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ACADEMIC CONFERENCE

Challenges for a
data-driven society

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Foreword

Chaesub Lee
Director
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The long-term vision of academia helps ITU to prepare for the future. At Kaleidoscope 2017, we saw that our future will be built on the smart use of data. 2017 will produce more data than the entire history of humanity. In our knowledge-driven modern economies, this data is quickly becoming our most valuable natural resource. Data will fuel innovation in all industry sectors and public-sector bodies. ITU’s standardization sector aims to provide the technical foundations of this innovation.

*Kaleidoscope 2017: Challenges for a data-driven society* called for original academic papers investigating the technical, business and policy challenges underlying effective data management and analysis. The conference encouraged the development of data-driven applications and services of benefit to society. It highlighted the importance of a shared, integrated data ecosystem in maximizing the collective benefits to be drawn from our fast-growing wealth of data.

The Kaleidoscope conference is ITU’s flagship academic event. Now in its ninth 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 ICT standardization experts. The conference identifies emerging trends in ICT research and associated implications for international standardization.

I would like to extend my gratitude to all of Kaleidoscope’s participants for their invaluable support to this series of academic conferences. Academic and research institutes are longstanding contributors to the work of ITU, a productive relationship that was formalized with the introduction of an ITU Academia membership category in 2010. Academic and research institutes are now able to participate in all areas of ITU work for a very modest fee. Over 150 academic and research institutes have become ITU members to participate in ITU’s expert groups alongside policymakers and industry-leading engineers and business strategists.
I would like to thank our generous sponsors of Kaleidoscope 2017, Jiangsu Institute of Communications, New H3C Technologies, Nanjing Fiberhome Starrysky, and Nanjing Ironhorse Information Technology; our technical co-sponsors, the Institute of Electrical and Electronics Engineers (IEEE); the IEEE Communications Society; and the International Conference on Standardization and Innovation in Information Technology (SIIT 2017). I also thank our supportive partners, the Chair of Communication and Distributed Systems at RWTH Aachen University; Chongqing University; Chongqing University of Posts and Telecommunications; the Competition Law Center of the University of International Business and Economics; the European Academy for Standardization; Hubei University; the Institute of Computing Technology of the Chinese Academy of Science; the Institute of Electronics, Information and Communication Engineers of Japan; the Institute of Image Electronics Engineers of Japan; Royal Holloway University of London; UNESCO Chair in ICT for Development; University of the Basque Country; Waseda University; and Zhejiang University. Let me also express my deep gratitude to our dedicated Steering Committee and Technical Programme Committee members; and, of course, our distinguished Chairman of Kaleidoscope 2017, Zhen Yang, President of Nanjing University of Posts and Telecommunications, China.

Chaesub Lee
Director
ITU Telecommunication Standardization Bureau
I would like to express my appreciation to ITU for selecting Nanjing University of Posts and Telecommunications as the host of Kaleidoscope 2017, a conference which addressed a topic of critical importance to our future as society.

Data is becoming the key to smart governance, supporting the delivery of citizen-centric public services. Data-driven insight will enable efficiency gains in every industry sector. Advances in data science will continue to unlock major breakthroughs in research. We saw all of these possibilities in the papers presented at *Kaleidoscope 2017: Challenges for a data-driven society*.

The Kaleidoscope 2017 Technical Programme Committee, chaired by Kai Jakobs of RWTH Aachen University in Germany, selected 23 papers from the 63 submissions received from 22 countries. The committee selected papers on the basis of double-blind reviews with the help of almost 80 international experts. The committee 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.

Kaleidoscope 2017 featured two distinguished keynote speakers. Jianhua Zhang, Professor of Beijing University of Posts and Telecommunications, China, gave a talk on data-driven future wireless communication. Fei-Yue Wang, Professor of Chinese Academy of Science and Secretary-General of the Chinese Association of Automation, spoke on emerging trends in autonomous driving in China.

In addition to selected papers, Kaleidoscope 2017 hosted one invited paper authored by Liu Duo, President of China Academy of Information and Communication Technology (CAICT)) on the legal challenges most relevant to our modern data-driven society.

Considering the state of today’s technology and the extraordinary possibilities appearing on the horizon, Jules Verne’s corner at this year’s Kaleidoscope conference focused on the “Quantum revolution”. Yuao Chen, professor of the University of Science and Technology (USTC), China, introduced his experience as the Leader of the Beijing-Shanghai Quantum Communication Project and highlighted its main achievements.
The conference also featured a special session and tutorial.

The special session presented ITU standardization work on future networks as well as data processing and management for the Internet of Things and Smart Cities & Communities. The session featured four expert panelists. Jun Kyun Choi, Korea Advanced Institute of Science and Technology, presented on “Open data platform and ITU-T Focus Group on Data Processing and Management to support IoT and Smart Cities & Communities”. Subin Shen, Nanjing University of Posts and Telecommunications, China, presented on “Blockchain and its possible related standardization work for the IoT”. Shao Weixiang, ZTE, China, presented on “How to make the interoperability of IoT data”. Ved Kafle, National Institute of Information and Communications Technology, Japan, and Rapporteur in ITU-T Study Group 13, presented on “Future network technologies for placement of IoT data and processing functions”. Ved Kafle also organized and ran a tutorial on the prospect of academic contributions to ITU standardization, highlighting potential for researchers to have their work incorporated into international standards.

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 Standards Magazine*. Extended versions of Kaleidoscope papers are also considered for publication in special issues of the International Journal of Technology Marketing, the International Journal of Standardization Research, and the Journal of ICT Standardization.

All accepted and presented papers have been submitted for publication in the IEEE Xplore Digital Library. The Kaleidoscope Conference Proceedings from 2009 onwards can be downloaded free of charge from [http://itu-kaleidoscope.org](http://itu-kaleidoscope.org).

I would like to thank our sponsors and technical co-sponsors, our supportive partners and Alessia Magliarditi and her team from ITU for playing the leading role in the year-on-year progression of the Kaleidoscope series of academic conferences.

Zhen Yang
President of NJUPT
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KEYNOTE SUMMARIES
DATA-DRIVEN FUTURE WIRELESS COMMUNICATION

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Besides supporting the traditional requirement of large-area coverage and high-data rate transmission services, IMT-2020 defined by ITU-R is also expected to supply smart and reliable interconnection among humans and things. Thus, the vision of IMT-2020 presents the convergence of wireless communication, Internet, Internet of Things (IoT) and machine-type communication (MTC), which together brings an explosive increase to traffic volume and stimulates wireless communication to the time of big data. Obviously, such vision poses big challenges to 5G and future wireless communication. This keynote speech discusses the application of computer science into future wireless communication, especially data mining techniques to accelerate the wireless research and development. Firstly, the big data tendency of wireless communication is presented and the possible ways to combine them are pointed out. In particular, a three-level structure of a wireless system is defined in order to classify the propagation environments, which will bring the complex combination into simplicity. Considering these three levels, there are different tasks like service prediction and pushing, self-organized networking, self-adapting large-scale fading modeling and so on, which can be abstracted into problems like regression, classification, clustering, etc. Since there are many powerful algorithms in the data mining domain to accomplish them, we can expect a data-driven future wireless communication to make our lives and society convenient.
The accelerated development of AI brings new opportunities for human life and social improvement. For promoting the holistic integration of AI and economic society and further enhance China's innovation capacity in intelligence technologies, the Chinese government has launched a major R&D program in AI, within the framework of "Science and Technology Innovation 2030", a national science and technology strategic development plan. The goal of this program is to explore the next generation AI theory and technology, and to focus on five areas: big-data-based AI, internet-based crowd intelligence, cross-media intelligence, hybrid augmented intelligence, and autonomous-intelligent systems.

Additionally, in 2008 the National Natural Science Foundation of China (NSFC) launched a major research plan on Cognitive Computing of Visual and Auditory Information (2008-2017), the total expenditure of this plan is about $27M. In this research program, autonomous vehicles have been used as an integrated verification platform for the study of new cognitive computing models. Since 2009, NSFC has held annual autonomous vehicle competitions, called Intelligent Vehicles Future Challenge (IVFC). This keynote speech will give an overview of the Chinese perspective and practice on developing AI and related connected and autonomous vehicle research activities in the last decade. It will also discuss the promising transition from cognitive intelligence towards cyber-physical-social systems (CPSS) based parallel intelligence. On the basis of parallel intelligence, parallel driving aims at offering a unified approach for synergizing connected automated vehicles as well as intelligent transportation.
SESSION 1

TOWARDS A UNIVERSAL, SHARED AND INTEGRATED DATA ECOSYSTEM FOR THE BENEFIT OF ALL

S1.1 Invited paper: Legal challenges for the data-driven society
S1.2 Open data & digital identity: Lessons for Aadhaar
S1.3 Open data development of countries: Global status and trends*
LEGAL CHALLENGES FOR DATA-DRIVEN SOCIETY

Liu Duo
President, China Academy of Information and Communication Technology (CAICT)

ABSTRACT

A legal system should bring to society expectations of stability, and should balance rights and obligations. But the emergence of revolutionary new technologies can change and even break the current order and balance. Big data applied to the everyday life of people is such a technology: it is deemed to create a brand new social paradigm bringing about entirely different perspectives in people's observations of the world. This poses a challenge to the existing legal system, such as how to balance the utilization of big data and the security of data resources, and the exploitation of the data available and the protection of personal privacy. Other challenges concern how to determine the ownership of data, and how to determine the rights and obligations in exchange of data.

This paper mainly discusses the changes that big data is bringing to society and the legal challenges that the data-driven society will be confronted with. It puts forward suggestions regarding the development and security of big data industry, protection of personal privacy through the establishment of commercial rules for big data and through international coordination mediated by international organizations.

Keywords – Big data, data-driven society, international organizations, legal challenges

1. SOCIAL CHANGES DRIVEN BY BIG DATA

Big data ushers in a new age and gives rise to a number of social changes, including our way of living and thinking, social relationships, associated rights and obligations, and social governance needs. Big data changed the form and content of data production and information processing, which directly changed human life and production. The use of big data has created new rights and expanded the scope of rights further. Big data has also brought about changes of public management, which has in turn provided the impetus for related public policy decision making.

1.1. Formation of a data-driven society

Along with the development of mobile Internet, social media networks, cloud computing, Internet of things and other innovations, human society is entering an age of big data and a data-driven society is taking shape, with data production and its utilization acquiring a more and more prominent impact and role.

