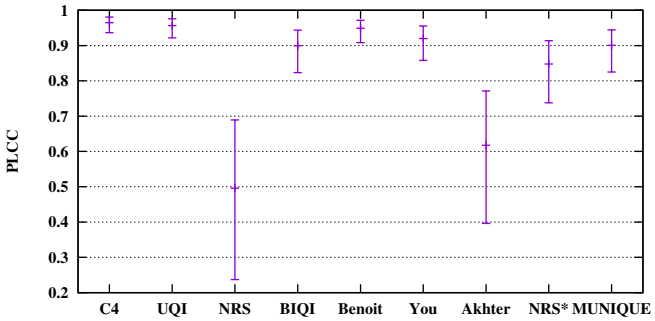
Algorithm	PLCC	SROCC	RMSE
FR 2D Algorithms			
C4 [18]	0.9649	0.9361	3.8003
UQI [19]	0.9565	0.9238	4.2222
NR 2D Algorithms			
NRS [12]	0.4960	0.4385	12.5681
NRS*	0.8476	0.8130	7.6812
BIQI [17]	0.8995	0.8596	6.3238
FR 3D Algorithms			
Benoit [10]	0.9488	0.9308	4.5714
You [5]	0.9198	0.8822	5.6798
NR 3D Algorithms			
Akhter [20]	0.6177	0.5549	11.3872
MUNIQUE	**0.9006**	**0.8647**	**6.2918**

(b) Fast Fading

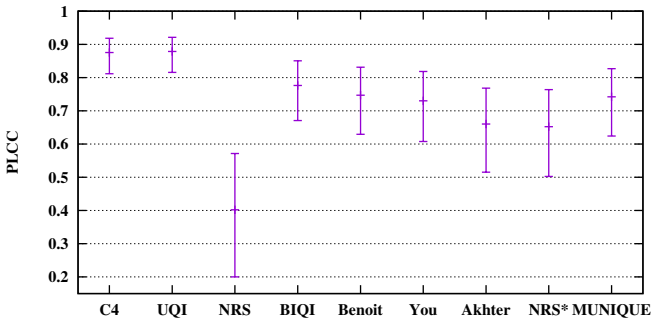
Algorithm	PLCC	SROCC	RMSE
FR 2D Algorithms			
C4	0.8754	0.8349	6.0067
UQI	0.8788	0.8322	5.9207
NR 2D Algorithms			
NRS	0.4023	0.3572	11.3759
NRS*	0.6521	0.6539	9.3787
BIQI	0.7762	0.7067	7.8679
FR 3D Algorithms			
Benoit	0.7472	0.6989	8.2578
You	0.7300	0.5883	8.4923
NR 3D Algorithms			
Akhter	0.6603	0.6393	9.3321
MUNIQUE	**0.7421**	**0.4763**	**8.3288**

Table 2: Hypothesis test for the correlation coefficient (Gaussian Blur – Fast Fading).

Algorithms	C4	UQI	NRS	BIQI	Benoit	You	Akhter	NRS*	MUNIQUE
C4	–	1 – 1	1 – 1	1 – 1	1 – 1	1 – 1	1 – 1	1 – 1	1 – 1
UQI	0 – 0	–	1 – 1	1 – 1	1 – 1	1 – 1	1 – 1	1 – 1	1 – 1
NRS	0 – 0	0 – 0	–	0 – 0	0 – 0	0 – 0	0 – 0	0 – 0	0 – 0
BIQI	0 – 0	0 – 0	1 – 1	–	0 – 1	0 – 1	1 – 1	1 – 1	0 – 1
Benoit	0 – 0	0 – 0	1 – 1	1 – 0	–	1 – 1	1 – 1	1 – 1	1 – 1
You	0 – 0	0 – 0	1 – 1	1 – 0	0 – 0	–	1 – 1	1 – 1	1 – 0
Akhter	0 – 0	0 – 0	1 – 1	0 – 0	0 – 0	0 – 0	–	0 – 1	0 – 0
NRS*	0 – 0	0 – 0	1 – 1	0 – 0	0 – 0	0 – 0	1 – 0	–	0 – 0
MUNIQUE	0 – 0	0 – 0	1 – 1	1 – 0	0 – 0	0 – 1	1 – 1	1 – 1	–



(a) Gaussian Blur



(b) Fast Fading

Figure 2: The 95% confidence intervals for the populational Pearson correlation coefficient.

algorithm. MUNIQUE presented a PLCC higher than 0.7, for all scenarios.

Additionally, the performance of MUNIQUE is still comparable, and in some cases better, to the performance of full-reference algorithms for multiview image quality assessment. Confidence intervals and hypothesis testing indicates that this improvement is truly significant. The performance, jointly with its simple design, makes MUNIQUE a competitive alternative for real-time multiview image quality evaluation scenarios.

Therefore, MUNIQUE can be used for practical video processing systems and applications. For future research, the authors plan to test their algorithm in real-time scenario for monitoring the quality of multiview video surveillance systems.

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A PRESENTATION FORMAT OF ARCHITECTURE DESCRIPTION BASED ON THE CONCEPT OF MULTILAYER NETWORKS

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ABSTRACT

Formal methods based on abstract models are becoming more and more important in the domain of complex computer networks. On the other hand, processes of design documentation transformation into the formal models are still bound to the skills and ingenuity of individual engineers. Moreover, the human factor involved in data transformation represents a major bottleneck due to the tendency of computer networks to be more and more complex. To address this problem, this work introduces a possible appropriate presentation format of architecture descriptions as a part of detailed design documentation that could allow automated development of trusted formal models for analysis and verifying of complex computer networks.

Keywords— architecture descriptions, computer networks, formal models, multilayer networks

1. INTRODUCTION

Art and science have their meeting point in method.
—Edward Bulwer-Lytton

Formal methods are mathematical techniques for developing software and hardware systems and can be used to conduct mathematical proofs of consistency of specification and correctness of implementation. Mathematical rigor enables users to analyze and verify abstract models at any part of the system life-cycle: requirements engineering, architecture design, implementation, maintenance and evolution [1]. These methods are particularly suitable for complex heterogeneous systems and are becoming more and more important.

However, model analysis requires specialized training, both in the models development - a model must be completely relevant to a system (a trusted model) - and in the interpretation of the analysis results. As a consequence, it depends on the qualification, ingenuity and intuition of individual engineers. The human work involved in data transformation represents a major bottleneck due to its tendency to be relatively unsophisticated and repetitive, but persistently tricky and time-consuming at the same time [2]. Challenges in the analysis process that repeatedly occur in analysis efforts are: (1) discover necessary data; (2) wrangle data into a desired format; (3) profile data to verify its quality and suitability; and (4) report procedures to consumers of the analysis.

Thus, to get full advantages of model analysis and verifying in the domain of complex systems, it is necessary to alleviate the burdens of learning model development and checking techniques for engineers and other non-technical stakeholders [3] or, ideally, completely eliminate the human factor. There have been some attempts to make model development accessible to those who are not trained in formal methods. These include Formal Description Techniques (FDT) [4] based on a technical language for unambiguous specification and description of the behavior of telecommunication systems. However, FDTs are intended to specify the behavioral aspects of software-intensive systems; the general parameters, which determine heterogeneous architectures and properties, have to be described using different techniques. Moreover, FDTs still require a considerable degree of user training because they do not eliminate the need for translating natural language requirements into their specialized language before applying model analysis.

To address this problem, we propose a possible appropriate presentation format of architecture descriptions as a necessary part of the detailed design documentation of complex computer networks, which could allow automated development of formal models based on this documentation for analysis and verifying of complex networks - particularly we focus on multilayer networks specifications.

The rest of this paper is structured as follows. Section 2 presents the background of the work. Section 3 introduces the formal model of complex computer networks based on the concept of multilayer networks. Section 4 focuses on the presentation format of architecture descriptions. Section 5 discusses the correlation between the formal model and the presentation format. Finally, conclusion remarks are given in Section 6.

2. BACKGROUND

The universal requirement for design documentation is simple the documentation should be based on standards like a formal document. Generally, the choice between interna-

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tional and regional standards depends on the state and/or corporate legislation but, fortunately, the majority of regional standards replicate their international predecessors.

As mentioned above, the Formal Description Techniques [4] are based on a technical language for unambiguous specification and description of the behavior of telecommunication systems. The main FDTs include: Specification and Description Language (SDL) [5], Message Sequence Chart (MSC) [6], User Requirements Notation (URN) [7], and Testing and Test Control Notation (TTCN) [8]. However, FDTs are intended to specify the behavioral aspects of software-intensive systems, not their architectures [5]. Furthermore, they do not cover the structure of design documentation.

The current revision of IEEE Std. 1362-1998 (R2007) [9] standard represents a Concept of Operations (ConOps). ConOps is a user-oriented document that describes characteristics of to-be-delivered systems from the end-users (or integrated systems) point of view. It also specifies recommended graphical tools (charts and diagrams).

The latest revision of ISO/IEC/IEEE Std. 15288:2015 [10] standard establishes a common process framework for describing the life cycle of man-made systems. It defines a set of processes and associated terminology for the full life cycle, including Architectural Design Process (or the process of elaboration of design documentation). In turn, the standard ISO/IEC/IEEE Std. 15289:2011 [11] specifies the purpose and content of service management information items (documentation). It defines the life cycle data of ISO/IEC/IEEE Std. 15288:2015 by relating tasks and activities to the generic types of information items such as descriptions and specifications (the main information components of design documentation). Furthermore, conceptualization of system architectures assists the understanding of the system essence and key properties pertaining to its behavior, composition and evolution, which in turn affect concerns such as the feasibility, utility and maintainability of the system. As a consequence, the standard ISO/IEC/IEEE Std. 42010-2011 [12] specifies architecture viewpoints, architecture frameworks and architecture description languages for use in architecture descriptions.

It is important to note that these international standards establish *what* should be contained in design documentation but not *how*: possible formats of information items or, at least, guidance on selecting appropriate presentations are NOT included in the scope of these standards.

3. FORMAL MODEL

Applying a system methodology to network analysis [13] is a relatively new approach, particularly in the Internet Protocol (IP) world. The fundamental concept is that network architecture should take into account services/applications which this network provides and supports. It is important to note that this concept is completely supported by the most recent practical approaches such as Business-Driven Design [14] and Application Centric Design [15].

On the other hand, one of the major goals of modern physics is providing proper and suitable representations of systems with many interdependent components, which, in turn, might interact through many different channels. As a result, interdisciplinary efforts of the last fifteen years have led to the birth of complex networks theory [16] [17] [18] including the concept of multilayer networks [19] [20] that explicitly incorporate multiple channels of connectivity and constitute the natural environment to describe systems interconnected through different types of connections: each channel (relationship, activity, category, etc.) is represented by a layer and the same node or entity may have different kinds of interactions (different set of neighbors in each layer). Assuming that all layers are informative, multilayer networks can provide complementary information. Thus, the expectation is that a proper combination of the information contained in the different layers leads to a formal network representation (a formal model) appropriated for applying the system methodology to network analysis.

A type of multilayer network of particular relevance for complex computer networks is a *hierarchical multilayer network* [19], in which the bottom layer constitutes a *physical* network (physical architecture layer) and the remaining layers are *virtual layers* that operate on top of the physical layer (at least logical and service architecture layers [21] [22]). From this perspective, the formal basic definitions [20] (adapted to the domain of computer networks [22]) denotes the complex computer network as a hierarchical multilayer projection network:

$$M = (V, E) \tag{1}$$

where M is a labeled 3D graph; $V(M)$ is a finite, non-empty set of components (hardware and software); and $E(M)$ is a finite, non-empty set of component-to-component interconnections. In turn:

$$V = \bigcup_{n=1}^{N} V_n \tag{2}$$

and

$$E = \left(\bigcup_{n=1}^{N} E_n \right) \bigcup \left(\bigcup_{n=2}^{N} E_{n,(n-1)} \right) \tag{3}$$

where V_n is a finite, non-empty set of components (hardware or software) on layer n; E_n is a finite, non-empty set of intralayer component-to-component interconnections on layer n; $E_{n,(n-1)}$ is a finite, non-empty set of interlayer (or cross-layers) relations (projections) between components of different coexisting layers n and $(n-1)$; and N is the number of layers (in our case $N = 3$).

In turn, a labeling of the vertices of M is a mapping [23]:

$$\psi : V_n \rightarrow A_n \tag{4}$$

where A_n is called the vertices label set on layer n. In our case:

$$A_n = \bigcup_{v_i^n \in V_n} S_i^n \tag{5}$$

where S_i^n is a finite non-empty set of component technical specifications or the label of the vertex $v_i^n \in V_n$ of M.

Table 1. Layer component specification.

Table columns		
No.	**Name**	**Description**
01	T1n.01 Record Number	Record identification number (component index)
02	T1n.02 Layer Identifier	Physical, logical or service layer (similar to T2n.02 and T3n.02)
03	T1n.03 Component Assignment	Component functional description
04	T1n.04 Component Identifier	Component name
05	T1n.05 Vendor Identifier	Vendor contact name (for COTS components)
06	T1n.06 Component Attributes	Component technical specifications such as supported connectors (according to T2n.05 and T2n.07) and protocols (according to T2n.08), performance metrics, RMA, etc.
07	T1n.07 Notes	Additional information

Similarly, a labeling of the intralayer edges of M is a mapping [23]:

$$\omega : E_n \to B_n \tag{6}$$

where B_n is called the edges label set on layer n. In our case:

$$B_n = \bigcup_{(v_i^n, v_j^n) \in E_n} S_{ij}^n \tag{7}$$

where S_{ij}^n is a finite, non-empty set of component-to-component interconnections technical specifications or the label of the edge $(v_i^n, v_j^n) \in E_n$ of M. Generally:

$$S_{ij}^n \subseteq \left(S_i^n \cap S_j^n \right) \tag{8}$$

i.e. components can communicate iff they have common specifications of interfaces and/or protocols.

It is important to note that the interlayer edges $(v_i^n, v_j^{(n-1)}) \in E_{n,(n-1)}$ of M are not labeled edges.

As a consequence, this formal model of complex computer networks can be represented in details by means of data structures of graph theory [23].

4. PRESENTATION FORMAT

As mentioned above, the current revisions of international standards establish *what* should be contained in design documentation but not *how exactly*. Nevertheless, Appendix I of ITU-T Recommendation L.72 [24] represents the example of a currently used presentation format of optical access network infrastructure descriptions (it is important to note that the appendix does not form an integral part of the Recommendation). However, this format is optimized for representation network infrastructures (it covers the physical architecture completely and the logical architecture partially) and, as a consequence, cannot be used to define a whole/completed system (i.e. a computer network and the distributed computing system it supports together) and represent technological

Table 2. Intralayer topology specification.

Table columns		
No.	**Name**	**Description**
01	T2n.01 Record Number	Record identification number (link index)
02	T2n.02 Layer Identifier	Physical, logical or service layer (similar to T1n.02 and T3n.02)
03	T2n.03 Link Assignment	Component-to-component interconnection functional description
04	T2n.04 Source Component Identifier	Component name according to T1n.04
05	T2n.05 Source Connector Identifier	Component attribute (according to T1n.06): (1) component interfaces for the physical layer; (2) IP addresses and masks for the logical layers; and (3) TCP/UDP ports for the service layer
06	T2n.06 Target Component Identifier	see T2n.04
07	T2n.07 Target Connector Identifier	see T2n.05
08	T2n.08 Protocol Identifier	Communication protocol
09	T2n.09 Link Attributes	Technical specifications of component-to-component interconnection such as cable length (for the physical layer only), performance metrics, RMA, etc.
10	T2n.10 Notes	Additional information

Table 3. Interlayer topology specification.

Table columns		
No.	**Name**	**Description**
01	T3n.01 Record Number	Record identification number (link index)
02	T3n.02 Layer Identifier	Physical, logical or service layer (similar to T1n.02 and T2n.02)
03	T3n.03 Link Assignment	Components interlayer relation functional description
04	T3n.04 Source Component Identifier	Component name according to T1n.04
05	T3n.05 Target Component Identifier	see T3n.04
06	T3n.06 Distribution Index Identifier	Cross-layer technologies: (1) $N_n : 1_{n-1}$ - virtualization and replication; (2) $1_n : N_{n-1}$ - clustering; and (3) $1_n : 1_{n-1}$ a special case of dedicated components
07	T3n.07 Link Attributes	Technical specifications of components interlayer relation (resources distribution across the network) technical specifications such as capacity metrics and modes (active/active, active/standby, etc.)
08	T3n.08 Notes	Additional information

solutions (hardware and software clusters, virtualization platforms, etc.) which are used to build the system.

To fill the gap, this section represents a set of design patterns for unambiguous architecture description as a possible part of the detailed design documentation (the term *design pattern* [25] aims to explicitly represent design knowledge that can be understood implicitly by skilled engineers and other non-technical stakeholders).

Based on the concept of layered networks [26], the architecture of complex computer networks can be represented by three main design patterns (tables) on each (physical, logical and service) layer:

- *Layer component specification.* The layer component specification design pattern is used for the components detail representation. It should cover: (1) software-based components (services/applications) for the service layer; (2) virtual components (VM, VLAN, etc.) for the logical layer; and (3) hardware-based components (equipment) for the physical layer. Table column structure includes (see Table 1):

- Record Number.
- Layer Identifier.
- Component Assignment.
- Component Identifier.
- Vendor Identifier.
- Component Attributes.
- Notes.

- *Intralayer topology specification.* The intralayer topology specification design pattern is used for the layer topology detail representation. It should cover architecture descriptions of: (1) flow-based models [13] for the service layer; and (2) topological models [13] for the logical and physical layers. Table column structure includes (see Table 2):

- Record Identifier (record number).
- Layer Identifier.
- Link Assignment.
- Link Identifier:
  - Source Identifier:
    - Component Identifier.
    - Connector Identifier.
  - Target Identifier:
    - Component Identifier.
    - Connector Identifier.
- Protocol Identifier.
- Link Attributes.
- Notes.

Table 4. Formal model and Layer component specification.