(a) Intensive or instantaneous data interaction becomes a way of living

Human society is now producing unprecedented large amounts of data; modern people are surrounded by a visible physical environment and an invisible environment of data, with the latter being just a basic state. In everyday life, vast amounts of information is produced, stored and exchanged as data to provide the base and substance for data-based life.

(b) Data resource becomes an important social resource

Considering the huge value to be derived from data, data resources are also an important social resource, being present everywhere and bringing endless innovation. Data will be the oil of the 21st century, and like other basic resources, data will have specialized producers, users, managers, and regulators. There will be a sector that acquires value from data production, while the capability to make use of data is a kind of core competitiveness for a country, society, businesses, and individuals.

(c) Data quantification becomes a way of thinking

Big data tends to make people think on a quantitative basis and gives rise to a new way of thinking that focuses on data and highlights statistics, quantification and relevant logic. As a result, people can retrieve, explore and analyze large amounts of data to find out more about complicated social and natural phenomena, to carry out valuable behavior prediction, trend forecasts and value analysis, and to also provide the basis for governments, businesses or individuals to make decisions in a more objective and scientific manner.

1.2. Expansion of rights and obligations in the data-driven society

Data has been produced since the beginning of human civilization, but it was not in a digitized form until the invention and application of information technology. Big data technology enables an unprecedented scale of data production, as well as an expanded scope of data utilization, and big data mining gives a value to data that otherwise
would have been useless; and such data, with value acquired, gives rise to new social relationships, around which new rights and obligations are formed.

(a) Data ownership

For the purpose of accurate and precise analysis for different industries and sectors, a premise is to collect data in connection with all participants. That is to say, the application of big data relies on an open data environment, namely, data produced by an individual in a network shall be readily accessible to other persons at any time. However, a core question arises: does the participant whose data is used own his data? In practice, such ownership may be disputed, but for sure, opening and using data will result in new rights and obligations in connection with data ownership.

(b) Right to data

Big data has been widely applied to facilitate the government to carry out social governance and provide public service, and as a result, open government data is an important issue across the world. Globally, the government tends to formulate guiding strategies or policy documents for open government data. For instance, in 2009 and 2013, US President Obama twice signed the open data executive orders; in 2010 and 2011, the UK twice published the Letter to Government Departments on Opening up Data, and the Chinese government also promulgated a series of national policies, including the Action Plan to Promote Big Data Development. As for the form, generally, data is opened at a single national portal, and for the present, such data platforms have been established in about 52 countries and regions. In such a context, a new concept of civic right is derived, i.e. the right to data. More and more countries and governments begin to attach importance to this right and consider it as fundamental and as important as other civic rights. To highlight this right is to allow the public to obtain any data without involving state security and secrecy. Moreover, the right to data also fairly reflects the degrees of social democracy and government openness.

(c) Data privacy

People produce and leave their digital footprints anytime and everywhere. These traces, if gathered and combined can reveal every aspect of a person’s life. Undoubtedly, personal privacy is involved in such traces of data. If the right to data is still characterized by traditional invisible property in many aspects, the lack of privacy arising from data footprints results in rights and obligations that are totally new.

1.3. Transformation of public policy making

In terms of social governance, the primary value of big data is to enable more scientific decision making. Recent practice in some countries indicates that big data can motivate the government, social organizations, businesses, and individuals to jointly participate in public policy making and to facilitate the government to pay due attention to the predictability, public participation and objectivity of public decision making.

(a) Predictability

The government always prefers a public policy to be predictable, while big data analysis technology can help to identify trends and establish a mechanism for a more effective and timely forecast of public affairs. The UN Global Pulse is a program using big data to monitor and analyze the sentiment of Twitter and Facebook data and text messages across the world and to provide an early warning of disease, turbulence or racial conflicts.

(b) Public participation

A characteristic of big data is that it is derived from scattered individuals that are connected in real-time. The collected data can be used to explore more valuable information. The advantage of policy makers is that, with big data, some public administration policies, previously dominated by governments only, now can be decided through collaboration between the government and social organizations. By involving all stakeholders in the process of policy making and allowing social organizations and individuals to participate in public administration, the government can effectively define public policy.

(c) Objectivity

Through data collection and in-depth quantitative analysis, big data can discover previously unknown relevance. Thus, objective data can be used to predict probabilities and changes, analyze trends, and provide a more objective basis for decision making. With regard to government administration, prior to the age of big data, mass data collection and processing was difficult; the government possessed more data than other social organizations and individual persons, but only to a limited extent, and its policy making had to be based on limited sample statistical data and rely heavily on personal experience and judgment. In contrast, the application of big data technology will provide policy making with a more objective basis, reduce personal subjective errors, and contribute to scientific policy making and efficient government administration.
2. MAJOR LEGAL CHALLENGES

As mentioned earlier, the rapid development and wide application of big data has had profound impacts on every aspect of society, and in particular, in light of the ongoing development of the global digital economy, the exploitation of data not only motivates social changes, but also challenges the social order and puts forth new requirements for legal systems. On the one hand, traditional issues, such as open government data and personal data protection, are facing new challenges in the context of big data; and on the other hand, in recent years, with the development of a data-driven society, some new issues, such as data exchange and cross-border data flows, have attracted attention from all parties.

2.1. Open government data

Open data is the prerequisite and basis for the development of big data, and the government possesses over 80% of the entire social information resource and is the largest data producer and owner. The openness of government data has a substantial effect on data development and utilization and is the number one problem to be resolved in the data-driven society.

In the early stages, the focus used to be on government information disclosure on the improvement of government information transparency. However, with the development of information and communication technology and big data technology, people began to realize that opening up government information, on the one hand, can consolidate democracy and public participation, and on the other hand, in an electronic form, government information is an important national resource that has significant economic and social value and plays an important role in enhancing government service efficiency, promoting economic growth and creating jobs. Currently, opening up government data has become an appeal for more and more people and an important consensus for the international community.

Globally, in January 2009, US President Obama signed the Memorandum on Transparency and Open Government, taking the lead to open up government data, and thereafter, a rising number of countries has joined in, and government data was opened up to a wider and deeper extent. On September 5, 2015, the Chinese Central Government published “Action Plan to Promote Big Data Development”. The plan proposed comprehensive requirements on key areas such as, open mechanisms, open platforms, and open criteria. It is also suggested in the plan to promote the opening of public data resources under the premise of strengthening security and privacy protection. Despite some achievements, currently there are still many challenges for opening up government data.

Firstly, according to the self-assessment by the United States and other forerunners, these countries are bottlenecked by inadequate awareness, poor policy implementation and absence of detailed criteria and thus prevented from deepening open government data and releasing higher data value.

Secondly, the gap between developed countries and developing countries is further widened. According to the “Global Open Data Index” published by the international non-profit Open Knowledge Foundation, in recent years, countries in Asia, Africa and Oceania have actively joined the open government data initiative, but are lagging far behind developed European and American countries, and the survey indicates that of the top 10 countries and regions, 9 are European and American countries.

Thirdly, most countries fail to define the elements in connection with open government data, including the principles, platforms, data management systems (such as data resource catalogue, open data catalogue and public participation mechanism), data reuse licenses, costs and charges, etc.

2.2. Data exchange

In recent years, big data applications have been rapidly penetrating various industries and sectors, with the value of data resources, as a production factor and social wealth, becoming increasingly recognized. Also, there has been a rising demand for online data exchange. Since 2008, the global big data exchange market has been taking shape, and several “data markets” and “data banks” have appeared. According to the White Paper of China’s Big Data Industry in 2016, the global big data industry in 2015 amounted to US$ 140.3 billion, and by 2020, this figure is expected to be up to US$ 1027 billion. As data trading develops so fast in China, the State Council published the “Action Plan to Promote Big Data Development” in 2015. According to the plan, the establishment of a data transaction market will be an important part of strengthening market mechanisms. The plan promotes the development, support, guidance and standardization of the mechanisms for data transactions and its exchanges in the whole country.

With the continuous expansion of data transactions, many problems are emerging. For the moment, data exchange faces mainly the following problems:

1. Sound legislation and regulation on data exchange is not yet in place. Across the world, so far there is no specific law and regulation on data exchange and the legal basis is not clear as to what data can be exchanged and how it can be exchanged. Meanwhile, no authority is clearly assigned to supervising data exchange, with access to data exchange market, data security, data abuse, data exchange disputes and other issues being poorly regulated, and to avoid risks, some data owners, including the government, tend to refrain from data exchange. Moreover, given the new circumstances, laws, and regulations in connection with data exchange,

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personal information protection, cross-border data flows and other related issues, need to be enacted and refined; see the detailed discussion below.

2. Data ownership is not yet defined. Without a consensus on ownership, it is impossible to decide which law is applicable to data, ownership law, property law or intellectual property law? Data rights as a subject has also not yet been decided.

3. Criteria for data exchange are absent. On the one hand, there are a variety of patterns of data exchange platforms, and each of them formulates its own rules, and is confined by limited data standardization, hidden blind areas and misconceptions, with few valuable applications available. At the same time, data exchange lacks a sound registration and clearing system, and resources of respective platforms cannot be integrated in any effective manner. On the other hand, the value of a data asset is hard to be assessed. The market lacks a standard pricing approach, with prices being decided in accordance with property rights, intellectual property rights or revenues.

Data exchange is an important means for an enterprise to turn data resources into corporate assets and to enhance competitiveness. In particular, in the digital economy, data has become an important means of production; therefore, without solving the exchange and circulation problems, businesses will be hindered from further development, and the process of digitalization for the entire society will be affected as well.

2.3. Personal data protection

At present, new technologies and businesses, rapidly growing and data-based, have totally transformed the applicable environment for personal information protection. The advance of big data technology enables the wide application of collection, processing and analysis of mass personal data, with governments and businesses becoming increasingly reliant on intensive data analysis (economic and social statistical analysis by the government, and business marketing by enterprises). Such activities, based on big data analysis, make the traditional society more transparent, imposing an unprecedented impact upon personal information protection and threatening personal rights.

Firstly, due to data mining and analyzing technologies, now it is more likely for data to be used, with an increased around risk when data is to be collected and applied, and when data becomes a strategic resource, businesses are highly motivated to collect information. Driven by commercial interests, the basic principles of limitation and necessity, as set forth in the law on personal information protection, have been repeatedly breached in practice, and too often mobile APPs have collected user information beyond the purpose and scope of business.