No.	Design pattern record	Formal model symbol
1	T1n.01	i
2	T1n.02	n
3	T1n.04	$v_i^n \in V_n$
4	T1n.06	S_i^n

- *Interlayer topology specification.* The intralayer topology specification design pattern is used for the resources distribution (cross-layer topology) detail representation. It strictly relies on the concept of layered networks [26] that a node in a given layer depends on a corresponding node (or nodes) in the layer below. Table column structure includes (see Table 3):

- Record Identifier (record number).
- Layer Identifier.
- Link Assignment.
- Link Identifier:
  - Source Identifier:
    - Component Identifier in a Given Layer.
  - Target Identifier:
    - Component Identifier in the Layer Below.
- Distribution Index Identifier.
- Link Attributes.
- Notes.

In turn, each table header structure should include:

- Table Identifier.
- Project Identifier.
- Facility Identifier.

In practice, these tables can be used (1) as independent documents or (2) as a database structure similar to ITU-T Rec L.72 [24].

5. FORMAL MODEL AND DESIGN PATTERNS CORRELATION

A model is any incomplete representation of reality - an abstraction [27]. In practice it means that design documentation usually contains much more data then we need to create models. In our case, from the perspective of the formal abstract model:

- The layer component specification is a node list (see Table 1): each row represents a node (vertex) in the graph and columns contain attributes (node labels). Data structures correlation between the formal model and this design pattern is shown in Table 4.

Table 5. Formal model and Intralayer topology specification.

No.	Design pattern record	Formal model symbol
1	T2n.01	k
2	T2n.02	n
3	T2n.04 T2n.06	$v_i^n \in V_n$ $v_j^n \in V_n$ $e_k^n = (v_i^n, v_j^n) \in E_n$
4	T1n.05 T1n.07 T1n.08 T1n.09	S_{ij}^n

Table 6. Formal model and Interlayer topology specification.

No.	Design pattern record	Formal model symbol
1	T3n.01	l
2	T3n.02	n
3	T3n.04 T3n.05	$v_i^n \in V_n$ $v_j^{n-1} \in V_{n-1}$ $e_l^{n,(n-1)} =$ $= (v_i^n, v_j^{(n-1)}) \in E_{n,(n-1)}$

- The intralayer topology specification is an adjacency list or a relational table (see Table 2): each row represents an edge in the graph and columns contain incident (source and target) nodes among other attributes (edge labels). Data structures correlation between the formal model and this design pattern is shown in Table 5.

- The interlayer topology description is an adjacency list or a relational table (see Table 3): each row represents an edge in the graph and columns contain incident (source and target) nodes among other attributes. Data structures correlation between the formal model and this design pattern is shown in Table 6.

It is obvious that the quality of formal methods based on abstract models is limited by the quality of these models. In our case, complex network architecture can be unambiguously represented using a set of tables (design patterns) that should be included as a necessary part of the detailed design documentation of a computer network. In turn, this set of tables provides unambiguous definition of the formal model (3D graph) for analysis and verifying of the network structure (such as model-based testing (MBT) [28] [29]). As a consequence, we can completely eliminate the human factor from the data transformation processes during the formal model generation activities - the process can be done in automated mode using the detailed design documentation as input data. In this case, the formal model is completely relevant to the design documentation (a trusted model from the viewpoint of network/system designers).

Furthermore, MBT techniques can be used for automated validation the formal model internal consistency with respect to the end-user requirements [28]. In the case of successful validation, the formal model is completely relevant to the end-user requirements (a trusted model from the viewpoint of end-users/customers). However, the techniques of transforming informal end-user requirements into formal operation specifications are beyond the scope of this paper. The problem requires a separate analysis in the case of complex or non-standard systems, it may not be a routine exercise in practice.

6. CONCLUSION

Formal methods based on abstract models are becoming more and more important in the domain of complex computer networks. On the other hand, processes of design documentation transformation into the formal models are still bound to the qualification and ingenuity of individual engineers. But in the case of complex or non-standard systems, personal experience and/or intuition can be inadequate. Moreover, the human work involved in data transformation represents a major bottleneck due to: (1) its tendency to be relatively unsophisticated and repetitive, but persistently tricky and time-consuming at the same time; and (2) the tendency of computer networks to be more and more complex. To address this problem, in this work we determined: (1) an appropriate formal model based on the concept of multilayer networks; and (2) a possible appropriate presentation format of architecture descriptions as a part of detailed design documentation that provides unambiguous interrelation between the documentation and the model. As a consequence, this presentation could allow automated development of formal models for analysis and verifying of complex computer networks.

Using the models of that kind and the graph theoretical metrics, both static and dynamic network analyses can be performed. The static analysis determines the characteristics of each layer based on the in-tralayer and interlayer topologies. It covers [30] [31]: (1) individual components; (2) component interactions on each layer; and (3) resources distribution across the system.

In turn, the dynamic analysis (or fault injection simulation) provides a means for understanding how a network behaves in the presence of faults. It includes [32]: (1) successive removals of vertices/edges from the model; and (2) impact assessments of those removals on the network internal consistency - disruption on an arbitrary layer might destroy a substantial part of the upper layers that are mapped on it, rendering the whole network useless in practice.

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PRIVACY, CONSUMER TRUST AND BIG DATA: PRIVACY BY DESIGN AND THE 3 C'S

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ABSTRACT

The growth of ICTs and the resulting data explosion could pave the way for the surveillance of our lives and diminish our democratic freedoms, at an unimaginable scale. Consumer mistrust of an organization's ability to safeguard their data is at an all time high and this has negative implications for Big Data. The timing is right to be proactive about designing privacy into technologies, business processes and networked infrastructures. Inclusiveness of all objectives can be achieved through consultation, co-operation, and collaboration (3 C's). If privacy is the default, without diminishing functionality or other legitimate interests, then trust will be preserved and innovation will flourish.

Keywords – Privacy by Design, Information and communication technologies (ICTs), technological innovation, information society, internet of things, Big Data, trustworthiness, security, privacy.

1. INTRODUCTION

It is a world where everything is connected – not only online, but also in the physical world of wireless and wearable devices. Through the global convergence of ICTs and the capability of these technologies to capture, digitize and make sense of an unknown magnitude of data, we are now in the era of Big Data. The digital universe is doubling in size every 2 years — in fact, more data will be created and captured this year than in all of human history. While a significant portion of this vast digital universe is not of a personal nature, there are inherent privacy and security risks that cannot be overlooked.

The promise and value of Big Data extends beyond the imagination and is limited only by our own human capabilities and resourcefulness. Make no mistake, organizations must seriously consider not just the use of Big Data but also the implications of a failure to fully realize the potential of Big Data. Big Data and big data analytics, promise new insights and benefits such as medical/scientific discoveries, new and innovative economic drivers, predictive solutions to otherwise unknown, complex societal problems.

Yet, with each statement or discussion of the critical success factors to unlocking or unleashing the benefits of Big Data, privacy and security looms large. At the same time that powerful computing devices are now literally 'in the hands' of individuals, the associated applications and services providing connectivity, ubiquity and predictability provide less control over one's personal information. Since informational self-determination is the basis for the definition of data privacy, we must find ways to engender trust in these technologies. The alternative would be a future world devoid of any privacy, the very basis upon which our individual freedoms are built. This is precisely what we have to consider – the growth of ICTs and the resulting data explosion could pave the way for the surveillance of our lives, at an unimaginable scale, thereby undermining any potential benefits. The purpose of this paper is to reflect on the approach needed to prevent privacy harms by embedding necessary privacy protective measures into the design of ICTs, networked infrastructure and business practices.

2. PRIVACY AND CONSUMER TRUST

Informational privacy refers to the right or ability of individuals to exercise control over the collection, use and disclosure by others of their personal information. No doubt, ICTs present challenges to what constitutes personal information, extending it from obvious tombstone data (name, address, telephone number, date of birth, gender) to the innocuous computational or meta data once the purview of engineering requirements for communicating between devices. [1] Addresses, such as the Media Access Control (MAC) number that are designed to be persistent and unique for the purpose of running software applications and utilizing Wi-Fi positioning systems to communicate to a local area network can now reveal much more about an individual through advances in geo-location services and uses of smart mobile devices. [2]

To be clear, however, where there is no reasonable possibility of identifying a specific individual, either directly, indirectly, through manipulation or linkage of information, there is no privacy issue.

Sometimes, information security is taken to mean that privacy has been addressed. While security certainly plays a vital role in enhancing privacy, there is a distinction --

security is about protecting data assets. It is about achieving the goals of confidentiality, integrity and availability. Privacy related goals developed in Europe that complement this security triad are: unlinkability, transparency and intervenability. [3]

Notwithstanding the need for security, some of the key privacy challenges in Big Data are: i) data maximization (collection, storage, retention) rather than data minimization; ii) emphasis on "unknown potential" uses of information and results that override purpose limitation; iii) ubiquity of the ICTs and flow of data leading to greater opacity rather than transparency; iv) correlation, pattern identification and sense-making algorithms that contribute to increased risk of re-identification on poorly anonymized or de-identified datasets; v) decisions based on questionable data quality, false positives, lack of causality and vi) inference-dependency leading to decision-making bias as well as power imbalances. [4] [5]

At a broader societal level, privacy is viewed as a fundamental human right and inextricably linked to freedom and democracy. We do not often extend our thinking of privacy to this end but we must as aptly noted in a report by the UN Global Pulse on Big Data for Development: "Because privacy is a pillar of democracy, we must remain alert to the possibility that it might be compromised by the rise of new technologies, and put in place all necessary safeguards." [6]

Trust not only influences decision-making for internet-based applications and services but also security policy specifications and may be defined as "the firm belief in the competence of an entity to act dependably, securely and reliably within a specified context," [7] Not only have consumer surveys revealed but also the after effects of a privacy breach, that while it takes time to build a relationship of trust and to build a positive reputation for trustworthiness, it takes only an instant to lose it. [8] Indeed, consumer confidence in an organization's ability to protect their online data is at an all-time low and the residual effect is that over 90 percent of individuals avoid doing business with organizations in which they have lost such confidence. [9]

If we are to preserve any semblance of privacy, we must ensure that it is built into the very systems that are being developed. Otherwise, the interconnected nature of virtually all that we do may lead us down a path of surveillance and fear that will be too great to conquer after the fact.

3. PRIVACY BY DESIGN AND THE 3 C'S

Privacy by Design (PbD) is a set of seven foundational principles that serves as an overarching framework for inserting privacy and data protection early, effectively and credibly into information technologies, organizational processes, networked architectures and, indeed, entire systems of governance and oversight. The goals are to ensure user control, enhance transparency and establish confidence and trust. Importantly, it does not rely solely on regulatory measures, which serve as effective means for enforcement and penalty determination and are often technology neutral.

Since the early 1990's, Privacy by Design has gained international recognition and support. At a time when the Data Protection Commissioner community was focused on determining how best to address online privacy concerns, a call to action was made for a united voice referring to the fact that "….information is inherently global; it respects neither geography nor legal boundaries." [10] It was made apparent that for Data Protection Commissioners to be effective, their efforts "must cut across borders despite the limitations of [their] individual authority." [10] At the October 2010 Assembly of International Privacy Commissioners and Data Protection Authorities, Privacy by Design was unanimously passed as an "essential component of fundamental privacy protection." Since then, the principles have been translated into 37 languages, giving Privacy by Design a true global presence by becoming an internationally recognized framework for privacy standards and the basis of several regulatory privacy regimes. [3] [11] [12] In 2014, one of the declarations by the International Data Protection Commissioners on the Internet of Things, is that Privacy by Design should become a key selling point of innovative technologies. On Big Data, at this same meeting, it was resolved that Privacy by Design needs to be implemented.

3.1. The 7 Foundational Principles

The 7 Foundational Principles that make up Privacy by Design [13] (see Figure 1) express not only the universal principles of the Fair Information Practices (FIPs) but incorporate a design-thinking approach. Integrally linked, the principles address the need for robust data protection and an organization's desire to unlock the potential of data-driven innovation. The main features that set Privacy by Design apart from existing privacy frameworks are as follows:

- We must begin with an explicit recognition of the value and benefits of proactively adopting strong privacy practices, early and consistently rather than taking a reactive stance when issues arise and trust is broken. This means to address the risk of harm to individuals before privacy intrusions or breaches can take place. For example, when designing technical architecture or Big Data algorithms that at the outset may not have any privacy implications, the potential for possible unintended uses that may lead to a privacy issue should be explored as part of a privacy/security threat/risk analysis. See for example, the European Commission's risk assessment tool for RFID application. [14]

- Privacy is often positioned as a barrier, thereby having to compete with other legitimate interests, design objectives, and technical capabilities, in a given domain. Its recognition at the early design stage should not be at the expense of or to the detriment of other valid objectives (e.g. security, public safety, improved health, economic growth, effective government, poverty reduction, ecological sustainability, to name a few). To the extent possible, there should be no trade-offs. When embedding privacy into a given technology, process, or system, it should be done in such a way that full functionality is not impaired, and that all requirements are optimized.
- This principle of inclusiveness of objectives and interests should be carried out with three key words in mind — consultation, co-operation, and collaboration (3 C's). Consultation keeps the lines of communication open. Co-operation is emphasized over confrontation to resolve differences. Collaboration is sought proactively by seeking partnerships to find joint solutions to emerging privacy and security issues. This should provide a macro view of the complete data lifecycle. The development of a shared understanding assists in facilitating a focus on the privacy rights of the individual and the achievement of innovative, user-centric results. In a Big Data context, such a commitment must be demonstrably applied throughout the ecosystem of players in the provision of Big Data applications and services. Some examples are: the Online Trust Alliance (OTA) IoT Trust Framework that involved a collaborative global multi-stakeholder approach to maximizing consumer trust with an emphasis on security and privacy by design [24]; the Pharmaceutical Users Software Exchange (PhUSE) de-identification standard that involved input from a wide range of stakeholders including privacy experts. [25]
- Another key principle is making privacy the default where the individual user does not have to actively engage privacy preserving features because such features will be embedded into the design of the application or service. We acknowledge that there will be choices to make at the design stage whether or not a feature is hard coded or configurable. Although this principle is to be applied to business processes/procedures, physical design, it also applies to technology. The concept of building privacy protections into ICTs, otherwise known as Privacy-Enhancing Technologies (PETs) goes back to the 1990's. A notable statement on privacy-enhancing technologies for the Internet made by Goldberg, Wagner and Brewer, in 1997 is still relevant, "If we can guarantee privacy protection through the laws of mathematics rather than the laws of men and whims of bureaucrats, then we will have made an important contribution to society. It is this vision which guides and motivates our approach to Internet privacy." [17]
- Visibility and transparency are essential to establishing accountability and trust. Building trust is a result of consciously designing applications and services around the interests and needs of individual users, who have the greatest vested interest in the management of their own personal data. Empowering data subjects to play an active role in the management of their own data may be the single most effective check against abuses and misuses of privacy and personal data. This extends to the need for user interfaces to be user-friendly so that informed privacy decisions may be reliably exercised.

1. Use proactive rather than reactive measures, anticipate and prevent privacy invasive events *before* they happen (*Proactive* not Reactive; *Preventative* not Remedial).

2. Personal data must be automatically protected in any given IT system or business practice. If an individual does nothing, their privacy still remains intact (Privacy as the *Default*).

3. Privacy must be embedded into the design and architecture of IT systems and business practices. It is not bolted on as an add-on, after the fact. (Privacy *Embedded* into Design).

4. All legitimate interests and objectives are accommodated. (Full Functionality — *Positive-Sum*, not Zero-Sum).

5. Security is applied throughout the entire lifecycle of the data involved. (End-to-End Security — *Full Lifecycle Protection*).

6. For accountability, all stakeholders are assured that whatever the business practice or technology involved, it is in fact, operating according to the stated promises and objectives, subject to independent verification. (*Visibility* and *Transparency* — Keep it *Open*).

7. Architects and operators must keep the interests of the individual uppermost by offering such measures as strong privacy defaults, appropriate notice, and empowering user-friendly options (*Respect* for User Privacy — Keep it *User-Centric*).

Figure 1. 7 Foundational Principles of Privacy by Design

3.2. Privacy Engineering

If Privacy by Design foundational principles provide the "what" needs to be taken into account deliver privacy and trust in ICTs and Big Data, then privacy engineering is emerging as the response to "how" to implement them. Essentially, privacy engineering shifts control over personal

information to the individual or data subject, but practically speaking, it results in a shifting of control *toward* the data subject. The reason being, the data subject may not always be in the best position to fully assess the risks involved in decisions on the Internet. In other words, the approach to designing privacy into a system that requires the direct collection of personal data from the individual, such as online shopping for service fulfillment will be different from a system that ubiquitously collects data for operational efficiency (e.g. smart meters, automobile insurance telematics, home security sensors). Just as we rely on security engineers to ensure that the technology and system may be trusted, we will rely on privacy engineers to appropriately embed risk-based controls within these same technologies, systems and processes. [2][18][19]

Ideally, privacy and data protection should be embedded into every standard, protocol, and data practice that touches our lives, by design. This will require skilled privacy engineers and common methodologies and tools, but will be well worth the effort. The future of privacy, and in turn freedom, may well depend on it. [20]

4. BIG DATA AND PRIVACY BY DESIGN

Contrary to what some may believe, privacy requirements are not obstacles to innovation or to realizing societal benefits from Big Data analytics—in fact, they can actually foster innovation as well as widespread and enduring user trust in ICTs.

In a recent report, Danezis et. al. [3] provide an excellent and comprehensive inventory of privacy design strategies and privacy techniques.

Technologies such as strong de-identification techniques and tools, and applying appropriate re-identification risk measurement procedures, make it possible to provide a high degree of privacy protection, while ensuring a level of data quality that may be appropriate for secondary use in Big Data analytics. [21][22] However, de-identification can and should be done effectively.

One important lesson from the primary literature is that creating anonymized datasets requires statistical rigor and should not be done in a perfunctory manner. Organizations should perform an initial risk assessment, taking into account the current state of the art in both de-identification techniques and re-identification attacks. Since de-identification is neither simple nor straightforward, policy makers should support the development of strong tools, training, and best practices so that these techniques may be more widely adopted. In particular, a governance structure should be in place that enables organizations to continually assess the overall quality of their de-identified datasets to ensure that their utility remains high, and the risk of re-identification sufficiently low.

Privacy preserving data mining has become an emerging area of research. [23] With the trend toward context computing and use of artificial intelligence in data analytics, efforts to delineate responsible and accountable algorithms are also being made by data architects.

Characteristics and design features of such Big Data analytics technologies should include, for example: i) data source and transaction pedigree (full data attribution); ii) data tethering that facilitates real-time data currency; iii) ability to conduct advanced analytics on encrypted data; iv) tamper-resistant audit logs that support transparency and accountability of the systems and administrators; v) preference for false negatives and additional checks/balances; vi) self-correcting false positives; and vii) information transfer dashboards to account for all uses and transfers of the data. [24]

Big Data and APIs is yet another area in which Privacy by Design is being incorporated. [25]

5. CONCLUSION

Surveillance is the antithesis of privacy, and by extension, the antithesis of freedom. If we embed privacy into the design of Big Data applications and services, we can have the best of both worlds: privacy *and* the value of Big Data.

It will be difficult. The flawed line of thinking that privacy stands in the way is so deeply engrained in our thought processes that trying to give it up poses a serious challenge. We can accomplish these goals by embedding or coding privacy preferences into the technology itself, to prevent the privacy harms from arising. This is eminently within our reach. No doubt, it will require innovation and ingenuity, through communication, consultation and collaboration (3C's), but if we are to continue with existing technological progress in an increasingly connected world, it will be essential to maintain our future privacy and freedoms. It will also require foresight and leadership, in an effort to reject unnecessary tradeoffs and false dichotomies. Indeed, in the interest of privacy and trust, we should take a lesson from the scientific process underlying much of computer security -- the back and forth between discovering new risks, followed by developing and deploying countermeasures to mitigate those risks. In other words, organizations must seek ways to use the wealth of knowledge they have about individuals to provide better services to them in ways that increase trust not suspicion or fear or else – Privacy by Disaster![1]

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SOSLITE: LIGHTWEIGHT SENSOR OBSERVATION SERVICE (SOS) FOR THE INTERNET OF THINGS (IOT)

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ABSTRACT

The importance and reach of sensors networks grows every year, however, there are still many challenges that must be addressed. One of them, is the standardized interchange of information that enable interoperability between different networks and applications. To answer this challenge, the Open Geospatial Consortium (OGC) has created the Sensor Web Enablement (SWE) specification. SWE has given place to different mature implementations for the enterprise sector; however, they are usually over dimensioned alternatives that require robust systems. This differs from the capacity of small sensors networks like those used in domotics or eHealth, which are part of the Internet of Things (IoT).

This work proposes a Sensor Observation Service (SOS) implementation, which is one of the fundamental components of the SWE specification, that fits small sensors networks environments and that does not require very robust systems to operate, thus providing a standard and agile platform. This implementation of the Sensor Observation Service provides independence from manufacturers and heterogeneous sensors networks, increasing interoperability because information is transmitted in a standard structure and through well-defined software interfaces. It also allows installation in devices of small capacity and low power consumption, reducing deployment costs and encouraging massive deployment of sensors networks and the Internet of Things (IoT).

Keywords— Internet of Things (IoT), Sensor Observation Service (SOS), Sensor Web Enablement (SWE), Sensor Networks, heterogeneous sensor sources, data interoperability.

1. INTRODUCTION

There are many environments in which sensors are being omnipresent and the need to collect, store and analyze information provided by them is more tangible every day. Sensors networks consolidate as the medium by which data provided by the large amount of sensors deployed today is collected; however, storage and analysis of this information are research lines that are still in early development state.

Collection of information by sensors networks is done at several levels. The lower levels are supported by different standard communication technologies such as: Wi-Fi, Bluetooth, Zig-bee, 6LowPAN, TCP, UDP, etc.; however there is not a protocol stack or technology mainly imposed upon them, although a point has been reached in which many of these technologies coexist successfully with one another. In the upper levels, there are still few standardized alternatives widely used, being remarkable the Sensor Web Enablement (SWE) [1] initiative from the Open Geospatial Consortium (OGC).

The Sensor Web Enablement (SWE) allows the integration of sensors and their data. Within the SWE the Sensor Observation Service (SOS) is very important because it is responsible for defining an interface for accessing sensor data and metadata [2]. The SOS provides a standardized web service interface that enables clients to interact with registered sensors and their observations [3].

This paper describes a system for handling the storage and sharing of the sensors information. The goal of this research is to provide interoperable services to guarantee access to heterogeneous data sources coming from Sensors Networks through a Sensor Observation Service (SOS) [4]. Allowing access to sensor observations in a standard way for any sensor system, either in-situ, remote, fixed or mobile sensors, complying with the "Observations & Measurements Schema" (O&M) [5] [6] specification for modeling sensor observations, and with the Sensor Model Language (SensorML)[7] specification for modeling sensors and sensors systems.

Considering that sensors must make their measurements data accessible in a fast and reliable way, the SOS, as an intermediary element between the clients and the data collected by sensors, must provide an interface that allows storing and querying measurements in an efficient way. In addition, given that a great amount of use cases in sensors networks have limited resources, the SOS must be lightweight.

The Internet of Things (IoT) was developed at the same time that sensors networks, and it involves uniquely identifiable objects and their virtual representations in an "internet-like" structure. On the other hand, sensors networks have become one of the most important sources of information in the IoT, allowing greater interaction with the environment.

In this way, by making sensors networks' data accessible in a standard manner within the IoT, heterogeneous equipments are allowed to interact with each other, so that the amount of information and knowledge generated from them is maximized. Unique possibilities are offered for the IoT deployment by making use of a low resource

consumption Sensor Observtion Service (SOS), because it enables the possibility of covering a greater amount of use cases with great performance by bringing closer the information storage and the place where it is generated and consumed.

The rest of this paper is organized as follows: Section II presents the background about OGC standards and enumerates related work. Section III describes the outline of the system. Section IV describes one case study, and the paper ends with conclusions and further work.

2. RESEARCH BACKGROUND

This section details the concepts that will be employed throughout the article, such as: Sensor Web Enablement (SWE) and Sensor Observation Service (SOS). Finally, some Sensor Observation Service implementations are presented and the new initiative of the OGC for Lightweight SOS is shown.

2.1. Sensor Web Enablement (SWE)

Sensor Web Enablement is a framework and a set of standards that allow exploitation of sensors and sets of sensors connected to a communication network. SWE is founded on the concept of "Web Sensor" and aims at making them accessible using standard protocols and application interfaces. "A Web Sensor refers to web accessible sensors networks and archived sensor data that can be discovered and accessed using standard protocols and Application Program Interfaces (APIs)" [8].

The aim of supporting SWE is to make all kind of sensors accessible and controllable via web, making use of Internet Web protocols and the XML language. Thus enabling the capacity to publish sensor features like: sensor capacities, localization and interfaces. This information can be used by applications to geolocate and process data collected by the sensor without the need to previously know the sensor system.

The SWE is a group of specifications covering sensors, related data models and services that offer accessibility and control over the Web. The SWE architecture is composed of two main models: the information model and the service model (Figure 1) [9]. The information model describes the conceptual models and encodings used, whereas the service model specifies related services specifications.

In the information model, the conceptual models are: transducers, processes, systems and observations; and the encodings are: Observations & Measurements Schema (O&M) [5] [6], Sensor Model Language (SensorML) [7] and Transducer Markup Language (TransducerML or TML) [10].

In the service model, the four services specifications are: Sensor Observation Service (SOS) [4], Sensor Planning Service (SPS) [11], Sensor Alert Service (SAS) [12] and Web Notification Services (WNS) [13].

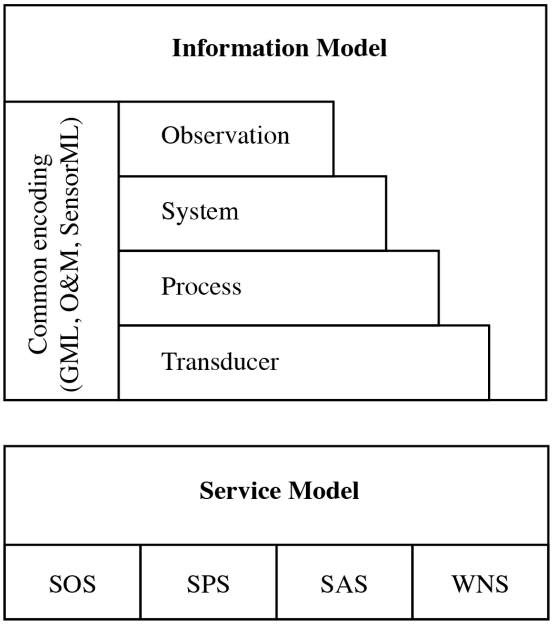

Figure 1. Sensor Web Enablement architecture

2.2. Sensor Observation Service (SOS)

The Sensor Observation Service (SOS) defines a common model for all sensors, sensors systems and their observations, which is "horizontal" since it applies to all domains that use sensors to collect data [14]. "The SOS is the intermediary between a client and an observation repository or near real-time sensor channel. Clients can also access SOS to obtain metadata information that describes the associated sensors, platforms, procedures and other metadata associated with observations" [8].

The SOS 2.0 specification was adopted in 2012 and four extension are defined within the specification: Core, Enhanced, Transactional, and Result Handling. These group its different operations as described in Table 1.

2.3. Featured SOS implementations

There are different Sensor Observation Service implementations in the literature that have been used in different projects and environments. The most notable SOS implementations are:

- 52°NORTH SOS: 52°North Initiative for Geospatial Open Source and released under the GPL license (GNU General Public License). The 52°North SOS is cross-platform because its implemented in Java, has a good software architecture, public documentation and a strong community that gives support. The SOS is part of a suite of sensor web service implementations by 52°North. [15].
- PySOS: PySOS, a python-based implementation of the OGC SOS standard. It was developed in the oceanic research community. PySOS has a simple architecture, it consists of one Python program file, a configuration file and three XML templates for each of the operations: GetCapabilities, GetObservation

and DescribeSensor. When the request is attended, the single Python program parses the appropriate XML template, generates dynamic content through database queries and outputs a completed XML document. [15].

Table 1. Sensor Observation Service 2.0 extensions

Extension	Operation	Description
Core	GetCapabilities	Requesting a self-description of the service
	GetObservation	Requesting the pure sensor data encoded in Observations & Measurements 2.0 (O&M)
	DescribeSensor	Requesting information about a certain sensor, encoded in a Sensor Model Language 1.0.1 (SensorML) instance document
Enhanced	GetFeatureOfInterest	Requesting the GML 3.2.1 encoded representation of the feature that is the target of the observation
	GetObservationById	Requesting the pure sensor data for a specific observation identifier
Transactional	InsertSensor	Publishing new sensors
	UpdateSensorDescription	Updating the description of a sensor
	DeleteSensor	Deleting a sensor
	InsertObservation	Publishing observations for registered sensors
Result Handling	InsertResultTemplate	Inserting a result template into a SOS server that describes the structure of the values of an InsertResult or GetResult request
	InsertResult	Uploading raw values according to the structure and encoding defined in the InsertResultTemplate request
	GetResultTemplate	Getting the result structure and encoding for specific parameter constellations
	GetResult	Getting the raw data for specific parameter constellations

2.4. OGC Best Practice for Sensor Web Enablement Lightweight SOS Profile for Stationary In-Situ Sensors

The original Sensor Observation Service (SOS) proposed in the Sensor Web Enablement is an excellent proposal, but it can be too complex to implement and use, which implies the need to count with a powerful hardware for its deployment. Besides, it can exceed the needs of most cases presented in different actual sensors networks that form part of the Internet of Things.

This problem has affected the OGC, which has started to create a less complex profile for the case of stationary in-situ sensors. [2]. With this objective, specific elements that are not necessary for the majority of use cases that occur in practice have been removed, reducing the number of operations and their complexity and focusing on fixed in-situ sensors. "At the same time, the profile is designed in such a way that all SOS implementations that conform to this profile are also compliant to the OGC specifications" [2].

3. OUTLINE OF THE SYSTEM

3.1. Nature of the Information in the Sensors Network

To achieve a good exploitation of resources, the nature of the information and the interactions that SOS will have with other systems must be understood. Based on that knowledge, an architecture that fits the nature of the system analyzed must be proposed.

In the case of Sensor Observation Service (SOS), sensors report their data following two temporary patterns: in constant time intervals or when a specific event is generated. In the same way, SOS clients can follow these same temporal patterns while querying data.

The sensors data can be heterogeneous and is generally represented by small pieces of information (relative humidity, temperature, luminosity level, etc.) that are reported following the temporal patterns described before. Data querying by the contrary, is usually massive, although it keeps its diverse nature.

With this in mind, to achieve a good performance, the proposed SOS implementation counts with a system that allows attending simultaneous requests with a low data load. The storage is able to adapt to heterogeneous data structures and respond quickly to multiple records queries, thus creating a unique implementation that provides a standard interface while consuming few resources and maintaining efficiency.

3.2. SOSLite Components

To be able to offer a standard data storage and distribution service in sensors networks for use in the Internet of Things (IoT), the starting point is the OGC specifications for the development of a SOS and the characterization of the traffic that circulates on these networks. This would allow making modifications that adapt to the common cases in the IoT and to resources that are more restricted, making way for light, versatile and economic implementations.

SOSLite is recommended for the development of light SOS because it's based on SOAP web services that permit CRUD (Create, Remove, Update, Delete) interactions, it implements the operations inside the Core and Transactional specifications but with a limited capacity to

make them less complex, imitating the workings of the SWE Lightweight SOS Profile [2] proposal.

Schematically, SOSLite is composed of (Figure 2): SOAP operations, WSDL descriptor file, NoSQL database and file system. SOAP operations are the ones that implement the Core and Transactional specifications adjusted to a light profile. The WSDL descriptor file enables SOSLite discovery and provides necessary information so that a SOAP client can make use of the service. The descriptor along with the SOAP operations are the public interfaces with which a client can interact. On their part, the private side of SOSLite is constituted by: the NoSQL database for sensors and events data, and the file system for sensor information backup in Sensor Model Language (SensorML) format.

The use of a NoSQL database responds to the versatility necessary to store heterogeneous information of events coming from the sensors, allowing for the structure of the storing records to change, without losing previously stored records and making them compatible with one another.

The storage of sensors descriptions in the file system, is linked to the fact that the operations DescribeSensors, InsertSensor, UpdateSensorDescription & DeleteSensor, return, insert, update or delete the sensor information in SensorML format as if it was an atomic data block without the need of transformations. Storing them this way makes the operations processing faster, because it prescinds from constructing the response in SensorML format from the database.

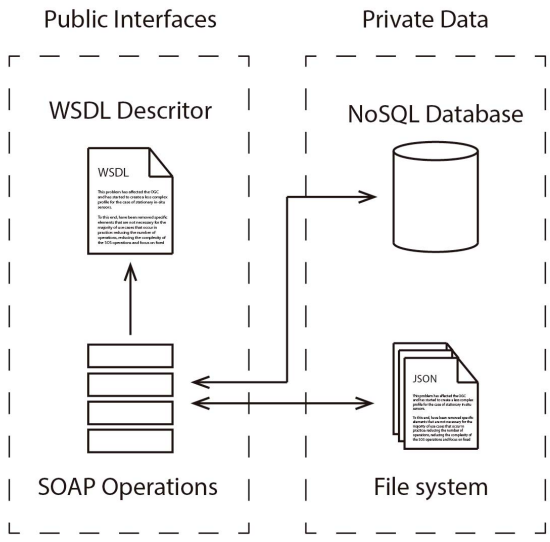

Figure 2. Sensor Web Enablement architecture

3.3. Operations of SOSLite

Operations provided by the SOSLite recommendation, are consistent with the SOS 2.0 Core and Transactional specifications (Table 1); however, adaptations for a light profile are made.

In the operations of the Core specification, an adaptation is made according to the "Sensor Web Enablement Lightweight SOS Profile for Stationary In-Situ Sensors". [2], taking into account that in the case of a mobile sensor, it will report a location change using the UpdateSensorDescription from the Transactional profile.

The transactional profile operations implement the SOS [4] standard but the same restrictions of the "Sensor Web Enablement Lightweight SOS Profile for Stationary In-Situ Sensors" [2] are made over the transmitted data in Sensor Model Language (SensorML) and Observations & Measurements Schema (O&M) format. In this way, the implementation is simplified and the standard compatibility is maximized at the same time.

3.4. Basic Operation

Any client that wishes to make use of SOSLite can start its interaction with the system by reading the WSDL descriptor file, from which the available operations in the SOS can be seen along with the supported interconnection interfaces and formats. Next, the available operations in the Core and Transactional specifications can be invoked.

GetCapabilities is the operation that usually generates bigger responses, and in it, the service is self described; including information about the type of filters that can be used in the requests, the type of spatial and temporal response, the available properties, among others. It is also the operation that is initially invoked to auto-configure the clients.

The sensors insert, update and delete operations (InsertSensor, UpdateSensorDescription & DeleteSensor) are invoked in the SOSLite so that the database is updated along with the associated files in SensorML format. In a similar way, it is the workings of the InsertObservation operation that makes the registry in the database and stores the file in O&M format (Figure 3).

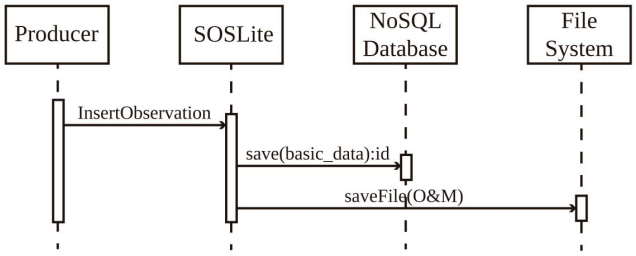

Figure 3. Basic sequence diagram for InsertObservation operation

Meanwhile, the select operations: DescribeSensor and GetObservation (Figure 4); read and filter out the requested data from the database and construct the response from this information and from the stored files in the file system.