Secondly, big data makes the border between personal and non-personal information more ambiguous. Prior to the age of big data, a great amount of data could remain anonymous, while in the present digital economy, the types of data are expanding, the development of software algorithms and analytics makes it easier for mass data to be associated and aggregated and serves to greatly strengthen the businesses’ capacity of turning non-personal information into personal information.

Thirdly, in a big data environment, personal information protection is under the full impact arising from the uneven distribution of the power of data control and the conflict of interest of data use by individual persons, public and private organizations.

At the end of 2012, the Standing Committee of NPC passed the “Decision of Reinforce Protection of Internet Information”. This is the first time in China that the protection of information security of citizens and corporations has been regulated at the law level. It also includes regulations about online identity, rights and responsibilities of different parties. At the end of 2016, the Cybersecurity Law was passed. The definition and scope of personal information, the principles of collecting personal information, and the responsibilities of relevant subjects have been regulated in Cybersecurity Law. But in practice, it is not rare to see the trading of personal data for commercial benefit. Consequently, relevant departments should reinforce enforcement to protect people’s personal information security.

Overall, personal information protection has become a core issue for the digital society, and how to balance personal information protection and socioeconomic development will be critical for the development of the future data-driven society.

2.4. Cross-border data flows

Following the rapid development of global digital commerce and economy and ongoing trade liberalization, regulations on cross-border data flows are becoming a focal issue for all stakeholders. In the report on Data protection regulations and international data flows: Implications for trade and development, UNCTAD has pointed out that “International data flows are increasingly important for trade, innovation, competition and data mobility for consumers. However, there is also a general consensus that the movement of data cannot be completely unrestricted if legitimate concerns are to be addressed. To promote compatibility, it is important to avoid duplication and fragmentation in the regional and international approaches to data protection.”

However, with different appeal and focus, countries have two contrasting attitudes toward cross-border data flows:

On the one hand, some countries, typically the United States, have been calling for cross-border data mobility to promote a global digital economy. In 2012, the United States and the

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Republic of Korea signed a *Free Trade Agreement* and provided for the rules of cross-border data flows in the Chapter of Electronic Commerce, agreeing that the Parties shall endeavor to refrain from imposing or maintaining unnecessary barriers to electronic information flows across borders. In 2014 and 2016, the United States twice submitted electronic commerce proposals to the WTO, both mentioning free cross-border data flows.

On the other hand, after the PRISM Incident in 2013, in order to protect personal data, prevent foreign surveillance and safeguard national security, the EU, Russia and more and more other countries began to tighten the restriction of cross-border data flows and adopt their own data enactments. The EU *Data Protection Directive 1995* and the *General Data Protection Regulation* (GDPR) 2016 all explicitly prohibit data transfer to a country without adequate regulations on data privacy protection. In 2014, Russia amended the *Federal Law on Data Protection* and the *Federal Law on Information, Information Technology and Information Protection* and established the rule of localized storage of Russian data, requiring that personal data of Russian citizens must be stored at servers within the territory of Russia.

In China, the general rules for the cross-border flow of data have been regulated by the Cybersecurity Law, Credit Reporting Industry Regulation and other related laws and regulations. According to the Cybersecurity Law, personal information and important data which is made or collected during the operation of critical information infrastructure must be stored in China. If it is necessary to transfer it outside of China for business purposes, the safety assessment must be carried out in accordance with the measures made by the Cyberspace Administration of China in conjunction with the relevant departments of the State Council. In accordance with the Credit Reporting Industry Regulation, the credit reporting agencies must arrange, preserve and process information collected within the territory of China. Besides, data on personal finance or health information, as well as data produced in Internet publishing and Internet rental must be stored in China.

In the future, maintaining the balance between security and development and between national data sovereignty and free cross-border data flows will be a key issue to be resolved by the international society.

### 3. FUTURE ACTIONS

In the face of legal challenges arising from big data, countries and international organizations across the world shall take active measures to handle them, seek lawful paths to resolve relevant legal obstacles and promote the overall development of the data-driven society. Internationally, international organizations can publish unified rules to guide the formulation of national data regulations. Domestically, countries shall speed up the process of data-related legislation and accelerate the development of big data technology and industry without prejudice to data security and the data right.

#### 3.1. Promote the formulation of harmonized international rules

Almost every country has to face legal challenges arising from big data development, and many countries and regions have already published data-related legislations. However, due to different national interests, historical conditions and other circumstances, such national data regulations tend to vary widely and even contradict to each other. In the meanwhile, international regulations which are relating to data ownership, data exchange and other issues arising from big data development are lacking. In light of varying national regulations and the lack of unified criteria, international organizations have an important role to play in formulating uniform principles and rules to provide guidance and reference for national legislations. For instance, in 1980, the OECD published the *Guidelines on the Protection of Privacy and Trans-border Flows of Personal Data*[^5], proposing eight principles about personal information protection, which have been incorporated into many national enactments. The ITU has been concerned with big data development from the perspective of the telecommunication industry, and in particular, it has been committed to formulating technical criteria for big data. In 2013, the ITU published a technical observation report, titled “Big Data: Big Today, Normal Tomorrow”[^6], pointing out challenges for big data development. In August 2015, ITU published the *Requirements and Capabilities for Cloud Computing Based Big Data*, the first set of big data criteria. At present, given the absence of international regulations on big data, the ITU shall pay close attention to the development of big data and timely formulate relevant international rules, and especially, as the most important international organization in the area of telecommunication, the ITU shall promote technological and industrial development in cross-border data flows, jurisdiction over cloud computing and other areas that require collaboration and consensus among national authorities.

#### 3.2. Maintain the balance between security and development

The international society has a consensus on deepening development of big data. However, due to the flow, development and usage of large amount of data, security risks arising from big data aggravating. The existence of mass data in itself will result in greater risks of data attacks and leaks. Moreover, given the large amount of data, once a


[^6]: See [https://www.itu.int/dms_pub/itu-t/oth/23/01/T23010000220001PDFE.pdf](https://www.itu.int/dms_pub/itu-t/oth/23/01/T23010000220001PDFE.pdf) last visit in Aug 23, 2017.
data security incident occurs, personal information and privacy as well as overall social and economic security and order, will be endangered. But countries shall not refuse to eat just for fear of getting choked, and instead, they shall take active measures to cope with data security risks and maintain the balance between big data security and development, and treat development as an aim and security as a safeguard. In addition to strategies that promote the development of the big data industry, countries can also give policy, financial and human resource support to big data. In the meanwhile, the relevant legislation that can clarify different data security responsibilities of individuals, businesses and the government shall be accelerated. And the awareness of data security for enterprises and individuals can also be cultivated through the relevant regulations.

3.3. Put emphasis on the protection of the right to data

Big data development is based on a large amount of data, and to ensure sustainable sources of data, the right to data must be protected. As the right to data is a new kind of right which is formed after the advent of the big data era, the right to data is not clearly and uniformly defined by international rules or national regulations so far. However, major countries and regions have specified the protection of the right to data. As an innovative move, the EU General Data Protection Regulation has provided for several new types of right, for example, the right to amend, the right to be forgotten and the right to data portability. In the future of data-driven society, the right to data must be specified and highlighted by way of legislation, and the legal liability for the infringement of personal data must be implemented. And the varieties of the right to data should be further enriched to offer full protection to personal data rights.

First of all, specific laws about the protection of personal information should be made to clarify the basic rights of citizens for their own information, and to standardize the collection and use of personal information of enterprises. Secondly, personal information protection in the field of new technologies and new business should be enhanced. With the development of Internet technologies, new businesses and technologies are continuously being created, and so attention should be paid to the basic rules of personal information protection, as well as the features of new technologies and new businesses. Lastly, international cooperation and dialog should be reinforced. Member countries shall take an active part in making international or regional rules of personal information protection, and strengthen cross-border enforcement cooperation in personal information and privacy protection.

3.4. Closely keep track of data problems in emerging areas

Based on big data, emerging technologies like cloud computing, Internet of things, artificial intelligence (AI) are rapidly growing, and social and economic development are facing some new problems, for example, cross-border data transmission, data openness and security for Internet of things, malicious source of data in connection with AI development and usage. To promote the development of the data-driven society, it is necessary to closely keep track of new data-related problems in emerging technological and industrial sectors and actively seek technical, policy and legal paths of solution, to promote faster development of new technologies.

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OPEN DATA & DIGITAL IDENTITY: LESSONS FOR AADHAAR

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ABSTRACT

Aadhaar, the largest biometric identification system in the world, has been lauded for its promise to bring efficiencies to government service delivery, and the stimulus to private sector innovation. However, its claims have been contested, and criticized for excesses in terms of potential threats to privacy on account of the vulnerabilities of biometric data, mandatory linkage with numerous schemes and the possibility of mass surveillance through linked databases. Even as the debate continues, every day, large volumes of data are being generated through the use of Aadhaar-enabled authentication and eKYC systems, both by government as well as private entities. There has been relatively less exploration of the resulting ‘open data’ potential of Aadhaar and the manner in which it can contribute to research, policymaking as well as strengthening accountability of the Aadhaar authority (UIDAI) itself. The challenge is to find ways to nudge UIDAI and all users of Aadhaar towards greater sharing of data, in privacy-protecting ways that do not create risks for Aadhaar-number holders. At this stage, we lean towards aggregate statistics as a means to open data while following the strictest standards of privacy.

Keywords — Aadhaar, digital identity, open data, privacy

1. INTRODUCTION

Aadhaar, meaning foundation, refers to a 12-digit random identification number issued by the Unique Identification Authority of India (UIDAI). Originally established under an executive order in January, 2009, UIDAI came to become a statutory body under the Aadhaar (Targeted Delivery of Financial and Other Subsidies, Benefits and Services) Act, 2016 (“Aadhaar Act”). The project currently holds a biometric database of more than 1,150 million individuals. Covering over 85 percent of India’s population, it is the largest national biometric database in the world. From its inception, Aadhaar was a unique government project - in part due to its collaboration with technologists and entrepreneurs, and a focus on the potential applications or use-cases the Aadhaar could lend itself to. This is also reflected in its API-based architecture that allows private companies to query the database for authenticating users. Its ability to ‘uniquely’ identify individuals based on their biometric / demographic information and Aadhaar numbers is the stated basis for the government’s push to integrate Aadhaar across (and even beyond) government services. Over the years, Aadhaar numbers have been linked to the transfer of direct cash benefits under schemes like public distribution of food grains, employment guarantee benefits, mid-day meals in schools, LPG subsidies, etc. It has also come to be widely used as identification proof for availing services like banking and finance, digital payments and utility connections, among others.