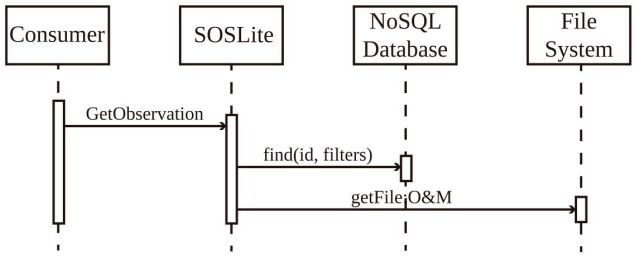

Figure 4. Basic sequence diagram for GetObservation operation

It is necessary to understand that the sensors observations in the insert and select operations, have a useful information payload in SensorML or O&M format that usually stays unaltered during considerable periods of time. Thus, storing them in the hard drive and returning them directly, according to the filters applied in the database query, is a performance improvement.

3.5. Benefits of SOSLite

SOSLite is recommended for the implementation of a light SOS, because it allows the deployment of a data storage and distribution system for sensors networks, making use of low resource devices, allowing these to be more affordable and available for massive distribution. With the consequence that this storage will be closer to the register and query of this data, thus making this operations faster.

In addition, an implementation based on SOSLite is much easier to develop and has the advantage of being adaptable to different scopes of application without making significant changes. These benefits are in line with keeping standard and well defined interfaces for data transmission, so that the interconnection among heterogeneous systems is made possible.

4. CASE STUDY

To ease the assimilation of the concepts presented in this article, an implementation of SOSLite [https://github.com/Juanvx/SOSLite] has been developed and its source code has been published under the GPL license. Code is written in PHP and can be deployed on Apache and NGINX servers among others.

Using the published open source implementation, a use case is given within the Internet of Things focused on eHealth. This allows the interconnection of sensors in a body area network, a home network and a metropolitan network; with a personal alert system and a health system inside the hospital (Figure 5).

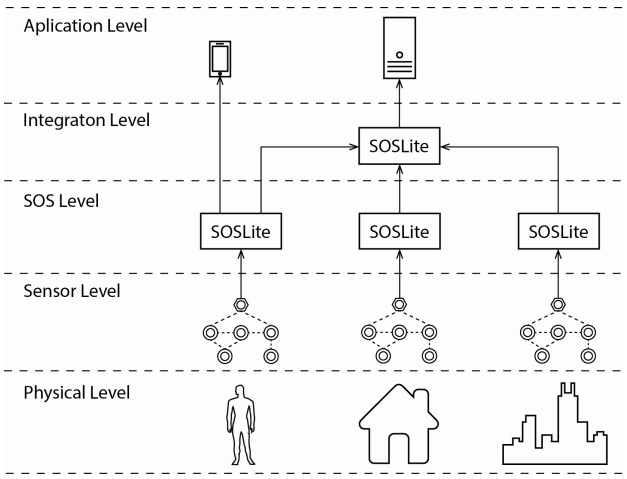

Figure 5. eHealth use case architecture

As it can be appreciated, the system is hierarchical and distributed; and is constituted by four levels: Sensor Level, SOS Level, Integration Level and Application Level. In the Sensors Level are all the sensors networks that measure physical parameters (cardiac rhythm, blood oxygen, arterial pressure, etc.) which can be used to detect abnormalities in the patient, home sensors which measure ambient parameters (air quality, temperature, movement, etc.) and city sensors which also measure ambient parameters (air quality, temperature, etc.).

In the SOS Level, every sensors network information is centralized in an independent way and is made accessible through a SOSLite in every network. In the same way, in the Integration Level, a SOSLite deployed on a higher capacity device, centralizes the information of the SOSs linked to every sensors network and creates a data bank accessible for the hospital applications.

Finally, the Application Level has two different solutions that show the potential for a system built like this. The first solution is an alert service linked to the physical sensors network. This service reads the data from the SOSLite of this network and if it detects a pattern that shows a dangerous condition for the patient, emits alarms to the patient, to a contact person and to the family doctor. The second solution analyzes data associated to the Integration Level SOSLite, and through BigData, detects trends that can be used by doctors to make recommendations to their patients; i.e. in the moment the average air particles count in the city exceeds 50 μg/m3 (PM10), asthmatic patients increment their respiratory problems by a 30%.

5. INITIAL PERFORMANCE EVALUATION

To verify the viability of SOSLite as a recommendation, and the possibility of testing a use case as the one discussed above, it has been made an initial performance test of the implementation of SOSLite on a Raspberry Pi 1 model B (CPU: 1176JZF-S a 700 MHz, SDRAM: 512 MB shared with GPU, Power ratings: 3.5 W).

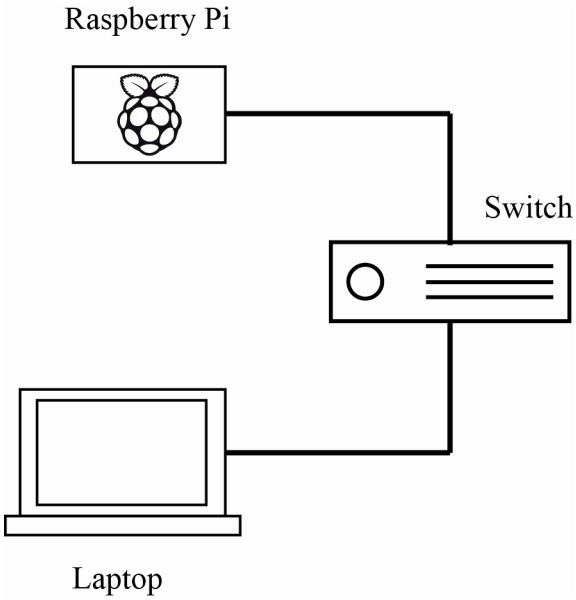

Figure 6. Test set-up

A test case was made using Apache Jmeter on Ubuntu Linux 14.04 LTS and deploying the SOSLite implementation on the event driven NGINX server, using Raspbian as operating system and MongoDB as database. The JMeter client runs on a personal computer while the server uses the Raspberry Pi; on its part, the interconnection is made with category 5 UTP cable and a personal switch (Figure 6).

The test case simulates the connection of 20 sensors that make 25 GetCapabilities operations to a SOSLite and evaluates the throughput as well as the average delay and standard deviation (Figure 7).

As can be seen in Figure 7, the average delay values are close to 4 seconds with a deviation up to 1 second. However, there are three important factors to take into account: in a traditional case, the GetCapabilities operation calls (which has been chosen for being the most resource consuming) are usually very few, the amount of sensors associated to a deployment on the tested hardware will be less, and the hardware employed is very limited compared to the actual devices that can be used. In example, a Raspberry 2 model doubles the capabilities of the Respberry used.

6. CONCLUSIONS AND FUTURE WORK

Counting with some standard interfaces and data transmission formats is the big challenge of the current Internet of Things (IoT). Although there are many providers promoting their initiatives, an international organism that associate diverse companies from the field, is essential to ensure compatibility of these systems and to allow a beneficial development for the society. For this reason, this article is based on a standard with these characteristics, adapting it to adjust it to the most frequent cases faced by the actual IoT.

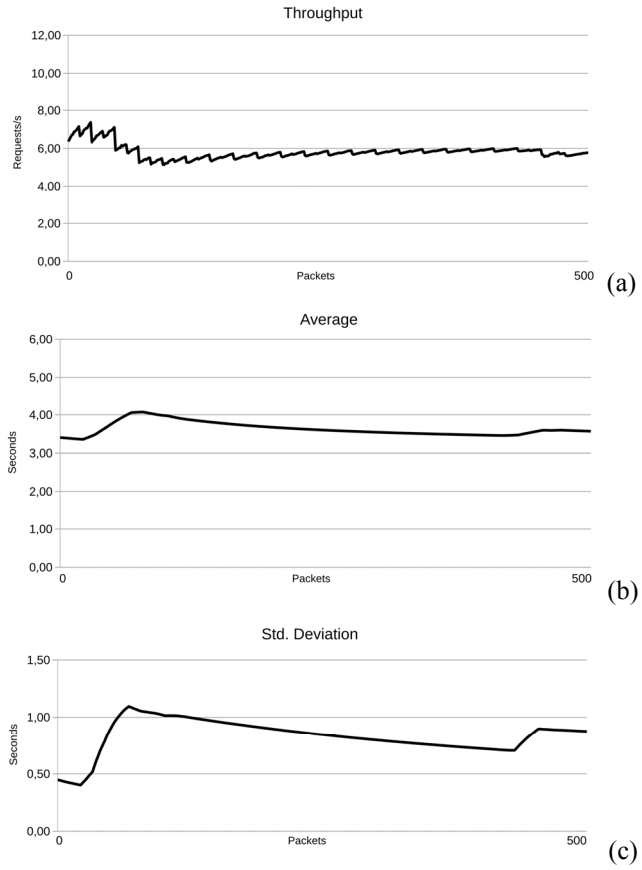

Figure 7. SOSLite GetCapabilities operation throughput (a) delay average (b) and delay standard deviation (c)

Today, there are many data sources coming from different sensor networks. The main concern about the huge amount of data provided by these sensor networks is the heterogeneity of the data.

Likewise, with the overcrowding of the Internet of Things (IoT), the need to decrease deployment costs is fundamental to keep the current momentum. To achieve this goal, modest and economic hardware must be employed. This can be attained by making software that is efficient and adequate to the market needs, leaving aside the less used operations and simplifying the most used ones.

Analysis of this information is beyond the scope of this work, however by giving a standard interface for information querying, the Sensor Observation Service (SOS) constitutes as the base to take full advantage of sensor networks.

In future works, the actual SOSLite implementation will be tested to determine its performance and versatility in diverse use cases in a way that it proves that it is an appropriate candidate to empower the IoT. Besides, it will continue seeking ways to increase the systems efficiency, and at the same time, adjusting properly to the type of traffic generated within the Internet of Things (IoT).

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FUTURE MOBILE COMMUNICATION SERVICES ON BALANCE BETWEEN FREEDOM AND TRUST

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ABSTRACT

Some applications introduced in each 5G mobile communication project (5G-P) assume special use cases such as when many people simultaneously use their mobile phone in a restricted area like a stadium or when using traffic safety systems are in common. And, some of them such as mobile healthcare and the Internet of things (IOT) have already been presented by many people. However, the reasons those applications will be widely used are uncertain. And then, most authors of articles related to future mobile communication made no mention of business schemes such as who deploys network infrastructure or who provides service content.

However, the histories of existing mobile communication markets may show applications that are different from the ones written in the above articles and new business schemes that are different from existing ones.

In this article, I analyze the dominant non-voice applications of the existing mobile communication systems including paging services and identify the primary factors that made them dominant. I also analyze the business models of the network carriers. This analysis leads me to forecast that the next-generation of dominant mobile communication applications will be developed on the basis of a balance between the freedom of participants and suspicion, and the business models will become more liberal. Moreover, I forecast that a service that comes after SNS messaging services will be the one in which experiences are shared.

***Keywords*—** mobile communication system, mobile evolution, 5G, context-aware communications and networking, user-centric networking

1. INTRODUCTION

Several projects aimed at developing 5G mobile communication systems are underway in various parts of the world. 5G PPP [1] and METIS [2][3] in the EU and the 5G Forum [4] in Korea have already issued white papers. The 5GMF [5][6] in Japan has signed a memorandum of understanding with the 5G PPP. Most such projects are based on special use cases in the 5G mobile (5GM) era and address the performance requirements for those cases. Moreover, they focus on the technologies needed and the challenges that must be overcome to meet those requirements. The use cases include smart cars, traffic collision avoidance, and heavy communication traffic volumes in a small area such as a stadium.

Some use cases introduced in 5G-PPP, 5GMF and ETSI are in common. And, most applications in 5G Forum have already been presented by many people. However, reasons those applications will be widely used are uncertain. And then, most authors of articles related to future mobile communication made no mention of business schemes such as who deploys network infrastructure or who provides service content.

Most major applications were developed at the last half of living mobile communication system, so a new generation system was required to handle the growing number of subscribers. For example, the i-mode mobile Internet service in Japan was developed in the 2G era, but the performance of 2G mobile was insufficient for full Internet service—performance of 3G mobile (3GM) was needed. It is still unclear which existing applications will need 5GM performance.

However, the histories of existing mobile communication markets may show applications that are different from the ones written in the above articles and new business schemes that are different from existing ones.

In this article, I analyze the dominant non-voice applications of the existing mobile communication systems including paging services and identify the primary factors that made them dominant. I also analyze the business models of the network carriers. This analysis leads me to forecast that the next-generation of dominant mobile communication applications will be developed on the basis of a balance between the freedom of participants and suspicion, and the business models will become more liberal. Moreover, I forecast that a service that comes after SNS messaging services will be the one in which experiences are shared.

After introducing related work in Section 2, I analyze existing mobile communication applications and business models to clarify the primary factors that made them dominant in Section 3. On the basis of these primary factors, I forecast which mobile communication applications and business schemes will be dominant in Section 4. I conclude in Section 5 with a summary of the key points and a personal note.

2. RELATED WORK

2.1. 5G projects

The 5G projects mentioned above sometimes compete and sometimes cooperate in taking the initiative on standardization and markets for 5GM. Their special use cases and applications target 2017–2020. They are listed in Table 1, along with their primary requirements.

Most of the use cases and applications must be limited for usage. Some cases would be very rare, and others could be solved by implementing suitable application software. For example, about ten years ago in Japan, so many young people visiting a shrine or temple on the first day of the new year were simultaneously sending messages with New Year greetings that the network carriers had to control the traffic volume to keep their systems operating. This led to an increased usage of social networking applications (SNSs) such as Facebook and LINE, which solved the New Year's Day traffic jam problem. This means that a huge amount of traffic in a stadium would not be a problem solved by 5GM. The traffic efficiency and safety use case of METIS and the smart cars use case of the 5G Forum require super low latency. Moreover, they also need the ability to identify vehicles and obstacles (including people) and to determine their locations. These latter two functions will be difficult to achieve. In addition, it is unclear whether these use cases and applications will be common in the 5GM era.

Table 1. Use cases, applications, and requirements of some 5G projects

	5G PPP/ 5GMF	METIS	5G Forum
Use cases and/or applications	Stadium traffic	Stadium traffic; Traffic efficiency and safety	Smart cars; Medical education; Games; Disaster relief
Peak data rate	10 Gb/s	10 Gb/s	50 Gb/s
Data volume	10 Tb/s/km^2	9 Gbytes/h in busy periods; 500 GB/mo /subscriber	—
Number of devices	1 M/km^2	300 K/access point	—
End-to-end latency	5 ms	5 ms	1 ms

2.2. Context-aware communications and networking

A new trend in communication research is context-aware communications and networking (CACN). Most existing communication systems do not take into account the context of such entities as people, vehicles, phones, and base stations. In contrast, in CACN, the contexts of entities (both real and virtual) are taken into account in end-to-end communication [7]. The concept of CACN is very wide and is applied in all communications and networking layers, from the physical and networking layers to the transport and application layers. Misra et al. applied this concept to the location of nodes and the rate of dissemination in wireless sensor networks and thereby effectively reduced the end-to-end delay of disseminated data with different priorities in an energy-efficient manner [8]. Researchers referred to the smart house, smart city, and so on would be included in CACN. Rao et al. proposed a context-event triggering mechanism in a smart cyber-physical space that works through energy harvesting [9]. Murata and Saito proposed a cloud service, called "cyber parallel traffic world" (CPTW), in which vehicles, pedestrians, and temporary obstacles exist and move in synchronization with their real-world counterparts [10]. In CPTW, drivers and pedestrians can communicate with other drivers and pedestrians by pointing to their positions rather than referring to an ID (e.g., a telephone number or address).

2.3. User-centric networking and device-to-device communication

Other new trends in communication research are user-centric networking (UCN) and device-to-device (D2D) communication. While existing 1 to 4G communication networks (including paging system ones) were deployed by network carriers, UCNs and D2D networks are created by the users themselves, who cooperate by sharing network applications and resources. They are thus characterized by spontaneous and grassroots deployment of wireless architectures [11]. In an article entitled "Spontaneous Smartphone Networks as a User-Centric Solution for the Future Internet," Aloi et al. describe building a local network using smartphones, WiFi access points (APs), Bluetooth devices, and network file systems that is organized in terms of spontaneous connectivity [12]. This approach could lead to low-cost operation, occasional super low latency, and high spectrum efficiency. However, if a malicious device terminal is implemented in a UCN as a relay node, that network would be risky to use. Important information could be stolen from a user's terminal. Therefore, security and trust functions are necessary for UCNs. Frangoudis and Polyzos identified the challenges of user centricity in terms of their effect on wireless networking architectures, particularly security, in an article entitled "Security and Performance Challenges for User-Centric Wireless Networking" [13].

3. EVOLUTION IN MOBILE COMMUNICATION

In biology, the evolution basically depends on the genetic mutation and the natural selection. The genetic mutation is caused by not only natural mutation but also viruses, radiation and so on [14]. Anyhow, whether new species of organisms can survive and thrive is dependent on coincidence. It is very difficult to predict which new species of organisms will thrive.

The other hand, in the mobile communication market, whether new applications, business models and so on are accepted by a lot of subscribers is mainly dependent on subscriber's values or preferences and social rules. Subscriber's values or preferences must not change so rapidly. This means that there would be solutions for which applications and so on will thrive in a history of mobile communication market. I analyze existing mobile communication applications and business models to clarify the primary factors that produce the dominant applications and business schemes.

3.1. Applications

In most articles related to the evolution or future of mobile communication, 1G cellular phone systems, which provided only analog voice service, are considered to be the first mobile communication system. However, the paging system was actually the first mobile communication system for non-voice service. Prior to the introduction of 2GM phone systems, paging systems provided one-way messaging service in its half period. Users could send a message by using a push-button phone, a PC mail system such as Lotus Notes or Internet mail. Paging applications were mainly used by business people in the U.S. and the EU, and by young people, especially female high school students, in Japan.

The advent of 2GM led to the integration of 1G mobile (1GM) phone systems and paging systems (2GP), enabling two-way messaging service (Internet mail) and limited World Wide Web (WWW) service in Japan, as shown in Figure 1. In the EU and U.S., the two-way short messaging service (SMS) became widely used as a consumer communication service. Full Internet service using smartphones started in the latter half of the 2GM era, and becomes popular in the 3GM era. One of most popular application in 3GM era is the SNSs such as Facebook and LINE. They suit for a mobile communication service in fact, most mobile mail user shifts to SNS's messaging applications. Anyway, messaging applications are dominant in any mobile communication systems.

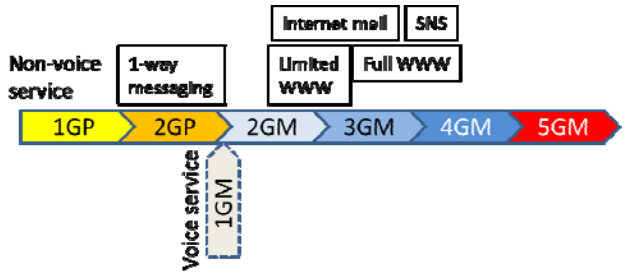

Figure 1. Evolution of non-voice applications in Japan

Researchers in both industry and academia university continue to develop new mobile communication systems, and network carriers are deploying them to enable subscribers to use their applications anytime and anywhere. Users can connect their smartphones to the Internet through not only 3GM and 4GM but also WiFi. Generally, users can connect to the Internet at lower cost and with a higher data rate by using WiFi rather than 3GM or 4GM. When connecting through a carrier network, the user generally does not need to worry about security. However, when connecting through a WiFi access point, the user has to consider whether it is safe or not, because some of WiFi access points would be malicious [15]. Unfortunately, most users do not do this.

The evolution of messaging service from the one-way messaging to two-way messaging to SNS messaging has been accelerated by seeking freedom for communication. However, in the period introducing unguaranteed network resources, keeping trust for participants is very important to expand the mobile communication market.

3.2. Business schemes

In most countries, a specified organization such as AT&T, and NTT provided mobile communication service in the first era of mobile communication. The mobile market was closed, and there was no competition. Since then, mobile communication markets have been opened somewhat in most countries. The number of carriers is still limited, and operations are controlled by the government. This means that competition is restricted.

The standard mobile communication business model is a vertically integrated one. I proposed an open heterogeneous mobile network (OHMN) model to accelerate competition in the mobile communication market at the first Kaleidoscope in 2008 [16]. In this model, mobile communication business activities are horizontally arranged on five layers, as shown in Figure 2. Each layer corresponds to a core activity;

- Terminal layer: manufacturing and selling terminals.
- Network layer: deploying and providing access networks.
- Connection service layer: setting up voice communication path between end terminals through different access networks. (Mobile virtual network operators are on this layer).
- Platform layer: user authentication and charging.
- Contents & application layer: developing and providing contents and applications for mobile users.

In the standard business model (1.0), the market is closed while in the proposed business model (2.0) the market is open. While carriers continue have the right to provide wireless networks, connection applications, and billing applications, newcomers such as Skype and LINE now provide voice exchange applications over the Internet, and most billing applications for application software have shifted from carriers to credit service providers. This means that it is impossible to maintain a monopoly on a service business through laws or rules; outsiders are finding ways to break or circumvent such laws and rules so that they can provide targeted applications. Moreover, most business people want the freedom to start up and run any type of business.

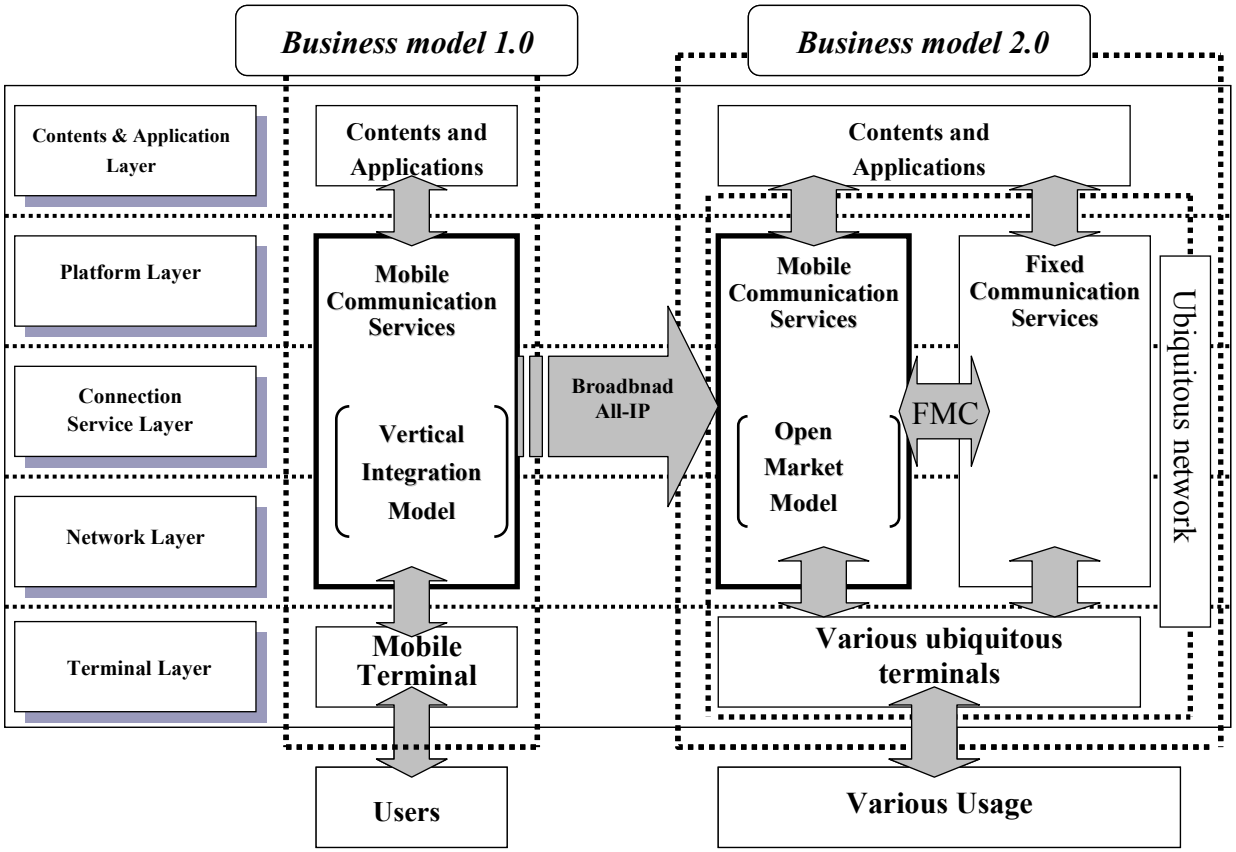

Figure 2. Open heterogeneous mobile network (OHMN) business layer model

4. FUTURE MOBILE COMMUNICATION SERVICE

In this section, I forecast trends in service provision and business schemes.

4.1. Service provision

I first forecast service provision from the standpoint of user freedom regarding "anytime, anywhere, anyone, and anything." It is very difficult to completely achieve "anytime, anywhere and anything" freedom, and the 5G projects present very special use cased which need advanced technologies to achieve them. However, there are some problems which do not need advanced technologies. The 5G projects make no mention of them. For example, mobile subscribers have to pay high roaming charges when they are out of their home country. Frequent visitors to foreign countries often buy a pre-paid subscriber identity module (SIM) card for each country to enable use of a smartphone or tablet without having to pay roaming charges in each country. Less frequent visitors typically do not use the mobile communication system but use WiFi instead. A roaming charge is simply an unfavorable aspect of mobile communication. It is not a technical problem to be solved. Since the principle involved is the same as the "increase of entropy principle," some network carriers could abolish the charge while others could continue to impose it.

Systems that use users' IDs to connect them do not provide "anyone" freedom. For example, a driver (A) stuck in a traffic jam cannot connect to a driver (B) at the front of the jam, since A does not know B's ID. This is one factor driving CACN research. It also led to my proposal to use the CPTW cloud service for solving traffic-related problems. Drivers using this service could learn the locations of other vehicles, pedestrians, and obstacles being tracked by the service and could communicate with each other by pointing to an object such as an automobile or pedestrian.

The concept of CACN is a very broad; the use cases described above are only a few of its potential applications. I call the actions in the above use cases "context-aware messaging (CAM)." A context and ID exchange (CIDX) server is needed for CAM, as shown in Figure 3. Its database is used to relate a subscriber's profile (including ID) to his or her context. When a person accesses the CIDX server, a graphical user interface such as a map on which context objects are plotted is displayed. The CPTW described in Section 2.2 is also one of CIDX servers. For example, if Mr. A, who has heart disease, falls down, his smartphone automatically sends an emergency signal including its location information. After receiving the signal, the CIDX server searches the context database for the IDs of doctors or other persons near Mr. A who have experience in the use of an automated external defibrillator (AED) and sends an appropriate person a message with a description of the problem and the location information.

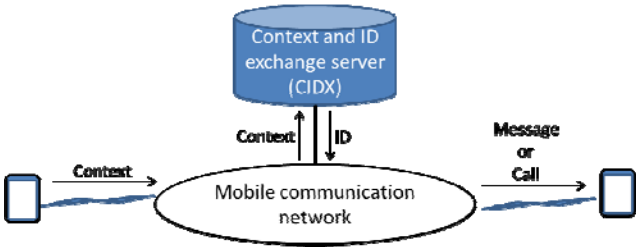

Figure 3. CAM system structure

While CAM would be very useful for law-abiding people, as shown by the example above, it would also be very useful for criminals. For example, a criminal could send a forged context signal that summons the police, enabling the criminal to easily commit a crime elsewhere. Therefore, the application of CAM to applications requires that trust between participants be maintained.

I next forecast the post-SNS messaging service. There are currently two types of SNS messaging: one type is messaging in which the destinations are anonymous, such as in Twitter; the other is messaging in which the destinations are limited to a group, such as in Facebook. The direction and relation of communications have been realized by existing messaging service. This means that there is no room for seeking freedom in the physical world. However, changing the point of view for exchanging messages generates a new direction for messaging applications. Assuming that the purpose of exchanging messages is to share one's thoughts, I forecast that one post-SNS messaging service will be one in which experiences are shared. For example, a subscriber could send messages to others who are in the same location, such as in a restaurant, to share their experience such as tasting good food or enjoying the atmosphere. Subscribers could exchange messages with other shoppers in the same shopping mall to obtain useful information. Climbers could exchange messages with other climbers on the same mountain to get updates on weather conditions and so on. This type of service is a Twitter-like application in which destinations are not anonymous but limited by the context. This idea of context-limited messaging has already been implemented for some network games, such as Ingress, in which one group of players competes against another group. The members in a group cooperate and share experiences with each other during a game by messaging. Trust within a group is very important for sharing experiences since subscribers are sometimes geographically very close. If a subversive person joined a group, the group's performance could be undermined.

4.2. Business schemes for service providers

Here I forecast the future of business schemes in the mobile communication market on the basis of the OHMN model shown in Figure 2.

4.2.1. Network layer

As discussed in the UCN and D2D, some parts of wireless networks will be open in the future. Before discussing the business scheme for the network layer, we have to consider the various types of wireless units that will be available. I expect that three types of wireless units will be used in the future:

- WU-1: XGM wireless unit; for outdoor use.
- WU-2: XGM wireless unit like a femtocell in 3GM and 4GM; for indoor use.
- WiFi-AP: WiFi access point; mainly for indoor use.

Here, the acronym "XGM" presents the future generation mobile system. WU-1 units will be closed, the same as for existing wireless units; only network carriers will deploy them. WiFi-AP units will be provided as an open terminal, the same as existing WiFi-AP units, so anyone can buy one.

Opening up the WU-2 units the same as the WiFi-AP units would activate the market. If the WU-2 units were open, the WU-2 and WiFi-AP units could connect to the carrier's exchange units or a third party's exchange units through the Internet, as shown in Figure 4.

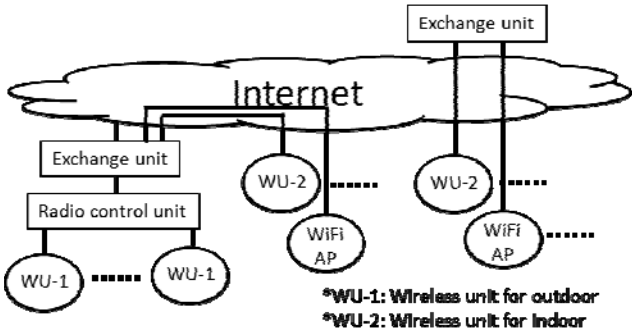

Figure 4. Structure of future mobile communication system

Each exchange unit has a subscriber identification function and call exchange function. When a subscriber's terminal connects to a WU-2 or WiFi-AP unit, the unit accesses a contracted exchange unit to identify the terminal's ID. In case of voice communication, the exchange unit creates a session path between the terminal and itself and keeps it while the two parties are talking.

Scenarios for WiFi-Ap or WU-2 connecting to which exchange unit would depend on three primary factors;

F1: A very low power wireless station unit for XGM like a femtocell is allowed to use the frequency band that has been allocated to WiFi.

F2: Frequency bands for XGM are independently allocated to each specified carrier or shared among carriers.

F3: Which takes the initiative, the operator or the third party?

I first discuss a connecting exchange unit for WiFi-AP. An operation of such a unit depends on F3, i.e., who has the initiative, as shown in Figure 5. There are two alternatives for the unit.

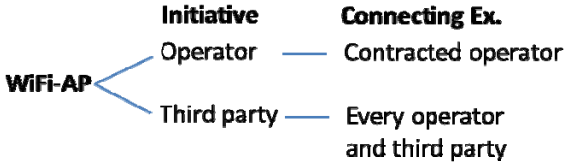

Figure 5. Scenarios of connecting exchange unit for WiFi-AP

In contrast, the operation of the connecting exchange unit for WU-2 depends on every factor. Therefore, its operation is rather complex, as shown in Figure 6. Scenario 8 (S8) is the one that will most activate the mobile communication market. I am looking forward to the government allowing WU-2 units to use the WiFi band and to standardization for XGM systems sharing the same frequency band. Two other problems related to opening the network layer are:

- maintaining security while freely selling WU-2 and WiFi-AP units.
- sustaining the business of third parties who deploy WU-2 or WiFi-AP units for general subscribers.

At least, WU-2 or WiFi-AP units have to be provided the same as the mobile terminal. The ordinance of radio equipment for mobile terminals should be applied to WU-2 or WiFi-AP units. When they will be connected to an operator's exchange unit, a chip like a SIM chip has to be mounted in the unit. If possible, an exchange unit should be able to examine whether a WU-2 or WiFi-AP unit has been contaminated with malicious programs such as computer viruses.

Alternatives for sustaining a third party's business are basically billing for usage and sending advertisements. They depend on the third party involved. A shopping mall, for example, could send information customized for each subscriber and shop. A restaurant could use a WU-2 or WiFi-AP unit to take orders or attract customers. In the "taking orders" example, the unit would need a function for charging for the provider's service. In the "attracting customers" example, the unit would need a function for using cloud applications.

4.2.2. Connection layer

As mentioned above, voice exchange applications are already being provided by several cloud service providers such as Skype and LINE. Skype can already handle exchanges between carriers for voice communication. However, they cannot handle fast hand-off service between WiFi routers. Technically, the IEEE has already standardized fast-hand-off for WiFi as IEEE 802.11r or 11ai [17]. The fast hand-off service between WiFi-AP and/or WU-2 units would be provided by some providers.

4.2.3. Platform layer

Billing for smartphone applications already has been opened to outsiders, and many such applications are in the Google Play Store and the Apple Store. It is possible to buy them by credit cards and prepaid cards. IC/Mobile wallet applications are now widely used in several countries such as Japan. It is possible to pay by IC card or mobile phone. Apple provides the Apple-pay app for its iPhone.

The Internet of Things (IOT) will be ubiquitous in the near future. For example, the fee for parking in most parking lots in Japan is paid using an on-site charging system, which is not cost effective. The application of IC/Mobile wallet or Apple-pay applications to them would be more convenient and effective. In the future, such charging systems will utilize the IOT and make our lives easier.

5. CONCLUSION

The analysis I have presented of existing mobile communication applications clarified the primary factors that made such applications dominant. I hypothesized that the evolution of mobile communication service was accelerated on the basis of a balance between the freedom of participants and suspicion. My forecast of mobile communication applications on the basis of these factors shows that sharing experiences will be the next stage in the evolution of messaging applications. The spread of very low power wireless stations using the WiFi band and of standardized XGM systems sharing the same frequency band will activate the mobile communication market. Finally, fast hand-off applications between WiFi-access

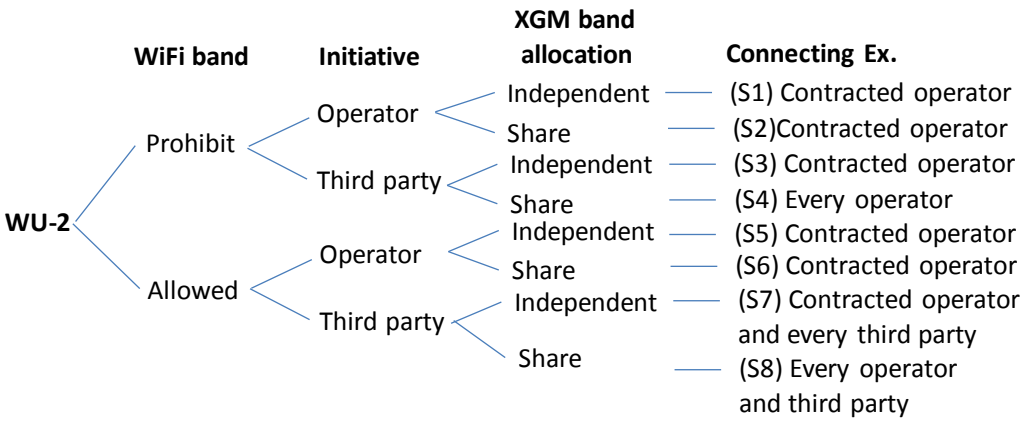

Figure 6. Scenarios of connecting exchange unit for WiFi-AP

points and very low power wireless stations, and billing applications to utilize the Internet of Things will be introduced in a future.