Despite this rapid proliferation, the goals and architecture of the project have been met with growing resistance. The Supreme Court of India is currently hearing a series of petitions challenging the constitutionality of Aadhaar, its compulsory linkage for the delivery of government benefits, potential for exclusion of beneficiaries; and impact on privacy, among others. These hearings recently led to a pronouncement by a nine judge bench of the Indian Supreme Court that there exists a fundamental right to privacy in India, which cannot be denied except through a fair, just and reasonable procedure established by law. The Court also spoke of other tests to question the existence of a legitimate state aim and proportionality of the measure to achieve that aim (Bhandari et al, 2017 [3]). These tests will now be applied for testing the constitutionality of Aadhaar. While the judicial determination of these issues remains pending, the Aadhaar database continues to be encouraged by the government and UIDAI as the focal point of a rapidly evolving data ecosystem. Hence there is a need to examine the data emanating from the Aadhaar system, and its varied uses. Aadhaar is a publicly funded resource, and as such, there is a strong case for promoting the disclosure of data points that can facilitate research, sound policy making as well strengthen the accountability of the UIDAI itself.

In this paper, we (i) identify the various streams of data generated both by the Aadhaar system, as well as its varied applications across sectors; (ii) identify the existing incentives for public and private sector to create open data; and (iii) suggest principles and an implementation framework to guide the release of more open data through Aadhaar.
2. SOURCES & POTENTIAL FOR AADHAAR DATA

The NYU GovLab research centre defines open data as - "publicly available data that can be universally and readily accessed, used and redistributed free of charge. It is structured for usability and computability" (GovLab, 2016 [5]). In case of Aadhaar, its open data potential is closely linked to its characteristic design, features and functionalities. We therefore begin by examining the architecture of the Aadhaar project and then proceed to identify the categories of data that can emanate from its different processes.

The UIDAI has been tasked with three key functional processes: enrolment, identification and verification (MeitY, 2017 [14]). Through an extensive network of enrolment agencies, UIDAI collects the demographic (name, date of birth, gender, address) and biometric (fingerprints, iris scan and photograph) information of individuals for the purposes of enrolling them into the Aadhaar system. All the collected information is housed in, and managed by, the UIDAI Central Identities Data Repository. The next step of “identification” refers to the de-duplication of biometric data in the UIDAI database. In this de-duplication process the Aadhaar system performs a check of the information collected for each new enrolment against all the enrolled data to ensure “uniqueness”. This results in the issuance of a unique Aadhaar number to the individual, which is meant to be a random number with no built-in intelligence.

Finally, it is the verification process that is employed in a variety of use-cases. This verification can be of two kinds - authentication and eKYC. The authentication services respond with a “yes” or “no” answer to the Aadhaar number holder’s claim of identity and no personal information is shared in the process with the querying entity. On the other hand, electronic know-your-customer functionality or eKYC allows authorized users to seek a person’s identity information (but not their biometric information) from the Aadhaar database. The UIDAI rules allow the authorized eKYC agencies to keep the collected data in their records and use it for the purpose of delivering their services.

The list of agencies that have already adopted Aadhaar-based authentication systems includes Government benefit transfers and e-governance initiatives, banks and financial service providers, telecom companies, and digital certifying agencies. As of April 2016, UIDAI reported over 1.5 billion authentication transactions and over 84 million eKYC transactions (PIB, 2016 [1]). These figures are known to have multiplied since. In the latter half of the financial year 2016-17, a monthly average of 139 million people were estimated to be authenticating themselves using Aadhaar (IDinsight, 2017 [11]). Similarly, the number of eKYC transactions have also risen dramatically, primarily through UIDAI’s encouragement of eKYC driven financial inclusion and its use in telecom services.

In September, 2016, a new telecom player, Reliance Jio, entered the Indian market employing Aadhaar eKYC as its primary mode of verifying and enrolling new subscribers. It is estimated to have added approximately 600 thousand new users per day in its first six months. More recently, the Department of Telecommunications issued a direction to all telecom service providers to re-verify their mobile subscribers through the eKYC process by February, 2018. Based on current figures, this move would cover a telecom subscriber base of about 1.2 billion connections.

As more and more Government and private agencies move towards Aadhaar-based authentication systems, we see two primary sources of data emanating from the Aadhaar ecosystem: (i) statistics of Aadhaar enrolment and usage of the database available with UIDAI; and (ii) data generated through government and private uses of Aadhaar. Each of these categories of data comes with a unique set of challenges pertaining to the ownership of the information, the extent to which it can and should be made public and the incentives that might drive such disclosure. Before turning to these issues in the next section, we first identify the types of information that can emerge from Aadhaar and its uses, and the potential value of such data.

2.1. Release of open data by UIDAI

The decision and the responsibility of creating open data vests upon owner or manager of the database. This right is exercised within the bounds of legally permissible disclosures. We therefore begin this section by examining the extent to which the Aadhaar Act permits (or, at the least, does not prohibit) UIDAI from making any Aadhaar related data publicly available.

The Aadhaar Act does not expressly vest the ownership of the collected demographic and biometric data with the UIDAI. However, its website clarifies that the “data pertaining to residents is held by UIDAI as a trustee/custodian”. UIDAI’s control over the collected data is further demonstrated by the fact that the individual providing her information does not have the option to exit from the system (although she can request access to her information).

Irrespective of the issue of ownership, the sensitivity of the information and scope for its misuse demands that UIDAI, as its custodian, deal with this data in a highly controlled manner. Privacy and data protection concerns demand that an individual’s Aadhaar number; the demographic or biometric information collected during the enrollment process; or authentication records of a person should not be released publicly, by UIDAI, its enrolment partners or the authorized users of its authentication and eKYC systems.

Accordingly, the Aadhaar Act casts an obligation on the UIDAI to ensure the confidentiality of the identity information and authentication records of individuals. Subject to certain exceptions, the law also specifically bars UIDAI from revealing any information stored in its database or authentication records to any person. The authority is also restricted from collecting or maintaining any information about the purpose of authentication. These provisions put some basic restrictions on the information that can legitimately and legally be released in the public domain by UIDAI.
However, UIDAI also has access to a number of other data points that would not be captured by existing restrictions in the Aadhaar Act. For instance, the Authority currently maintains an online dashboard that offers data about the State-wise status of enrolments, including by age and gender and the entities involved in the process. Compared to this, the information that is made available about the usage of the UIDAI authentication / eKYC architecture by its approved agencies is almost negligible. While the law restricts UIDAI from recording or disclosing the purpose of an authentication request, there is nothing that bars it from disclosing aggregated details of the number of authentication requests received by it, the authorized entity making the request, the geographic location from where the request was made and so on, on a daily basis. Similarly, transparency also demands that the number of failed transactions, in terms of generation of Aadhaar number, authentication or eKYC requests should also be made public.

The availability of this information will guide the users of Aadhaar, researchers and other third parties in assessing the extent of its adoption, the purposes for which it is being deployed and the failure rates. The last of these elements can serve a legitimate basis for conducting a systematic audit of the extent and cost of the potential exclusion from the benefits that have been linked to Aadhaar. This is a prerequisite for an open and informed debate on issues relating to Aadhaar, including in the context of the ongoing litigations on the project.

2.2. Data generated by Aadhaar users

**Authentication:** Every day, large volumes of data are being generated through the use of UIDAI’s authentication and eKYC systems, both by government as well as private entities. In case of an authentication query, the Aadhaar repository offers only a positive or negative response to confirm whether the submitted information matches with the information recorded in UIDAI’s database. None of the Aadhaar information is shared with the requesting entity although the process of authentication in itself leads to the creation of new data. For instance, a bank that uses Aadhaar authentication to verify the identity of a customer prior to authorizing the transfer of funds from her account is creating new data in the process. The bank is then in a position to use the fact of Aadhaar authentication along with customer data already available with it to generate daily details of the number of persons of different age groups who used Aadhaar authentication to carry out fund transfers of different denominations.

The Aadhaar Act and the regulations framed under it circumscribe the manner in which information collected through Aadhaar can be used by requesting agencies. As per Section 8(2), a requesting entity can use the identity information of an individual only for submission to the UIDAI repository for authentication purposes. In the above example, the bank would not need to (or be able to) use the customer’s identity information collected by UIDAI, although it would already have similar information in its records. The bank would, however, need to utilize the authentication logs generated through Aadhaar. The current regulatory framework constrains such use by providing that the authentication logs can only be used for certain identified purposes. This includes sharing of the logs for grievance redressal, dispute resolution and audits by UIDAI. The regulations will therefore need to be appropriately amended, as discussed further in Section 4.

**eKYC:** There is marked difference, however, when it comes to the amount of data made available to and generated by authorized eKYC partners. The Aadhaar (Authentication) Regulations, 2016 allow the requesting entity to gain access to the person’s demographic information that is filed with UIDAI. This information can be used by it “for its own purpose”, i.e. for the purposes of its business. It may also share the e-KYC data with other agencies for a specified purpose, with the consent of the individual.

With eKYC agencies, there is scope for release of valuable data points. To take an example, it has been reported that there exists a vast gender divide in the adoption of technology in India (Aneja and Mishra, 2017 [7]). Yet, we do not have any official statistics on the ratio of men and women among telecom users in India, either at the country-wide level or in local areas. The move towards eKYC verification of all telecom subscribers in India, means that telecom operators will soon have an Aadhaar-verified (private) database of telecom users in the country. This would include the gender and geographic information of each operator’s user base. Aggregated together, it can be used to find out the total number of female telecom users in every geographic location. Further, periodic disclosure of such data by all telecom operators will also allow the trends to be tracked over a period of time. A lot of this information may available with the companies today also. However, the fact that all of this information would now be available in a digitally organized and readily available format, will make it easier to process and compare from the perspective of creating open data.