These forecasted developments should result in improved human ability, more convenient living, and new markets.

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MAURITIUS EHEALTH – TRUST IN THE HEALTHCARE REVOLUTION

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ABSTRACT

The aim of eHealth infrastructure is to harness innovations in digital infrastructure that can enable the seamless access to, sharing and reuse of data (e.g. clinical records, genomic data and images) irrespective of source [1]. eInfrastructure is comprised of networked, interoperable, service-oriented, scalable computational tools and services. The key element is the interaction of human users and computers so as to facilitate discovery, linking and reasoning [2].

Keywords— Mauritius, eHealth, mHealth, Doctor Assistant, Africa Health, Innovation, Medical, Information, eInfrastructure, Big Data, Health Informatics, Global eHealth

1. INTRODUCTION

During the 1990s, as the Internet gained public attention, a number of e-terms began to appear and proliferate. The introduction of eHealth represented a promise of information and communication technologies to improve health and the healthcare system. [3] eHealth infrastructures are viewed as central to the future provision of safe, efficient, high quality, citizen-centered health care. While Western countries have raced forward in developing eHealth, many developing countries remain on the start line. There is evidence that better tapping ICT (Information Communication Technology) could result in more effective utilization of health services and increased efficiency [4]. A communication revolution is brewing in the delivery of health care and the promotion of health fueled by the growth of powerful new health information technologies [5]. Mauritius has one of the most successful and competitive economies in Africa; 2008 GDP at market prices was estimated at $8.128 billion (official exchange rate) and per capita income at $ 12,100 (purchasing power parity), one of the highest in Africa [6].

2. MAURITIUS EHEALTH POTENTIAL

Mauritius has a population of 1.2 million residents. There are five regional hospitals and two district hospitals. The number of beds in government health institutions was 3,581 at the end of 2013. In the private sector, there were seventeen private health institutions with a total of 690 beds. The total number of beds in the public and private sectors at the end of 2013 was thus 4271, that is, 285 inhabitants per bed. In 2013, a total of 5.2 million cases was seen by doctors at the out-patient service points in the public sector [7]. There is a need to extend healthcare services beyond medical premises. Despite being built for acute events, many hospitals allot a significant number of their beds to chronically ill patients, with considerable cost consequences. Mobile penetration rate was around 82% in 2009, paving way for intense competition among operators to retain their customers and acquire new ones. Today, mobile penetration is nearly 100%. HSPA (High Speed Packet Access) and EV-DO (Evolution Data Optimized) based 3G services are competing with fixed-line DSL (Digital Subscriber Line) and other wireless broadband offering, including WIMAX (Worldwide Interoperability for Microwave Access) [8]. Efficient remote monitoring and care has a great potential. Adopting a proper eHealth infrastructure can strengthen our health systems by:

- Improving the availability, quality and use of information and evidence through strengthened health information systems and public health surveillance systems
- Developing the health workforce and improving performance by eliminating distance and time barriers through telemedicine and continuing medical education
- Improving access to existing global and local health information and knowledge
- Fostering positive lifestyle changes to prevent and control common diseases.

The Mauritian Government seeks to enhance prosperity for its citizens and to ensure that it is available to everybody, to develop the island further in order to compete with other states in a globalized world and to expand and cultivate the welfare and education systems to promote de facto equal opportunity, regardless of gender, ethnicity, social class or religion. This is the case too in terms of Mauritius ICT policy and strategies where a holistic approach has led to successive policies aimed at ensuring that ICTs contribute to the wealth and prosperity of the country [9].

Since 1989, Mauritius has been a front-runner in an overall comprehensive national ICT policy and liberalized telecommunications framework, more recently in line with the Millennium Development Goal (MDG) [10].

Despite all the opportunities that Mauritius have compared to other African country, a proper eHealth infrastructure has

failed to be set up. Major barriers for successful implementation are: [11].

- Limited Awareness of eHealth

Policy makers, health authorities and health practitioners are not fully aware of the potential benefits of the use of ICT for health. The long-term strategic plans for developing eHealth infrastructure is limited.

- Lack of an enabling policy environment

National policies, strategies or regulatory framework are necessary for establishing common technical infrastructure, interoperability and standardization protocols. Mauritius also needs to address ownership, confidentiality, security of data and quality of information.

- Weak leadership and coordination

The challenge is to strengthen coordination and collaboration among stakeholders, partners and donors as well as improve the capacity of the health sector to lead the process.

- Inadequate human capacity to plan and apply eHealth solutions

Number of health workers capable of leveraging ICT in their work remains limited. Health workers are not systematically trained in use of ICT. Mauritius needs health workers with the capacity to design, deploy and effectively manage eHealth projects.

- Weak ICT infrastructure and services within the health sector

Ministries in charge of communications, technology and finance are primarily responsible for national ICT infrastructures. eHealth requires a dedicated team to sustain eHealth initiatives.

- Inadequate financial resources

Collaboration and coordination between multiple partners from both private and public sectors is required.

Despite these challenges, opportunities exist for planning and deploying eHealth solutions. These include the rapid advances in ICT, increasing access to mobile phones and broadband connectivity, increasing interest by donors and countries in strengthening health systems, and the partnerships being built by agencies such as WHO, International Telecommunications Union (ITU), World Bank, United Nations Economic Commission for Africa and others. These partnerships seek to develop national road maps for eHealth, and provide access to a suite of eHealth applications and solutions for enhancing professional capacity. Policy makers should see the eHealth change as innovative, new and valuable. eHealth innovations can gain momentum and acceptance rapidly in the Mauritian society [12].

"We have beautiful hotels, beautiful beaches, and first-class service. Why not make Mauritius a hub, a place where people can combine a holiday and medical treatment" (Former Minister of Health). [13]

"Involve the user" is a mantra in IT development, yet numerous projects fail (some sources report 70% failure [14]) because of inability to capture user insights. It is attributable to failure on the part of developers to understand the workflow of health professionals and to meaningfully involve users in the design, development and implementation [15]. There is also resistance from clinicians who perceive the project as an effort to introduce technology for 'policing' their clinical practice. A possible solution for this resistance, is to spend time and energy into building a rapport with clinicians through informal chats, gatherings and social activities.

eHealth infrastructure should support clinician and researcher in time-consuming evaluation tasks to get meaningful results faster and with less effort [16]. Data protection is a major issue which eHealth has to address. It is easy to being stuck in an endless "yes-no" debate regarding Data protection. An interesting solution to the problem is pseudonymisation which means de-identification of medical data [17]. However, we should not forget that not only persons or legal entities may has their identity protected. This goes as well for systems or even molecules (e.g. in drug discovery projects where pharmaceutical research institutes have a need to share basic research information, without exposing intellectual property details).

Patients are now taking responsibility of their own health, receiving information about health matters, and participating in decision making related to personal health issues from prevention to care and follow up [18]. The application of Big Data into eHealth systems will generate a new era of evidence-based medicine.

3.MHEALTH

mHealth interventions is on the rise. There is no ideal way of deploying mobile technology. Learning from early mHealth deployments is important so that ineffective approaches are not duplicated. Successful projects need to be replicated and scaled. In each mHealth thematic area, the challenges, barriers, and gaps in mHealth manifest themselves in unique and interrelated ways both in LMIC (Low and Middle Income Countries) as well as in high-income countries [19]. A general observation is that mHealth interventions in high income countries focus on chronic diseases while in LMIC on infectious diseases mostly. In high income countries, mHealth addresses mostly the following health conditions according to a Global health report in 2006: [20]

- Diabetes (blood sugar monitoring)
- Breast cancer (telephone counseling)
- Tuberculosis (adherence to medication)
- Attendance to health facility appointments

- Depression outcomes
- Immunization rates
- Asthma management
- Smoking cessation

Mobile technology plays an empowering role for patients. They feel to have control over their health. The text messaging support system "Sweet talk" was evaluated by Franklin, Greene, Waller and Pagliari. C for its effectiveness in encouraging good diabetes management in young people. The randomized controlled trial (RCT) consisted of sixty-four young diabetes patients. The study concluded that "Sweet talk" effectively engaged young people in self-management of diabetes [21]. Compared to traditional paper and pen methods mobile technologies provide several benefits namely:

- Improved accuracy
- Reduction in time
- Reduction in human resources
- Reduction in cost
- Improved data quality
- Potential for real time authentication of data
- Less interviewer bias

In a paper entitled "Catalysing a perfect storm", the authors describe how mobile phones are equipping populations with a convenient tool to become better informed, motivated and self-managed to integrate more healthful daily activities [22]. Medic Mobile has been described as Weapon Number one for the war against AIDS [23]. Medic Mobile developed an open source software which is a web-application for sending and receiving messages as well as scheduling time-targeted confirmation notes to conventional $10 mobile phones. A parallel SIM transforms inexpensive mobile phone into a sophisticated wireless data collection terminal. Once the parallel SIM is installed beneath a carrier's normal SIM card, the software allows for wireless data collection in remote or Internet inaccessible locations (Medic Mobile, "Impact," 2012).

The Ebola epidemic is a major recent crises. International collaboration has a crucial role in tackling epidemic. The technology company IBM launched a disease-mapping system in October 2014. AirTel and IBM collaboration allowed local people to send free text messages about Ebola to the Government. Heat-maps that link emerging issues to location information were created [24]. In Sierra Leone, the Red Cross has worked in collaboration with AirTel to launch a platform to send informative text messages to people in most affected areas. 2 million people are thought to have been reached via this platform with messages encouraging simple hygiene measures such as regular hand washing and appropriate personal protective equipment when taking care of ill patients at home [25]. This clearly shows the role of mHealth interventions as both preventive and educational. The spread of cholera after 2012 earthquake in Haiti has been mapped by tracking population movements via mobile phone [26]. The Humanitarian OpenStreetMap Team (HOT), an NGO (Non-Governmental Organisation) that works, train, coordinate and organize mapping on OpenStreetMap for humanitarian, disaster response and economic development has mobilized volunteers from around the world to help map since the Haiti earthquake. In the recent Nepal earthquakes, more than 4300 mappers have made 86 000 edits to map, adding up to 30 000 roads and 240 000 building [27]. Imagine mapping all phone signals in a particular devastated area and this helping rescuers to allocate resources to organize help. Mobile phones can actually save lives and an appropriate disaster management plan using mobile phone resources contributes to disaster preparedness of the country. SMS is an effective strategy to raise fund during recovery phase of a disaster. 27 million Euros have been raised for the United Nations Children's Fund (UNICEF) in Italy after the tsunami in December 2004 [28].

However mHealth interventions face many barriers namely:

- Lack of data security
- Difficulties for users in finding the right mHealth solutions
- Devices do not meet clinical requirements e.g. hygiene
- Lack of standardization
- Missing or unknown legitimacy of mHealth publishers
- Mismatch of target group and smartphone owners (elderly/chronic disease)
- Missing regulations
- Patient's discomfort with change in their healthcare routine
- Lack of profitable business models
- Resistance from traditional healthcare providers
- Lack of high quality clinical studies
- Lack of reimbursement for mHealth apps from company funds and insurance
- Lack of interoperability of mHealth app-based solutions
- Lack of high quality mHealth apps

The demand for wearables is on the rise namely with Apple Watch and Samsung Gear. Soon, there will be an overflow of patient data. The tsunami of information presents a challenge for summarizing all data into usable and meaningful format. In Mauritius, a patient Electronic Health Record (EHR) can be used to collect data, follow up on treatment compliance and draft disease management programs on a national as well as an individual basis. The shift toward integrated mHealth intervention is a new strategy for healthcare providers to adopt technology.

4. MAURITIUS EHEALTH START-UP

A survey conducted in Mauritius by the authors, disclosed that, according to patients, doctors have limited time to communicate with them. Furthermore, the waiting time in hospitals is increasing. In several cases, hospitals are perceived by patients to be disorganised. Many patients that were interviewed said that they are frustrated when Doctors ask them the same questions repeatedly. It has also

been observed that patients have reported that they have not been well informed about drug usage and follow ups. Patients are unhappy that their medical folders are not transferred across hospitals and when it is done among some hospitals, the folders get lost all too often in the process. They also complain that their blood results also get lost often in the hospital and it is depressing to have blood samples withdrawn several times.

According to patients the above points constitute the main causes of medical negligence. Moreover the survey disclosed that 66% of patients believe that the current health system is the source of the problem. The issue of medical negligence is further accentuated by poor communication between patients and doctors. The authors later developed Doctor Assistant which is a free Electronic Medical Record (EMR) application available for free from Google Play [29]. The application is now being used by 2240 users worldwide and bears a rating of 4.6 upon 5 among medical apps on Google play (Fig. 1). Doctor Assistant will be published in the WHO Compendium of Innovative Health Technologies 2014-2015. See annexed illustrations regarding Doctor Assistant features. The project has been taken up by the Mauritius Research Council and State Informatics Limited for further development and the main aims of the final software will be.

- Development of a National Healthcare Information System (patient-centered) for Mauritius and for the region, to improve health services in public and private hospitals, as well as for private practitioners
- Provide a common robust and scalable platform to stakeholders of the medical sector, which will enable global visibility on issues and trends, and contribute to an early health warning system through timely access and secured sharing of medical information (Smart Data, Big Data, Data mining, Open Data)
- Conceive a user interface which is adapted and customised for the healthcare sector, with features to minimise human errors and mitigate cognitive overload (Fig. 2)
- Enable self-monitoring of patient in real-time of his/her health status and treatment history
- Support and improve diagnosis and decision making through the use of intelligent algorithms and techniques (out-patient and casualty)
- Make full use of mobile, tablet and cloud technologies to support above objectives (Fig. 3, 4, 5, 6)

Mobile technologies are rapidly becoming an essential part of all healthcare services. Mobile devices will be fully integrated into the way that healthcare is designed and delivered. Mobile phones could become the new stethoscopes. Health-related apps have grown in numbers as well as sophistication and impact, with some 100,000 now on the market and many more to come. Whether it is appointment reminders, video demonstrations, social nudging, coaching interactions of any other potential application, mobile is set to become the consumer healthcare communications centerpiece.

In its wider sense, development is about the re-distribution of wealth and growth, ensuring sustainable livelihoods, integrating people who have been left at the margins of society and bridging the digital divide. ICT is an ‘enabler’ and it will dramatically improve the chances of any given country towards meeting its commitments under the Millennium Development Goals (MDG).

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ANNEXED ILLUSTRATIONS OF DOCTOR ASSISTANT ANDROID APPLICATION

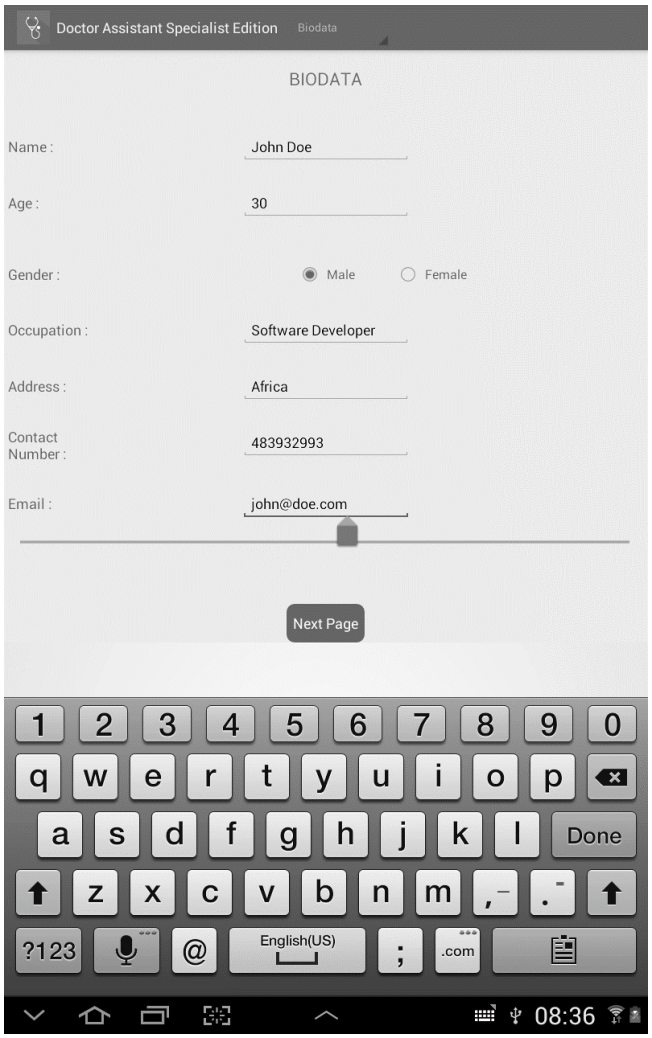

Fig: 1 The Biodata template provides a practical and easily fits clinician's daily use

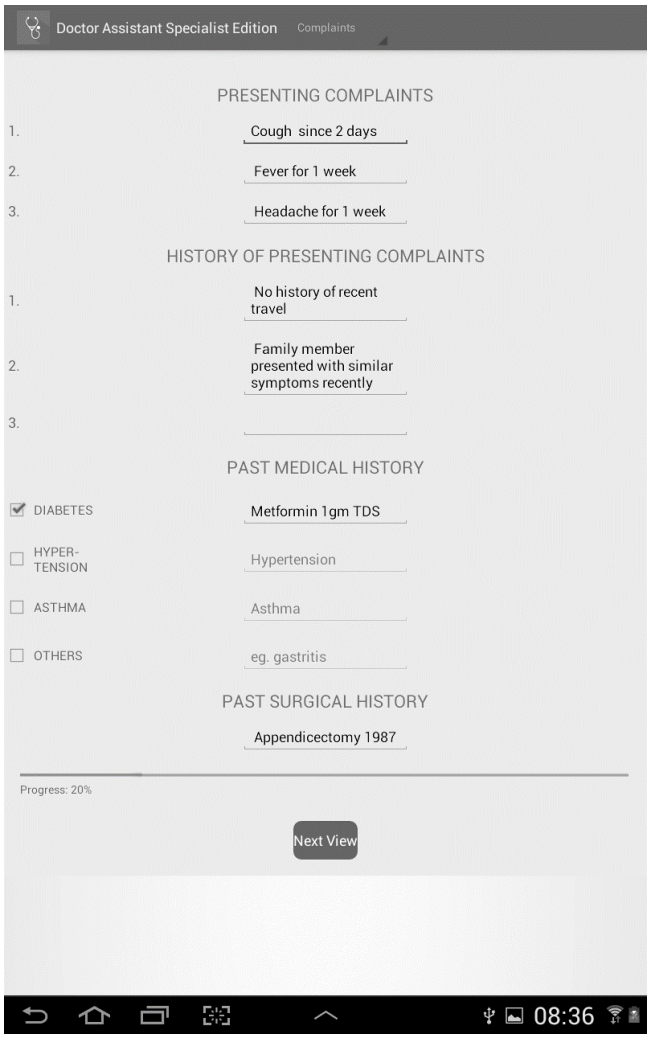

Fig: 2 Medical template helps clinicians reduce medical errors

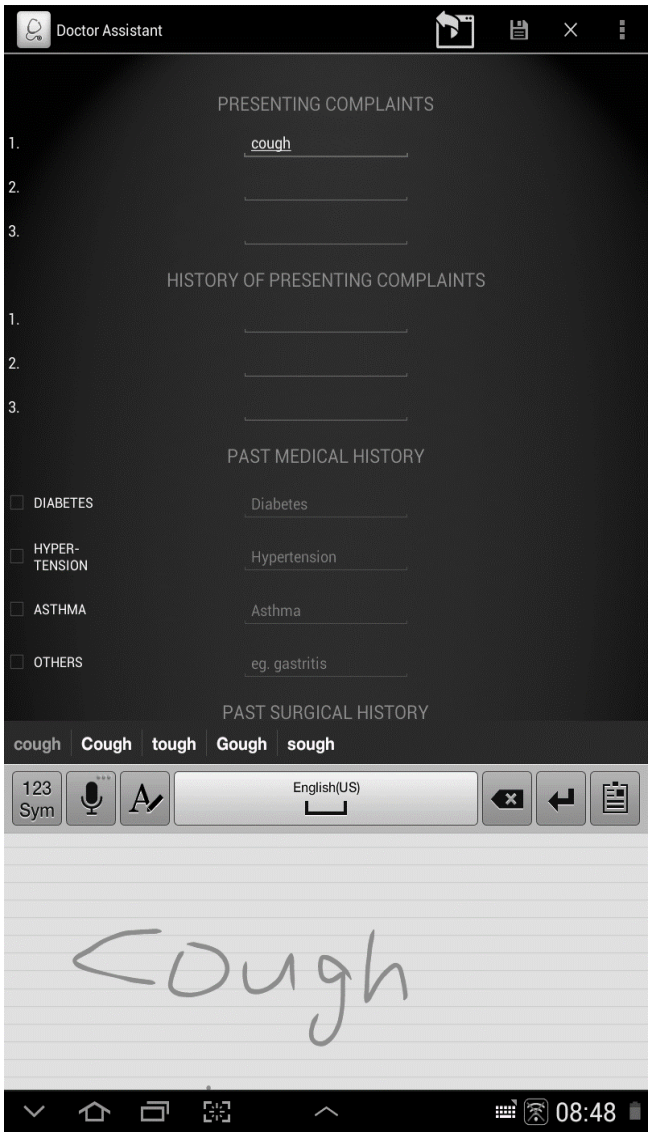

Fig: 3 Handwriting recognition is an integral part of the EMR thus facilitating the task of clinicians

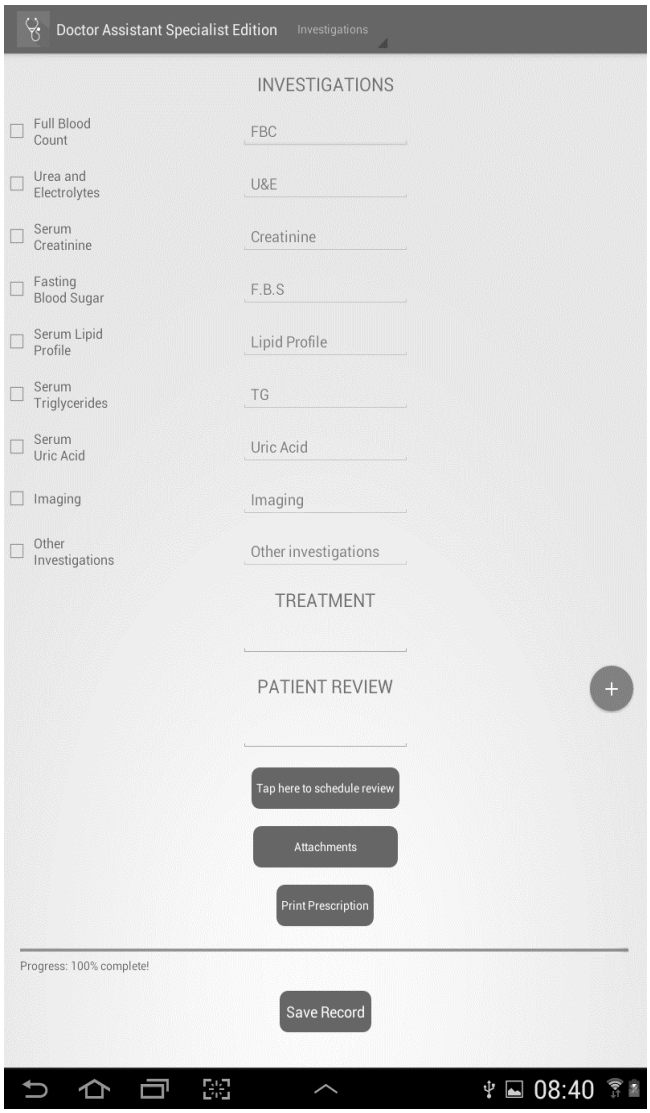

Fig: 4 The final page of the consultation process allows the clinician to schedule an appointment, add attachments and print the prescription using Cloud printing services.

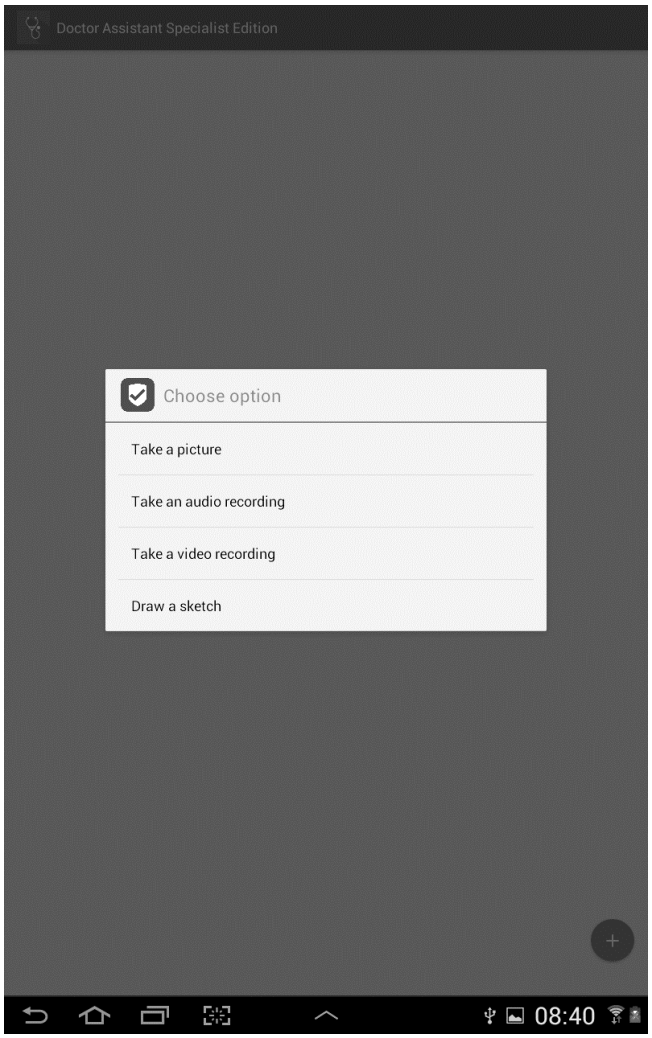

Fig: 5 Attachments which can be made are: Picture, Audio recording, Video recording and Sketch

Fig: 6 Drawing a sketch is a convenient method for clinicians to document findings

ABSTRACTS

Session 1: Trust in the Infrastructure[1]

S1.1 Invited paper: Strengthening Trust in the Future ICT Infrastructure.

Tai-Won Um (Electronics and Telecommunications Research Institute (ETRI), Korea); Gyu Myoung Lee (Liverpool John Moores University (LJMU), United Kingdom); Jun Kyun Choi (Korea Advanced Institute of Science & Technology (KAIST), Korea)

Moving towards a hyperconnected society in the forthcoming "zettabyte" era requires a trusted ICT infrastructure for sharing information and creating knowledge. To advance the efforts to build converged ICT services and reliable information infrastructures, ITU-T has recently started a work item on future trusted ICT infrastructures. In this paper, we introduce the concept of a social-cyber-physical infrastructure from the social Internet of Things paradigm and present different meanings from various perspectives for a clear understanding of trust. Then, the paper identifies key challenges for a trustworthy ICT infrastructure. Finally, we propose a generic architectural framework for trust provisioning and presents strategies to stimulate activities for future standardization on trust with related standardization bodies.

S1.2 Wi-Trust: Improving Wi-Fi Hotspots Trustworthiness with Computational Trust Management.

Jean-Marc Seigneur (University of Geneva, Switzerland)

In its list of top ten smartphone risks, the European Union Agency for Network and Information Security ranks Network Spoofing Attacks as number 6. In this paper, we present how we have validated different computational trust management techniques by means of implemented prototypes in real devices to mitigate malicious legacy Wi- Fi hotspots including spoofing attacks. Then we explain how some of these techniques could be more easily deployed on a large scale thanks to simply using the available extensions of Hotspot 2.0, which could potentially lead to a new standard to improve Wi-Fi networks trustworthiness.

S1.3 WifiOTP: Pervasive Two-Factor Authentication Using Wi-Fi SSID Broadcasts.

Emin Huseynov, Jean-Marc Seigneur (University of Geneva, Switzerland)

Two-factor authentication can significantly reduce risks of compromised accounts by protecting from weak passwords, online identity theft and other online fraud. This paper presents a new easy solution to implement two-factor authentication without affecting user experience by introducing minimum user interaction based on standard Wi-Fi. It has been validated with different software and hardware implementations in a real life environment to show it can easily be deployed in many cases.

S1.4 Vulnerability of Radar Protocol and Proposed Mitigation.

Eduardo Casanovas, Tomas Exequiel Buchaillot, Facundo Baigorria (Instituto Universitario Aeronautico, Argentina)

The radar system is extremely important. Each government must ensure the safety of passengers and the efficiency of the system. This is why it has to be considered by suitable and high-performance professionals. In this paper, we have focused on the analysis of a protocol used to carry the information of the different flight parameters of an aircraft from the radar sensor to the operation center. This protocol has not developed any security mechanism which, itself, constitutes a major vulnerability. Every country in the world is going down this road, relying just on the security provided by other layer connections that could mean a step forward but definitely still not enough. Here we describe different parts of the protocol and the mitigation politics suggested to improve the security level for such an important system.

Session 2 - Trust through Standardization	
S2.1	Raising trust in security products and systems through standardisation and certification: the CRISP approach. *Irene Kamara (Vrije Universiteit Brussel, Belgium); Thordis Sveinsdottir (Trilateral Research & Consulting, LLP, United Kingdom); Simone Wurster (Technische Universität Berlin, Germany)* The need for security systems and related ICT solutions poses new challenges to the individuals in terms of fundamental rights such as the right to privacy. Those challenges generate mistrust at the same time to the end-users. Standardisation and certification can have a significant role in changing the picture and help reinstate the lost confidence. This paper examines the concept of "trust" to ICT employed for security purposes, identifies the needs of the stakeholders and concludes with recommendations for the potential role of standardisation and certification through the implementation of a pan-European seal based on robust standards.
S2.2	Drones. Current challenges and standardisation solutions in the field of privacy and data protection. *Cristina Pauner (Universitat Jaume I, Spain); Irene Kamara (Vrije Universiteit Brussel, Belgium); Jorge Viguri (Universitat Jaume I, Spain)* The issue of drones has burst onto the public agenda due to the rapid expansion from their military and enforcement use to the domestic market where seemingly endless uses appear. This paper is focused on the analysis of the risks to privacy and data protection that arise from these devices and the efforts in Europe to establish a framework to address the problems. The paper's thesis is double: first, the current data protection rules in the European Union (EU) do not adequately cover the implications for civil liberties of the potential use of pervasive aerial surveillance systems and second, the idea that privacy standards have a supportive role to the regulations as they can have added value by mitigating some privacy risks and promoting compliance of the drone operators and data controllers with data protection principles.

[1] Papers marked with an "*" were nominated for the three best paper awards.

Session 3 - Trust in the Cloud

S3.1 Regulation and Standardization of Data Protection in Cloud Computing.

Martin Löhe (Technical University Berlin & Fraunhofer FOKUS, Germany); Knut Blind (Berlin University of Technology, Germany)

Standards are often considered as an alternative form of regulation to legislative rule setting. However, standards also complement legislative acts, supporting their effective implementation and providing precise definitions for sometimes vague legal concepts. As we demonstrate, standards are not mere technical regulations but relate to sensitive political issues. The genesis and contents of ISO/IEC 27018 illustrate the interaction between both forms of regulation in the case of data protection in cloud computing. While the standard has been written with intensive consideration of the legal framework, we argue that the standard could reciprocally influence legal rule-making in the same domain.

S3.2 Autonomic Trust Management in Cloud-based and Highly Dynamic IoT Applications.

Suneth Namal and Hasindu Gamaarachchi (University of Peradeniya, Sri Lanka); Gyu Myoung Lee (Liverpool John Moores University, United Kingdom); Tai-Won Um (Electronics and Telecommunications Research Institute, Korea)

In this paper, we propose an autonomic trust management framework for cloud based and highly dynamic Internet of Things (IoT) applications and services. IoT is creating a world where physical objects are seamlessly integrated in order to provide advanced and intelligent services for human beings in their day-to-day life style. Therefore, trust on IoT devices plays an important role in IoT based services and applications. Cloud computing has been changing the way how provides are looking into these issues. Many studies have proposed different techniques to address trust management although non of them addresses autonomic trust management in cloud based highly dynamic IoT systems. To our understanding, IoT cloud ecosystems help to solve many of these issues while enhancing robustness and scalability. On this basis, we came up with an autonomic trust management framework based on MAPE-K feedback control loop to evaluate the level of trust. Finally, we presents the results that verify the effectiveness of this framework.

S3.3 The Impact of Cloud Computing on the Transformation of Healthcare System in South Africa.

Thembayena Mgozi and Richard Weeks (University of Pretoria, South Africa)

An increasing number of organisations around the world are making use of information and communications technology (ICT) for health (eHealth) to address healthcare challenges. This includes aggregating vast amounts of data from various sources to create evidence for policy and decision making. However, the eHealth initiative in South Africa is hindered by unreliable ICT platforms. This research study is designed to leverage eHealth and propose a conceptual cloud computing model to improve healthcare service delivery. The aim of this research study is to instigate new collaborative efforts for the creation of evidence value-based healthcare system. The findings attest that the sensitive nature of clinical data remains a challenge. Similarly, the South African government should resolve concerns on regulatory frameworks for proper governance of eHealth standards implementation, whilst accelerating healthcare improvements within the public health sector in particular.

Session 4: Advances in networks and services I

S4.1 WhiteNet: A White Space Network for Campus Connectivity Using Spectrum Sensing Design Principles.

Hope Mauwa, Antoine Bagula (University of Western Cape, South Africa); Marco Zennaro (ICTP - The Abdus Salam International Centre for Theoretical Physics, Italy)

To this day, the technical challenges of accessing TV white spaces through spectrum sensing can be summed up into its inability to provide maximum protection to primary users from interference. Yet, off-the-shelf spectrum sensing devices, which are emerging on the market at low cost, and the low computation and implementation complexities of the sensing technique, make them more and more attractive to the developing world. Building upon "WhiteNet", a white space network management platform for campus connectivity, this paper proposes design principles that can be incorporated in a spectrum sensing-based white space identification system to minimise probability of causing interference to primary users. The principles are designed around the cooperative spectrum sensing model to further reduce chances of interference to primary users. Evaluation of the principles was done using real-world indoor measurements and based on a real TV transmitter-allocation at the University of the Western Cape in Cape Town, South Africa. The results reveal the relevance of using these design principles in white space networking using the emerging White-Fi protocol to boost the capacity of current Wi-Fi campus networks.

S4.2 A DCO-OFDM system employing beneficial clipping method.

Xiaojing Zhang and Peng Liu (North China Electric Power University, P.R. China); Jiang Liu (Waseda University, Japan); Song Liu (North China Electric Power University & Waseda University, P.R. China)

The existing clipping researches in direct current biased optical orthogonal frequency division multiplexing (DCOOFDM) systems generally originate from insufficient DC bias and the nonlinear transmission characteristics of physical devices which will distort the system performances. In contrast to conventional clipping theories, the beneficial clipping method demonstrated in this paper aims to improve the transmission effects of DCO-OFDM systems. Using the Bussgang theorem, the signal to noise ratio (SNR) and bit error ratio (BER) of DCO-OFDM systems with the beneficial clipping method are modeled mathematically. It is found that the beneficial clipping method can effectively reduce the system BER, compared with the no clipping situation, when the clipping ratio is mapped over an appropriate range. Also, the optimal clipping ratio changes with variation of the modulation depth. These results illustrate that the beneficial clipping method can enhance the performance of DCO-OFDM systems, although it does introduce clipping noise.