The online registration system (ORS), a framework that links various government hospitals across the country to an Aadhaar based online registration and appointment system, might be another use case. The ORS facilitates eKYC of the patient, which is then used for providing appointments at various departments of different hospitals. Using the appointments database along with the Aadhaar identification information, ORS will be in a position to disclose aggregated data about the age and gender profiles of the patients visiting different departments. This information can be sewn together to gain insights into the broad categories of health problems faced by different groups, the burden on different departments and the variations based on the location of the hospital. All of this can contribute towards evidence-based research and policy-making in the field of healthcare.

Another notable feature of the Aadhaar database is that it was among the first government-issued identifications in the country to recognize “transgender” as a separate category (Nilekani and Shah, 2014 [12]). The release of aggregated data related to use of banking, payments, telecom, health, education and other Aadhaar linked
services by members of the transgender community offers a unique opportunity to study the extent of their exclusion from the mainstream discourse. This however remains subject to concerns about the targeting of individuals and possibility of re-identification from aggregated data, given the relatively small size of the data set. These issues will need to be addressed through careful thinking about the principles that should govern the sharing of Aadhaar linked open data, as discussed further in Section 4.

3. INCENTIVES TO ‘OPEN’

The case for promoting disclosures of open data emanating from Aadhaar applies equally to all authorized users of Aadhaar. However, the incentives for public and private users to disclose this data are very different. Unlike the public sector, where legal requirements and policy initiatives compel and encourage government agencies towards proactive disclosures, private companies are outside the purview of this legal framework. They also typically view data as a source of competitive advantage, and would be reluctant to disclose data points voluntarily. The challenge therefore is to find ways to nudge all users of Aadhaar towards greater sharing of data, in the interests of transparency for accountability, research and more sound policy making.

3.1. For public bodies

Legal basis for proactive disclosure: The legal basis for the government to open up datasets to the public comes from the ‘right to information’ (known in some jurisdictions as freedom of information) regime. The idea of open government data presupposes willingness of governments to proactively disclose information to its citizens, and has been a hard fought battle in many countries. In India, this right of access to information held by public authorities has been codified through the Right to Information Act, 2005 (RTI Act). The passage of the law emanated from a grassroots movement that insisted on “peoples’ audit” of government services to address corruption.

There is a comprehensive proactive disclosure provision in Section 4 of the RTI Act, which puts a general duty on every public authority to provide “as much information suo moto to the public at regular intervals through various means of communication, including the internet”. This puts the onus on public authorities to release data, so that the public has to minimally resort to the use of the law to obtain information. The provision also states that all public authorities shall routinely disclose a varied list of information including about its functions, decision-making norms, documents held, employee contracts, budgets – along with a catch-all direction to release “such other information as may be prescribed”. Some studies however suggest that the promise of Section 4 has been watered down significantly in practice due to insufficient proactive disclosures (RaaG & SNS, 2017 [6]).

Outside of the RTI Act, there have been a few other measures to encourage disclosures. The President of India, in her address to the Parliament in June 2009, voiced the need for “A public data policy to place all information covering non-strategic areas in the public domain. It would help citizens to challenge the data and engage directly in governance reform”. In March 2012, the Indian Government brought out the National Data Sharing and Accessibility Policy (National Data Policy). It remains the only official policy document on open data, with the stated objective of increasing accessibility and easier sharing of “government-owned”, “non-sensitive” data amongst registered users particularly for scientific, economic and social development purposes. Pertinently, the policy rationale for open data is the investment of public funds that goes into collecting and processing such data. The emphasis on government ownership and the use of public funds is also reflected in the scope of the policy, which defines data to be limited to that generated “using public funds by various ministries/ departments/ organizations and agencies of the Government of India”. The policy however has not been operationalized in the form of binding legal rules.

Impact of Aadhaar-seeding on open (government) data: In a speech given by Nandan Nilekani, founding Chair of the UIDAI, in 2010, he stated that “Aadhaar enabled applications the UIDAI envisions can turbo-charge the enforcement of Section 4 provisions (of the RTI) across our subsidy and welfare schemes”. He further said that the “availability of electronic records within such programmes” would be a “natural outcome” of its linkage with Aadhaar.

The digitization of records, however, on its own has not led to proactive disclosure. At present, on the government’s open data portal “data.gov.in”, the UIDAI has uploaded some heads of information. Yet, there are still some gaps in publicly available data emerging from UIDAI, particularly relating to its various applications, or “use cases”. Research group IDinsight identifies “transaction or beneficiary-level data” as one area which would benefit those doing data-driven studies of the efficacy of the project. However, such granular disclosures would raise privacy concerns – which we address more fully in Section 4 on principles.

For areas where there has been proactive disclosure of government databases seeded with Aadhaar, there has been significant controversy around the disclosure of Aadhaar numbers in the process, which is not permitted under the Aadhaar Act. A report by a civil society group found that government portals using Aadhaar for making payments had uploaded the bank account numbers, and Aadhaar numbers of 13 crore people, raising serious data protection concerns (Amber Sinha & Srinivas Kodali, [8]). These proactive disclosures on the disbursement of welfare schemes serve as a means to ensure accountability in the disbursement of social welfare benefits. It is therefore essential to devise an acceptable mechanism of disclosures without compromising on the confidentiality requirements of Aadhaar.

Section 8(1)(j) of the RTI Act provides that personal information which does not relate to any public activity or interest, or could cause unwarranted invasion of an individual’s privacy should not be disclosed. Further,
Section 6 of the Aadhaar data security regulations also lay down a requirement that no government agency should publish Aadhaar numbers, unless they are redacted or blacked out “through appropriate means”. Absent clear specifications about these means, governments could err on the side of caution by removing entire datasets. In the next section we explore how best to achieve the balance between the goals of open data for research and transparency for accountability on one hand, and privacy concerns on the other.

3.2. For private bodies

As discussed, Aadhaar is a public infrastructure being used by various private companies for authentication (through seeding) and verification (through eKYC). These companies, like telecom operators or banks, are custodians of several useful demographic data points, some of which have been identified above. We argue that there is scope to encourage and facilitate disclosure of information held by entities that use Aadhaar. This could be done through various means. In the next section we propose a proactive disclosure regime, akin to the one in the RTI Act, which will be enforced through the UIDAI’s contracts with such entities. Other options could include encouraging disclosures by way of non-enforceable but enabling government policies. This could be coupled with ongoing guidance on kinds of data that would be a priority for disclosure, along with the necessary safeguards. Specific disclosures might also be mandated by particular government agencies or sector regulators.

This debate also needs to be situated within a broader global push to encourage private companies to contribute more to publicly available data, particularly for research and policy making. Although, the term open data is usually used in the context of government or government funded data, some like the Open for Business Report, 2014 (Gruen et al, 2014[2]) suggest that the term would also encompass private sector data. For private sector data, the challenge is to incentivize the companies to release non-strategic data that would contribute to research and development. The International Open Data Charter (a collaboration between more than 70 governments and stakeholders) also questions the boundaries of the data that a typical policy should cover. They state that while the focus has been primarily on “government owned data” - “often the datasets that most matter, and that could have the most impact if they were open, do not belong to governments” (Davies & Tennison, 2017[3]). In fact, it goes further to recommend that governments should have the power to mandate open data publication as part of giving licences to run a register, or negotiating directly with private providers to secure access to data which can then be shared as open data. Apart from government facilitated or enforced disclosures, the coinage of “data philanthropy” has been used to describe the trend of companies volunteering anonymized and aggregated data with (usually select) third party users who might use this for research or policy purposes. Facebook’s decision to share data on disaster maps, including valuable location information shared by users, with trusted organizations like UNICEF and Red Cross (Facebook Research, 2017[15]) and ‘data grants’ by the Mastercard Centre for Inclusive Growth (Randy Bean, 2017 [14]) offer some examples.

We also find similar instances from the telecommunications sector. Orange Telecom’s Data for Development challenge encouraged researchers to use aggregate data in pursuit of development goals like health, transport and agriculture (Orange Telecom, 2015 [17]). They also rewarded best practices of anonymization and cross-referencing of data. In 2014, it was reported that South African telecom operator MTN made anonymized call records available to researchers through a data analytics firm that provides predictive solutions (UN Global Pulse, 2014 [18]). It is however useful to distinguish these voluntary initiatives, which focus on disclosures to certain trusted intermediaries, from actual open data that strives to create unrestricted public access. While these restricted disclosures are valuable, it is important to think about additional frameworks that enable the release of data points publicly making it accessible to a larger and growing pool of researchers and policy makers. The next section explores ways in which this may be made possible.

4. PRIVACY AND IMPLEMENTATION FRAMEWORK

While we have made the case for responsible data disclosures by the UIDAI and other government and private users of Aadhaar, the contours of this responsibility also need to be spelt out. First and foremost, is the concern that any open data disclosures should not threaten the privacy of the individual data subjects, leaving them vulnerable to a host of harms, including financial fraud.

4.1. Privacy framework for open data

Most data protection regimes today afford legal protection only to personal data or “personally identifiable information” (PII). The ability of this information to be traced to a particular individual is what creates the potential for harming the person’s privacy. It is therefore unsurprising that anonymization, which refers to the process by which information is manipulated to make it difficult to identify data subjects, has come to be adopted as safeguard to privacy concerns. As a result, anonymized data is often carved out as an exception to privacy principles. The European Data Protection Directive, arguably one of the most comprehensive legal regimes on this subject, states that the principles of data protection shall not apply to “data rendered anonymous in such a way that the data subject is no longer identifiable”. ¹ However, in the last few years, there is mounting evidence

that traditional anonymization techniques do not adequately prevent the risk of re-identification of the data subject, thus leaving them vulnerable to similar threats as though they were explicitly identified. For instance, a study in United States found that 87.1 percent of the people were uniquely identified by their combined five-digit ZIP code, birthdate and sex (Sweeney, 2010 [13]). Another study re-identified data subjects based purely on their movie preferences on Netflix (Arvind Narayanan et al, 2008 [16]). Thus, the science of what data fields might lead to re-identification when combined with other fields (and even other available databases) is an evolving one. That said, Paul Ohm offers a sobering conclusion in his research on anonymization and re-identification - “Data can be either useful or perfectly anonymous but never both” (Ohm, 2012 [5]). In doing so, the author highlights a necessary tension between the usefulness of data disclosures and privacy interests.

Accordingly, in proposing a framework for open data related to Aadhaar and its uses, we begin with the foundational principle that a person’s Aadhaar number or other PII can never constitute a part of an open dataset. Even when such data is sought to be anonymized, it is critical to assess the risks of re-identification, and propose privacy principles that minimize these risks. We do not attempt a granular analysis of the re-identification risk in the sharing of raw data possibilities from Aadhaar (although such an exercise would also be valuable). Instead, we attempt to provide a heuristic by which to understand these risks, and recommend some approaches versus others.

In the following section we look at two such approaches:

1. Redacting “identifying information”: This is the process of redacting fields of information that are typically understood to identify individuals. In the case of, say, the telecom subscriber database, this might include name, phone number and legally mandated confidential categories like Aadhaar number. For a researcher it might well be that the existence of a unique identifier would allow far greater linkages and insights, particularly when comparing several telecom companies’ datasets. However, it is precisely this that would make individuals identifiable and vulnerable to privacy threats, including from firms that seek to utilize this data for various purposes like marketing or promotions. Techniques like adding “noise” - variations at random to the dataset - are being explored as potential solutions. The re-identification risk in any Aadhaar linked dataset, including that of subscribers with only licensed service area, gender and age, should also be subject to such rigorous assessments.

2. Releasing aggregate statistics: Ohm points to another critical lesson - when PII is actually redacted from the dataset, with minimal risk of re-identification, then the release of the dataset on its own has little value for research. In the telecom dataset example, the primary insights would be aggregate statistics about total number of male/female/transgender, as well as statistics relating to age and licensed service area, and a combination of the three. Therefore, the release of summary statistics, without underlying full datasets, might be a preferred option. These data points could still prove very valuable for the purposes of accountability, research and policy making. Accordingly, the immediate focus of our recommendations and the framework suggested in the next section remains specifically on the release of aggregated summary statistics.

As discussed earlier, there could be various granular statistics, like authentication volumes and error rates, about the operation of the Aadhaar system that would help to evaluate the various programmes it is linked to and the operation of the system itself. Similarly, crucial information about the demography is held by multiple entities, and remains unknown to both government and the public. We discussed gender-base split up of telecom subscribers and health care disbursements as some examples.

Another variation of aggregation could be interactive techniques. Here, the data administrator (say, in this case, UIDAI, government departments, banks, telecom companies) answers specific questions about the dataset without releasing the underlying dataset. The RTI Act allows individuals to make such queries to public authorities, but the onus here would once again fall on individuals or research groups, taking away from the principle of open data altogether. In addition, private companies are not included in its scope. Yet the interactive method might still be instructive. For example, if priority areas for open data were identified in advance, then this could act as a guide for the disclosures made subsequently. This is discussed further in the next section on implementation.

4.2. Monitoring and enforcement framework

The requirements of the Aadhaar Act are implemented by UIDAI through regulations framed by it and the terms and conditions stipulated in the agreements that it enters into with authorized authentication and eKYC agencies. Further, Section 23(2)(p) of the Aadhaar Act entitles UIDAI to “appoint such committees as may be necessary to assist the Authority in discharge of its functions for the purposes of this Act”. Drawing from these instruments, we propose the following steps to create an implementation framework that can leverage the existing provisions of the Aadhaar Act to create an open data framework that is compatible with the principles suggested above.

Step I: The preamble to the Aadhaar Act recognizes the importance of good governance and efficiency, particularly in the context of use of public resources. Recognizing the importance of transparency and accountability as critical tools of good governance, the government and UIDAI should agree on the key priority areas around which Aadhaar related open data needs to be built. Given the nature of data collected by UIDAI, gender, age and geographic location, would appear to be the logical choices.

Step II: UIDAI should formulate a new set of regulations to implement the Aadhaar open data policy, which would include the creation of a multi-stakeholder open data committee. The regulations will encode principles and processes for generating Aadhaar related open data. This process should be accompanied by a review and amendment of existing regulations that might constrain such use. For instance, the Aadhaar authentication
regulations would need to be amended to allow the authentication records to be used for the purpose of generating aggregated statistics for the release of open data. **Step III:** The open data committee should identify the types of aggregate statistics that may be generated by (i) UIDAI; and (ii) different categories of agencies that use Aadhaar for authentication and eKYC. Further, it should also drive the process of developing Aadhaar-specific principles of anonymization and carrying out an open, consultative process to test their robustness.

To the extent that disclosures are sought to be enforced through UIDAI contracts, the committee would also recommend the appropriate provisions to be incorporated in the agreements between UIDAI and the relevant agencies. This step becomes particularly important in light of the fact that the information generated by each entity would vary based on the nature of its business and the likely purpose of its linkage with Aadhaar. For instance, an e-governance programme will have very different uses of Aadhaar compared to a payments service provider or a telecom company.

**Step IV:** UIDAI should review the recommendations of the open data committee, which should be made available publicly, and incorporate appropriate open data standards and provisions in the agreements entered into with different categories of authentication and eKYC agencies.

**Step V:** The open data committee should also assist UIDAI in the implementation of the open data principles by identifying potential violations and notifying UIDAI for the purposes of initiating necessary actions against any breach. It can also play a key role in adopting a communications strategy for sensitizing Aadhaar users about the principles and use of Aadhaar related open data.

The proposed UIDAI-led open data policy will ensure both private and public sector participation, and a narrow focus on anonymized aggregate statistics will minimize privacy risks, while still contributing valuable data points to the public domain. The full benefits of open data will however accrue over time, as we develop a shared understanding of Aadhaar-specific principles of anonymization and disclosures. All of this will contribute towards better research, informed policy making and enhanced public accountability in the Aadhaar ecosystem.

**REFERENCES**


ABSTRACT

Open data plays a key role for governments strategy to deal with challenges of the future. It has the potential to improve public sector’s transparency, engagement of civil society, and economic growth.

This paper contributes to answering the questions: Can open data have an impact on innovation? Under which condition is this the case? Which data can be used to assess the progress on a country level? Which countries are successful with open data? How successful are the government actions to support economic development through open data? The exploratory analysis investigates the relationship between open data readiness and measures on impact, and on changes in open data development level and the influence of the country’s level of ICT development, transparency and freedom. This paper also takes a specific look at economic impact scores and their correlation with government initiatives for training and innovation on open data.

It was found that success on open data at the country level is based on good levels of ICT development, freedom and in the interest of becoming more transparent. There are indications that countries with low ICT development do not profit from open data, but the evidence is limited, due to the small number of countries observed. There is a strong correlation between support for entrepreneurship & business readiness and economic impact. However, the relationship between the development of these indicators during the time of the study and the measured impact is unclear.

Keywords— Open data, status, trends, Open Data Barometer, impact.

1. INTRODUCTION

Open data plays a key role for governments strategy to deal with challenges of the future. It has the potential to improve public sector’s transparency, engagement of civil society, and economic growth through new open data business. In the information age in which we are living having access to quality data implies an advantage to make better-informed decisions, to plan better strategies, to produce better innovative ideas and new insights, and to find more suitable solutions for complex problems. For these reasons the concept of open data, which is data that “can be freely used, modified, and shared by anyone for any purpose” [27] has been adopted by governments around the world.

This paper is part of a research on the open data impact on innovation. The motivation behind this paper is to contribute to answering the questions: Can open data have an impact on innovation? Under which condition is this the case? Which data can be used to assess the progress on a country level? Which countries are successful with open data? How successful are the government actions to support economic development through open data?

This research is planned to have two phases, the first phase presented in this paper is on the global open data status and development over last four years. The second phase of the research will further deepen the analysis of the main observations present in this paper to comprehend the relationships between the different indicators.

The analysis presented in this paper is on the relationship between the indicators of open data readiness for entrepreneurs & business of a country and the measure for economic impact. This measure includes the level of available training on the use of open data and the support for innovation with open data offered by governments.

Without going into in-depth econometrics this paper also analyses the correlation between the level of open data readiness for entrepreneurs & business of a country and the measure for economic impact. This measure includes the level of available training on the use of open data and the support for innovation with open data offered by governments.

This exploratory analysis is done at a global level using secondary data from the historical datasets of the Open Data Barometer (ODB) of the World Wide Web Foundation 2013-2016, and other reliable sources such as the ICT Development Index (IDI) 2016 by International Telecommunication Union (ITU), Freedom in the world status 2016-17 by the Freedom House; Corruption Perceptions Index (CPI) by Transparency International; as well as the Gross National Income (GNI) per country given by the World Bank.

For the last 4 years, the ODB has provided data that scores and ranks the countries’ level of readiness for open data initiatives, implementation of open data programs, and the impact that open data has on business, politics and civil society. The historical data of the ODB with it latest released
early this summer allows making the first observations of the
global open data development trends such as the one
presented in this paper.

Studies on open data have been focused on open data
initiatives [2] [17], impact and value creation through open
data [7] [15] [16], open data for innovation and growth [1]
[19] [24] [28], open data business models [18]. There are not
many studies on open data trends, because of the novelty of
the topic and the few reliable historical data about open data.

Studies on different specific subjects of open data
development are from major institutions such as the ODB.
This year's study of the ODB itself focuses on the changes
of the general and regional ranks, on the datasets published,
and on the impact rank [20].

Although the ODB has published four editions of datasets, it
was found that only a few studies have used the datasets of
the ODB. Those using this data have used it for reference or
extensible the datasets of the ODB second edition for their
study.

This paper is organized as follows: the first part deals with
the current global status of open data, the second treats the
development of open data over the last four years, and the
third part presents a specific analysis on open data
entrepreneur & business readiness and the economic impact.

2. DATA

The data used for the analysis presented in this paper are
datasets of the four editions of the ODB from the years 2013
to 2016 [10] [20]. The World Wide Web Foundation
produces the ODB in collaboration with the Open Data for
Development (OD4D) network, and with the support of
the Omidyar Network. The number of countries included in the
ODB has increased from 77 to 115 over the four years. These
datasets are open and available to use by anyone.

Primary and secondary data is used in the ODB. The primary
data are a peer-reviewed expert surveys on open data policy,
implementation and impacts, and a government self-
assessment on the open data implementation and impact.
Secondary data from the World Economic Forum, World
Bank, United Nations e-Government Survey and Freedom
House was selected to complement the data [21].

In the last years a number of other benchmarks on open data
apart from the ODB have appeared, such as the Global Open
Data Index (GODI), run by the Open Knowledge Network,
which is an annual benchmark for publication of open
government data [9]; and the Open Data Readiness
Assessment (ODRA), which is produced by the World
Bank’s Open Government Data Working Group [22]. Each
of these benchmarks has different scopes and uses a different
approach in order to understand the various elements of open
data as well as, metrics and methodologies affecting their
fluctuation. However, the applicability of each benchmark
varies depending on the situation [11].