S4.3 Adaptive Video Streaming Over HTTP through 3G/4G Wireless Network Employing Dynamic On The Fly Bit Rate Analysis.

Dhananjay Kumar, Nandha Kishore Easwaran, A Srinivasan, Manoj Shankar (Madras Institute of Technology, Anna University, India); Arun Raj L (B. S. Abdur Rahman University, India)

The smooth video streaming over HTTP through 3G/4G wireless network is challenging as available bit rate in the internet changes due to sharing of network resources and time varying nature of wireless channels. The present popular technique Dynamic Adaptive Streaming over HTTP (DASH) provides solution up to some extent to stored video, but the effective adaptive streaming of a live video remains a challenge in a high fluctuating bit rate environment. In this paper, an intelligent algorithm based on client server model where client system analyses the incoming bit rate on the fly and periodically sends report to server which in turns adapts the outgoing stream as per the feed-back, is proposed. The bit rate analysis process at the receiver estimates the link data rate dynamically by comparing it with some pre-defined pattern. The proposed system was implemented and tested in real-time in CDMA 1xEVDO Rev-A network using internet dongle. An improvement of 37.53% in average PSNR and 5.7% increase in mean SSIM index over traditional buffer filling algorithm was observed on a live video stream. The proposed system was also evaluated on a stored video.

S4.4 Cloud Based Spectrum Manager for Future Wireless Regulatory Environment.

Moshe Timothy Masonta (Tshwane University of Technology & Centre for Scientific and Industrial Research (CSIR), South Africa); Dumisa Ngwenya (Council for Scientific and Industrial Research, South Africa)

The regulatory environment in radio frequency spectrum management lags the advancement of wireless technologies, especially in the area of cognitive radio and dynamic spectrum access. In this paper we argue that the solution towards spectrum Pareto optimal allocation lies with dynamic spectrum management as a policy and regulatory tool for addressing the dichotomy of technical, economic and socio-economic considerations. Different radio frequency bands have different technical characteristics and economic manifestation and, thus, a versatile tool would be desirable to deal with technical, economic and socio-economic objectives in various bands. While approaches based on geolocation spectrum databases and radio environment map architecture have served the cognitive radio and dynamic spectrum access industry, their focus has been on networks and technologies. In this paper we propose a cloud based spectrum manager as a tool focused towards regulatory processes. With the proposed approach it is possible to deal with technical consideration of interference control resulting in achieving economic consideration of reducing rivalry and exclusivity with various spectrum policy and regulatory prescripts. The proposed spectrum manager should be able deal with all regulatory processes favouring cognitive radio and dynamic spectrum access, while enhancing economic value of radio frequency spectrum and achieving socio-economic benefits.

Session 5: Advances in networks and services II

S5.1 Seamless Mobility in Data Aware Networking.

Jairo López (Hitachi Ltd. Research & Development Group, Japan); Mohammad Arifuzzaman (Memorial University of Newfoundland, Canada); Li Zhu, Zheng Wen and Takuro Sato (Waseda University, Japan)

The underlying networks (of the Internet) have been reworked to make way for new technologies, some serious inefficiencies and security problems have arisen. As a result, over the past years, fundamentally new network designs have taken shape and are being tested. In ITU Recommendation Y.3001 [1], four objectives are identified in line with the requirements for Future Network; one of them is data awareness. In ITU Recommandation Y.3033 [2], the 'Mobility' is addressed as one of the key problem spaces of data aware networking (DAN). This paper proposes Named-Node- Networking (3N), a novel architecture for DAN. We design a simulator (nnnSIM) [3] for evaluating our proposed 3N architecture which is the second major contribution of this paper. The nnnSIM simulator is written in C++ under the ns-3 framework [4] and has been made available as open-source software for the scientific community. Considering the importance of a unique DAN architecture, we propose a study for standardization work in the ITU as an initiative which can lead to its rapid adaptation.

S5.2 Proactive-caching based Information Centric Networking Architecture for Reliable Green Communication in Intelligent Transport System.

Quang Ngoc Nguyen, Takuro Sato (Waseda University, Japan); Mohammad Arifuzzaman (Memorial University of Newfoundland, Canada)

In this article, we construct a concrete model as the prototype of efficient and reliable wireless Information Centric Networking (ICN) within the context of Intelligent Transport System (ITS). This research proposes a novel proactive-caching technique in ICN providing the robust and effective content delivery to the mobile nodes (commuters) for transportation system and fitting numerous ICN mobility scenarios of transportation system thanks to our "smart scheduler". We also propose a wireless ICN architecture which can adapt the power consumption of network nodes to the actual values of their optimized utilizations for greening the transportation communication network. Moreover, we identify that there are currently various ICN-based models and emphasize the need of an official international standard for wireless communication in general and transportation system in particular. Then by evaluating our proposal, we show that our proposal is a promising and feasible contribution for the ITU standardization process of Data Aware Networking (DAN) by integrating Green networking into DAN to combine the benefits of innovated rate-adaptivity and proactive-caching based schemes for achieving highly scalable, reliable and energy-efficient network performance in future transportation Information-centric communication system with data-awareness.

S5.3 Network Failure Detection System for Traffic Control using Social Information in Large-Scale Disasters.

Chihiro Maru (Ochanomizu Universiy, Japan); Miki Enoki (IBM Research - Tokyo, Japan); Akihiro Nakao and Shu Yamamoto (University of Tokyo, Japan); Saneyasu Yamaguchi (Kogakuin University, Japan); Masato Oguchi (Ochanomizu University, Japan)

When the Great East Japan Earthquake occurred in 2011, it was difficult to grasp all network conditions immediately using only information from sensors because the damage was considerably heavy and the severe congestion control state occurred. Moreover, at the time of the earthquake, telephone and Internet could not be used in many cases, although Twitter was still available. In an emergency such as an earthquake, users take an interest in the network condition and provide information on networks proactively through social media. Therefore, the collective intelligence of Twitter is suitable as a means of information detection complementary to conventional observation. In this paper, we propose a network failure detection system that detects candidates of failures of telephony infrastructure by utilizing the collective intelligence of social networking services. By using this system, more information, which is useful for traffic control, can be detected.

Session 6: The Need for Speed (Measurements)

S6.1 5G Transport and Broadband Access Networks: The Need for New Technologies and Standards.

Tien Dat Pham, Atsushi Kanno and Naokatsu Yamamoto (National Institute of Information and Communications Technology, Japan); Tetsuya Kawanishi (Waseda University, Japan)

In addition to new radio technologies, end-to-end transport networks will play a vital role in future 5G (and beyond) networks. In particular, access transport networks connecting radio access with core networks are of critical importance. They should be able to support massive connectivity, super high data rates, and real time services in a ubiquitous environment. To attain these targets, transport networks should be constructed on the basis of a variety of technologies and methods, depending on application scenarios, geographical areas, and deployment models. In this paper, we present several technologies, including analog radio-over-fiber transmission, intermediate-frequency-over-fiber technology, radio-on-radio transmission, and the convergence of fiber and millimeter-wave systems, that can facilitate building such effective transport networks in many use cases. For each technology, we present the system concept, possible application cases, and some demonstration results. We also discuss potential standardization and development directions so that the proposed technologies can be widely used.

S6.2 A unified framework of Internet access speed measurements.

Eduardo Saiz, Eva Ibarrola, Eneko Atxutegi and Fidel Liberal (University of the Basque Country, Spain)

The evolution of Internet access technologies, together with the wide diversity of customer devices, has led to a complex scenario where measuring basic metrics with accuracy has become a rather complicated task. Although nowadays there are a lot of tools to assess the rate of Internet speed, most of them share neither the methodology nor the infrastructure to produce comparable results. In this regard, the development of a unified approach to measure the Internet speed would be beneficial for all ICT players. The establishment of such proposal would inspire better confidence in consumers through the provision of precise comparisons, and it would also be very useful to operators, regulators and providers. Towards this aim, the ITU-T has been working on the definition of a unified methodology and measurement framework to assess the rate of Internet speed. This paper presents a detailed description of the work that is being done at present in the definition of the aforementioned framework.

S6.3 Why we still need standardized internet speed measurement mechanisms for end users.

Eneko Atxutegi, Fidel Liberal, Eduardo Saiz and Eva Ibarrola (University of the Basque Country, Spain)

After several years of research towards sophisticated QoS measurement tools and methods, the results given to end users by most commonly used on-line speed measurement tools are still far from being precise. In order to define a reliable Internet speed measurement methodology for end users, the impact that the static and dynamic constraints of network nodes and TCP/IP implementations could impose must be first carefully analyzed. Such constraints will determine the measurement methodology to be defined in terms of measurement periods, number of concurrent connections and convergence time by deployment of controlled simulation/ emulation environments and real world comparisons. This paper presents a detailed description of the works and leaves hints to be followed, aiming to get a full understanding of cross-layer effects during a speed test targeting end-user.

Session 7: Trust but verify!?

S7.1 Connecting the World through Trustable Internet of Things.

Ved P. Kafle (National Institute of Information and Communications Technology (NICT), Japan); Yusuke Fukushima and Hiroaki Harai (National Institute of Information and Communications Technology, Japan)

The Internet of Things (IoT) is envisioned to connect things of the physical world and the cyber world to make humans ever smart by greatly improving their efficiency, safety, health, and comforts, as well as solving numerous challenges related with the environment, energy, urbanization, industry, logistic, transportation, to name a few. Consequently, the IoT has been an important topic of study in the International Telecommunications Union (ITU) for several years in different Study Groups. The new ITU-T Study Group 20 has just been established in June 2015 for further promoting coordinated progress of global IoT technologies, services and applications. In this paper, we review the IoT related activities being pursued in ITU by presenting the IoT reference model. We then describe a number of key requirements the IoT infrastructure should satisfy to make it economically and technologically deployable for useful services and applications. We present some prospective technologies, such as software-defined networking, information-centric networking, and ID-based communication, while pointing out to the related technologies that are worth further study in ITU.

S7.2 Is Regulation the Answer to the Rise of Over the Top (OTT) Services? An Exploratory Study of the Caribbean Market.

Corlane Barclay (University of Technology Jamaica, Jamaica)

Over the Top (OTT) content has seen unprecedented growth in recent years that has disrupted the traditional telecommunication business model. As a consequence, countries have offered different regulatory responses. The Caribbean market has seen similar evolution in OTT content which has transformed the telecommunication market and has influenced the growth in access to technology. An analysis of this market has seen fractured regulatory responses with the telecommunication providers chiefly driving the process. It is argued that such an approach may result in an unbalanced ecosystem, limited consumer protection with privacy and security concerns. The purpose of this paper is to report on the regulatory responses in key countries in the Caribbean and propose a regulatory framework that may aid in the effective management of OTT services and its evolution in the region. The framework considers the perspectives of the multiple stakeholders including regulatory agencies, telecos and customers and includes domain understanding, OTT understanding, regulatory process understanding, regulatory design and development, evaluation, implementation and review and monitoring stages.

Session 8: Establishing Trust for Networked Things

S8.1 Invited paper: A Required Security and Privacy Framework for Smart Objects.

Antonio Skarmeta, José Hernandez-Ramos, Jorge Bernal Bernabe (University of Murcia, Spain)

The large scale deployment of the Internet of Things (IoT) increases the urgency to adequately address trust, security and privacy issues. We need to see the IoT as a collection of smart and interoperable objects that are part of our personal environment. These objects may be shared among or borrowed from users. In general, they will have only temporal associations with their users and their personal identities. These temporary associations need to be considered while at the same time taking into account security and privacy aspects. In this work, we discuss a selection of cur- rent activities being carried out by different standardization bodies for the development of suitable technologies to be deployed in IoT environments. Based on such technologies, we propose an integrated design to manage security and privacy concerns through the lifecycle of smart objects. The presented approach is framed within our ARM-compliant security framework, which is intended to promote the design and development of secure and privacy-aware IoT-enabled services.

S8.2 Smart Doorbell: an ICT Solution to Enhance Inclusion of Disabled People.

Lucas M Alvarez Hamann, Luis Lezcano Airaldi, Maria E Báez Molinas, Mariano A. Rujana, Juliana Torre, Sergio Gramajo (Universidad Tecnológica Nacional - Facultad Regional Resistencia, Argentina)

In daily life, people have the need to know the identity of a visitor who comes to their homes, regardless of whether they are there at that time. This need is even greater for people who suffer from some kind of disability that prevents them from meeting the visitor. To provide a solution in this sense, this paper proposes a smart model that performs the task of a doorbell, which should recognize the visitor and alert the user. To achieve that, this proposal incorporates technologies for facial recognition of people, notifications to users and management of their responses. The process to solve the problem was divided into interrelated stages and standardization issues are discussed later. Finally, to test the effectiveness of the model, three scenarios were simulated; each one was composed by different households over which the recognition of known and unknown individuals was analyzed.

Poster Session

P.1 MUNIQUE: Multi-view No-Reference Image Quality Evaluation.

José Vinícius de Miranda Cardoso (Federal University of Campina Grande - UFCG, Brazil); Carlos Danilo Regis (IFPB & Iecom, Brazil); Marcelo S. Alencar (Federal University of Campina Grande & Institute for Advanced Studies in Communications, Brazil)

This paper presents a novel no-reference objective algorithm for stereoscopic image quality assessment, called MUNIQUE, which is based on the estimation of both two dimensional and stereoscopic features of images, namely local estimations of blockiness and blurriness and the disparity weighting technique. Applications of stereoscopic image and video quality assessment in surveillance systems are discussed. Simulation results using LIVE 3D Image Quality Database Phase I, which includes Gaussian blur and fast fading degraded images, are presented and a comparison of performance of MUNIQUE with several state of the art algorithms is made. Correlation coefficients between subjective and predicted scores indicate a superior performance of the proposed algorithm, when it is compared with others no-reference algorithms. An implementation of the proposed algorithm coded in C# programming language is publicly available at: https://sites.google.com/site/jvmircas/home/ munique.

P.2 A presentation format of architecture description based on the concept of multilayer networks.

Andrey Shchurov and Radek Marik (The Czech Technical University in Prague, Czech Republic)

Formal methods based on abstract models are becoming more and more important in the domain of complex computer networks. On the other hand, processes of design documentation transformation into the formal models are still bound to the skills and ingenuity of individual engineers. Moreover, the human factor involved in data transformation represents a major bottleneck due to the tendency of computer networks to be more and more complex. To address this problem, this work introduces a possible appropriate presentation format of architecture descriptions as a part of detailed design documentation that could allow automated development of trusted formal models for analysis and verifying of complex computer networks.

P.3 Privacy, Consumer Trust and Big Data: Privacy by Design and the 3C's.

Michelle Chibba (Privacy and Big Data Institute, Ryerson University, Canada); Ann Cavoukian (Ryerson University, Canada)

The growth of ICTs and the resulting data explosion could pave the way for the surveillance of our lives and diminish our democratic freedoms, at an unimaginable scale. Consumer mistrust of an organization's ability to safeguard their data is at an all time high and this has negative implications for Big Data. The timing is right to be proactive about designing privacy into technologies, business processes and networked infrastructures. Inclusiveness of all objectives can be achieved through consultation, co-operation, and collaboration (3 C's). If privacy is the default, without diminishing functionality or other legitimate interests, then trust will be preserved and innovation will flourish.

P.4 SOSLite: Lightweight Sensor Observation Service (SOS) for the Internet of Things (IoT).

Juan Vicente Pradilla, Carlos E Palau, Manuel Esteve (Universitat Politècnica de València, Spain)

The importance and reach of sensors networks grows every year, however, there are still many challenges that must be addressed. One of them, is the standardized interchange of information that enable interoperability between different networks and applications. To answer this challenge, the Open Geospatial Consortium (OGC) has created the Sensor Web Enablement (SWE) specification. SWE has given place to different mature implementations for the enterprise sector; however, they are usually over dimensioned alternatives that require robust systems. This differs from the capacity of small sensors networks like those used in domotics or eHealth, which are part of the Internet of Things (IoT). This work proposes a Sensor Observation Service (SOS) implementation, which is one of the fundamental components of the SWE specification, that fits small sensors networks environments and that does not require very robust systems to operate, thus providing a standard and agile platform. This implementation of the Sensor Observation Service provides independence from manufacturers and heterogeneous sensors networks, increasing interoperability because information is transmitted in a standard structure and through well defined software interfaces. It also allows installation in devices of small capacity and low power consumption, reducing deployment costs and encouraging massive deployment of sensors networks and the Internet of Things (IoT).

P.5 Future Mobile Communication Services on Balance between Freedom and Trust.

Yoshitoshi Murata (Iwate Prefectural University, Japan)

Some applications introduced in each 5G mobile communication project (5G-P) assume special use cases such as when many people simultaneously use their mobile phone in a restricted area like a stadium or when using traffic safety systems are in common. And, some of them such as mobile healthcare and the Internet of things (IOT) have already been presented by many people. However, the reasons those applications will be widely used are uncertain. And then, most authors of articles related to future mobile communication made no mention of business schemes such as who deploys network infrastructure or who provides service content. However, the histories of existing mobile communication markets may show applications that are different from the ones written in the above articles and new business schemes that are different from existing ones. In this article, I analyze the dominant non-voice applications of the existing mobile communication systems including paging services and identify the primary factors that made them dominant. I also analyze the business models of the network carriers. This analysis leads me to forecast that the next-generation of dominant mobile communication applications will be developed on the basis of a balance between the freedom of participants and suspicion, and the business models will become more liberal. Moreover, I forecast that a service that comes after SNS messaging services will be the one in which experiences are shared.

P.6 Mauritius eHealth - Trust in the Healthcare Revolution.

Leckraj Amal Bholah (University of Edinburgh, United Kingdom); Kemley Beharee (University of Mauritius, Mauritius)

The aim of eHealth infrastructure is to harness innovations in digital infrastructure that can enable the seamless access to, sharing and reuse of data (e.g. clinical records, genomic data and images) irrespective of source [1]. eInfrastructure is comprised of networked, interoperable, service-oriented, scalable computational tools and services. The key element is the interaction of human users and computers so as to facilitate discovery, linking and reasoning [2].

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