The ODB was selected for this research because it considers
the complete path from the readiness for open data
initiatives; implementation of open data programs, to the
impact of open data on business, politics and civil society.

In contrast to other benchmarks, such as GODI, that focuses
on datasets, the ODB contains indicators for both inputs and
outputs of open data. It is unique in the way that it also
provides indexes for the impact, and supporting factors.

The structure of the data of the ODB is as shown in Figure 1.
The overall ODB rank is based on a global score. The global
score is the sum of the scores of the sub-indexes readiness,
implementation, and impact. These scores are scaled from 0
to 100. In each sub-index, the score is created from
components, three in each sub-index. For example, in the
sub-index impact, the components are political, economic
and social. At the same time, each component is built on
indicators. Most of these indicators are based on primary
data, while five indicators are based on secondary data. An
overview of the ODB sub-indexes, components, indicators
and weights are shown in Table 1.

![Fig. 1. Structure of Open Data Barometer data.](image-url)
by individuals in the country. Data from the Global Innovation Index (GII 2017), was used as a measurement of innovation [25]. The ICT Development Index (IDI) 2016 by the International Telecommunication Union (ITU) [12] measures the ICT development of the countries based on eleven indicators contained in the categories ICT access, use and skills.

Table 1. Open Data Barometer – indicators and weights.

<table>
<thead>
<tr>
<th>Sub-index</th>
<th>Data (%)</th>
<th>Scale</th>
<th>Wgt</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Government policies</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open data policies/strategies</td>
<td>p</td>
<td></td>
<td>1/4</td>
</tr>
<tr>
<td>Open data management</td>
<td>p</td>
<td></td>
<td>1/3</td>
</tr>
<tr>
<td>Importance of ICT to government vision</td>
<td>s</td>
<td></td>
<td>1/3</td>
</tr>
<tr>
<td><strong>Government actions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open government initiative</td>
<td>p</td>
<td></td>
<td>1/4</td>
</tr>
<tr>
<td>City/region freedom running open data initiatives</td>
<td>p</td>
<td></td>
<td>1/3</td>
</tr>
<tr>
<td>Government on-line service index</td>
<td>s</td>
<td></td>
<td>1/3</td>
</tr>
<tr>
<td><strong>Entrepreneurs &amp; business</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability of training on open data</td>
<td>p</td>
<td></td>
<td>1/4</td>
</tr>
<tr>
<td>Support for innovation through open data</td>
<td>p</td>
<td></td>
<td>1/3</td>
</tr>
<tr>
<td>Firms level of technology absorption</td>
<td>s</td>
<td></td>
<td>1/3</td>
</tr>
<tr>
<td>Internet users</td>
<td>s</td>
<td></td>
<td>1/3</td>
</tr>
<tr>
<td><strong>Citizens &amp; civil Society</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right to-information law</td>
<td>p</td>
<td></td>
<td>1/4</td>
</tr>
<tr>
<td>Legal/regulatory framework for protection of personal data</td>
<td>p</td>
<td></td>
<td>1/3</td>
</tr>
<tr>
<td>Engagement of civil society and IT professionals with government regarding open data</td>
<td>p</td>
<td>1/4</td>
<td></td>
</tr>
<tr>
<td>Political freedoms and civil liberties index</td>
<td>s</td>
<td>1/3</td>
<td></td>
</tr>
<tr>
<td><strong>Implementation</strong></td>
<td>35</td>
<td>0-100</td>
<td>1/3</td>
</tr>
<tr>
<td>Innovation</td>
<td>p</td>
<td>1/3</td>
<td></td>
</tr>
<tr>
<td>Social policy</td>
<td>p</td>
<td>1/3</td>
<td></td>
</tr>
<tr>
<td>Accountability</td>
<td>p</td>
<td>1/3</td>
<td></td>
</tr>
<tr>
<td><strong>Impact</strong></td>
<td>30</td>
<td>0-100</td>
<td>1/3</td>
</tr>
<tr>
<td>Government efficiency and effectiveness</td>
<td>p</td>
<td>1/3</td>
<td></td>
</tr>
<tr>
<td>Transparency</td>
<td>p</td>
<td>1/3</td>
<td></td>
</tr>
<tr>
<td><strong>Social</strong></td>
<td>1/3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental sustainability</td>
<td>p</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inclusion of marginalized groups on policy making and access to government services</td>
<td>p</td>
<td>1/3</td>
<td></td>
</tr>
<tr>
<td><strong>Economic</strong></td>
<td>1/3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Country’s economy (positive)</td>
<td>p</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entrepreneurs successful use of open data to build new business in the country</td>
<td>p</td>
<td>1/3</td>
<td></td>
</tr>
</tbody>
</table>

Note: Primary data (p), secondary data (s). More details on the ODB research methodology under http://opendatabarometer.org/4thedition/methodology/

3. OPEN DATA GLOBAL STATUS AND TRENDS

3.1. Global status of open data

For the analysis on the global status of open data, the 115 countries included in the 4th edition of the ODB were considered. The analysis is based on the geographical regions and on the income categories based on the Gross National Income (GNI) given by the World Bank. The regions are North America, South Asia, East Asia and Pacific, Middle East & North Africa, Latin America & Caribbean, Europe & Central Asia and Sub-Sahara Africa. The income-level categories are high-income, upper-middle-income, lower-middle-income, and low-income. The WB gives the following definitions of the levels for the current fiscal year, high-income economies are those with a GNI per capita of $12,476 or more; upper middle-income economies are those with a GNI per capita between $4,036 and $12,475; lower middle-income economies are those with a GNI per capita between $1,026 and $4,035; low-income are those with a GNI per capita of $1,026 or less in 2015 [30].

3.1.1. Regions and GNI based analysis

An overview of the ODB rank 4th edition is shown in Figure 2. From this heat map, one observes that the open data rank follows expected results regarding regions and income levels of countries. The countries at the top of the ODB rank are the United Kingdom (UK), Canada, France, the United States of America (USA), Australia, Japan. The top ten countries according to the ODB rank 4th edition are shown in Table 2.

Table 2. Top ten countries according with the ODB 4th edition rank and scores.

<table>
<thead>
<tr>
<th>Country</th>
<th>Rank</th>
<th>Score</th>
<th>Readiness</th>
<th>Implem.</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>1</td>
<td>100</td>
<td>99</td>
<td>100</td>
<td>94</td>
</tr>
<tr>
<td>Canada</td>
<td>2</td>
<td>90</td>
<td>96</td>
<td>87</td>
<td>82</td>
</tr>
<tr>
<td>France</td>
<td>3</td>
<td>85</td>
<td>100</td>
<td>71</td>
<td>88</td>
</tr>
<tr>
<td>USA</td>
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<td>Norway</td>
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The average OBD rank per region reflects the current global economic trends, in which East and South Asia are the most dynamic regions of the world, and the low-income countries still being left behind [30]. Figure 3 that there is a wide difference in performance of countries within the same region. An analysis of the countries’ income level helps to understand the difference between an in each region.

In the East Asia-Pacific region, Australia, New Zealand and Japan are scoring significantly higher than the other countries of the region, which are in the lower-middle-income category as expected. However, the Philippines is a lower-middle income country and ranks (22), one place higher than Singapore (23), a high-income country. Also, the Philippines and Indonesia (38) scored better than upper middle-income countries like China (71) and Malaysia (53). In the Middle East and North Africa region, high-income countries like the United Arab Emirates (59) and Bahrain (74) did not score much better than those lower-middle income countries like Egypt (85) and Morocco (79) and were worse than Tunisia (50).

In the Latin America and Caribbean region, Mexico stands out, ranked (11).
In the Sub-Saharan Africa region, Kenya (35) ranked better than the upper-middle income countries. Burkina Faso also did better than the mean of the upper-middle income countries.

3.1.2. Open data readiness, implementation and measures of impact

Figure 4 shows that there is, in general, a higher level of readiness than implementation by the countries, while there is a clear correlation between readiness, implementation and the measures of impact. Further, low-income countries do not show any impact regardless the level of readiness and implementation.

One of the weaknesses of the ODB in assessing impact and innovation of open data is that it relies on expert survey results only. Independent measures of innovation are given for instance in the GII [26]. While there is not one canonical measure of innovation, for the purpose of this paper ‘New business density’ per country of the GII, which refers to new registrations per thousand population 15–64 years old in 2014 is found to be more appropriate for the case of open data as other measures such as patents.

Figure 5 shows the relation between the implementation and readiness scores. It reveals a more complex relationship than the one shown by the ODB impact in Figure 4.

3.1.3. ODB rank and countries’ level of freedom, transparency and ICT development

For this first part of the analysis, the influence of the level of ICT development, public sector transparency, and the level of political rights and liberties of each country on the rank of countries on the development of open data, are considered. In the group of high-income countries, it is possible to see how the level of freedom is more related to the ODB rank than the levels of ICT development and transparency (Figure 6). For instance, Qatar, South Arabia, United Arab Emirates, Bahrain rank high in the IDI index and transparency, but have a low level of freedom and a low ODB rank.

The countries in the upper-middle income group are scoring badly in transparency (between 20-60), and together with the level of ICT development, it seems not having any relationship with the ODB rank. Regarding the level of
freedom in this group, it is possible to see a slight correlation with the ODB rank. The exception is Russia, which ranks well, despite having low levels of freedom and transparency. The level of freedom among these countries is quite diverse since there are different kinds of governments found in this group. Countries with low freedom scores are China, Belarus, Thailand, Jordan, Kazakhstan, and Russia, where Russia ranks better in the ODB than the others.

Democracies rank comparatively good in the ODB. Venezuela is a special case scoring badly in both transparency and freedom, which is a reflection of the current political crisis in the country. Other countries such as Ecuador, Paraguay, Mexico and Colombia are democracies scoring as free countries, but they have problems with transparency. Expect for Mexico these countries rank middle in the ODB. The case of Mexico with a good ODB rank could be read as if the country were investing in open data to improve its transparency.

Lower middle-income countries are doing similar to upper middle-income ones. They are also relative worse than the upper middle-income countries in both transparency and freedom. However, there is a wide variation in the freedom status among the countries. For instance, India and Tunisia are free, but Yemen and Vietnam are considered not free. This group of countries is also ranking low in the ICT development index, yet it is possible to observe that similar to the other income groups, the level of freedom is related to the level of ODB.

Countries in the low-income group are similar in terms of freedom and transparency ranking similarly to the lower middle-income countries. Regarding the ICT development, these countries are far behind, scoring the worst in the IDI index. This low ICT development is really influencing the ODB rank of these countries since they have limitations in the use of data.

For the analysis on the trends of open data, only the original 77 countries included in all editions of the ODB were considered. Here the focus is on the changes from 2013 to 2016 in the ODB rank as well as, in the readiness, implementation, impact and the relationships scores.

From Figure 8 it is possible to observe that East Asia & Pacific and Latin America & Caribbean had a big improvement in readiness and implementation especially in comparison to Europe. East Asia & Pacific is the one region with the biggest improvement in the impact, although having lower improvement in implementation than Latin America & Caribbean. Europe & Central Asia had no changes regarding readiness, and it has gone down in the ODB rank. One reason for this could be that the region started already with a high-level of readiness for first ODB rank in 2013.
It is possible to see in Figure 9 that the Scandinavian countries that used to be at the top of the ODB ranking lost rank, because of implementation and readiness sub-indices.

Fig. 9. Relationship between change in implementation and readiness scores and the measured impact scaled from 1 to 100 (best) (top); Change in ODB rank from 2013 to 2016 vs ODB rank 2013 (bottom). Rank is from 1 (best) to 77 (worse). Negative change ODB (y-axis) implies improvement in rank. Countries grouped by level of GNI.

4. ECONOMIC IMPACT THROUGH OPEN DATA ENTREPRENEURSHIP

This part of the analysis investigates the correlation between the level of open data readiness for entrepreneurs & business of a country and the measure of economic impact considering only the indicators on the countries’ level of available training on the use of open data, the support for innovation with open data offered by governments, and the measure for economic impact of the ODB for 2016 and the change from 2013 to 2016.

4.1. Relation between open data entrepreneurship and the economic impact

All high-income countries have a middle or high level of entrepreneurs & business readiness, except Hungary with a low level, and the majority of the countries in this group present some level of economic impact. However, for many of those countries with middle level of entrepreneurs & business readiness the economic impact is very low (Figure 10).

Fig. 10. Relationships between measures of economic impact scaled 1 to 100 (best) with: countries’ level of available training on the use of open data, the support for innovation with open data offered by governments, and entrepreneurial & business readiness scaled from 1 to 100 (best) – (bottom). Countries grouped by level of GNI.

The lower middle-income countries have a lower level of entrepreneurs & business readiness and economic impact. However, similar to the upper middle-income group, there is a relation between readiness with impact. For the majority of the low-income countries based on the ODB, there is no economic impact except Nepal with a very low impact of (16/100).

In the group of the upper middle-income countries, Mexico and Russia are having the highest levels of entrepreneurs & business readiness and economic impact. However, the level of economic impact is middle-low. In general, it is possible to observe that there is a relation on entrepreneurs & business readiness and the economic impact in this group of countries, the higher readiness is, the higher impact is. Exceptions exist like Malaysia, that yet having an upper middle level of entrepreneurs & business readiness presents almost no economic impact.

Fig. 11. Comparison of development over years implementation, readiness citizens & civil society, entrepreneurs & business readiness, economic impact for countries: Spain, Sweden and the United Kingdom.
The case of Spain is analyzed further using Figure 13. Spain presents the highest change over the four years in the economic impact, although not having an equally high entrepreneurs & business readiness. Moreover, as mentioned other countries such as Italy and Ireland with higher readiness do not achieve half of what Spain does. However, from observing Figure 11 it is not possible to determine the indicators causing this big impact.

4.2. Development of economic impact scores from 2013 to 2016

In this part, the analysis is on the changes in the entrepreneurs & business readiness and the economic impact. As can be seen in Figure 12, it is not possible to conclude that changes in implementation and readiness during the time of the study has led to changes in the economic impact, as there is no obvious relationship between the change in the sub-indexes and the overall economic impact measure. From this observation, one could draw three possible conclusions. The first is that the time of four years is not long enough time to actually notice a direct influence on the economic impact through these measures, the second is that the measures themselves have been ineffective, and the third that the fact that countries started from very different levels has been more important to what they have done during these four years than the recent development, especially for those countries that started at the top of the rank back in 2013.

Fig. 12. Relationships between changes in measure of economic impact scaled 1 to 100 (best) and change in - countries’ level of available training on the use of open data, support for innovation with open data offered by governments from 1 to 10 (best) - (upper-left); implementation scaled from 1 to 100 (best) (upper-left); entrepreneurs & business readiness scaled from 1 to 100 (best) - (bottom). Countries are grouped by level of GNI.

5. CONCLUSIONS

Open data rank follows the regional and income level ranks as expected. However, even within groups with comparable income levels, there are big differences in open data implementation, readiness and impact.

For countries to be successful in open data, they have to not only have a good ICT development level but also a good level of freedom and will of becoming more transparent. That is especially true for countries in the Middle East, which could start already profiting from open data since they have the ICT development and economical means yet do not seem to have the interest. Opposite cases are countries in Latin America like Mexico, that although being an upper middle-income country it seems to invest in open data to improve the transparency. There are indications that countries with low ICT development (ICT access, ICT use, and ICT skills) do not profit from open data, but the evidence is limited, due to the small number of countries observed. The current status shows that there is a correlation between entrepreneurs & business readiness and economic impact. However, it is not possible to see that changes in entrepreneurs & business readiness during the time of the study have an obvious relationship with changes in the economic impact. To measure innovation is very difficult. When replacing the ODB impact score with an independent measure, the new business density per country, a more complex relationship is observed. As can be expected this high level measure is influenced by many other factors. There is wide room for further research in this area.

Further study should investigate whether the time frame of four years too short to notice influence on the economic impact through these measures, the measures themselves have been ineffective, or different starting levels have been more important in further development than actual changes during the four years of observation.

REFERENCES


[9] Global Open Data Index (GODI), Open Knowledge Network https://index.okfn.org/about/


[27] The open definition http://opendatabarometer.org/open-data/


SESSION 2

ENVISIONING FUTURE STANDARDS DEVELOPMENT

S2.1 A holistic approach to exploring the divided standards landscape in e-health research*
S2.2 Intellectual property licensing tensions in incorporating open source into formal standard setting context - The case of Apache V.2 in ETSI as a start
S2.3 Governance within standards development organizations: Who owns the game?
S2.4 The standards revolution: Who will first put this new kid on the blockchain?*
A HOLISTIC APPROACH TO EXPLORING THE DIVIDED STANDARDS LANDSCAPE IN E-HEALTH RESEARCH

Doyoung Eom, Heejin Lee

Yonsei University, Republic of Korea

ABSTRACT

Based on the importance of standards in providing safe, interoperable, and quality healthcare, a growing body of literature explores e-Health services and systems in combination with standards and standardization. Yet a holistic approach to assess the state of academic research that involves standards and e-Health across diverse disciplines has not been taken up to date. To understand the dynamics of e-Health standards, particularly on the role and effect of those standards, this paper systematically reviews the standards landscape in e-Health research. We found three key themes: first, standards for e-Health in developed and developing countries; second, types of standards and their effects on interoperability, quality and security; third, implementation of standards in terms of adoption by healthcare organizations and application in the process of e-Health framework developments. This paper makes academic contributions by extracting common themes across disciplines and intends to provide practical implications for facilitating e-Health interventions while taking the benefits and challenges associated with standards into consideration.

Keywords—e-Health, standards, standardization, systematic review

1. INTRODUCTION

The delivery of healthcare is going through a massive transformation process with the advances in information and communication technology (ICT). Implementations of healthcare initiatives that incorporate ICT have been undertaken in a number of countries such as the U.K., Denmark, Singapore, and Canada. These countries are seeking ICT implementations that go beyond the simple digitalization of records towards systems that allow information sharing between providers [1] for the reduction of healthcare expenditures and the improvement of healthcare service delivery to patients. E-Health, defined as the use of ICT in support of health and health-related fields [2], has enabled such transformations. Main functions of e-Health technologies are enabling the storage, retrieval, and transmission of data, supporting clinical decisions, and facilitating remote care [3].

Standards play an important role with regards to e-health. E-health standards enable reliable and interoperable information sharing over communication networks and between devices in which common standards are agreed upon [4]. These standards enable interoperability among ICT technologies and systems that are not made by the same providers, provide common information formats for the exchange of health-related data, or represent unified security structures [4]. However, standardization in the area of e-Health is complicated because of the large installed base of proprietary systems and technologies and the involvement of many stakeholders [5]. The core issue surrounding e-Health is fragmentation. Legal frameworks are fragmented, lack of interoperability hinders the continuum of care, each actor in the e-Health landscape is specialized in its own practices, and the practices of different agencies lack coordination. We are witnessing standardization efforts made at national and international levels to achieve the goal of providing integrated, efficient, and secure healthcare services. Still, problems to be addressed include the adoption of new e-Health technologies, implementation and harmonization of e-Health standards, and the improvement of technological and standards infrastructure in developing countries.

Since the term e-Health came into use in literature starting from 2000 [6], studies on the topic of e-Health as well as e-Health standards have been on the rise. Research in the earlier years was aimed at discovering the definition and scope of e-Health in the academic environment. Some of them focused on mapping the scope of e-Health and identifying where e-Health is positioned with respect to the wider field of medical informatics [6]. In previous research, there was a general sense of optimism surrounding the potential benefits of e-Health to improve health care processes and patient outcomes [6]. Compared to the optimistic approaches, recent studies find barriers and facilitators as one of the major themes of e-Health research. In existing studies, barriers and facilitators that affect public engagement with e-Health services [7], factors that influence the implementation of e-Health systems [8], and healthcare professionals’ organizational barriers to health information technologies [9] have been examined.

Research that combines e-Health with standards is widely found throughout diverse disciplines. Approaches and use of standards made by standards development organizations
(SDOs) such as Health Level Seven International (HL7), Digital Imaging and Communications in Medicine (DICOM), ISO/TC 215 (Health Informatics) are often found in the literature. Based on a preliminary review of the literature, it has been found that a lot of them are engineering-based or focused on technical issues and solutions related to e-health standards implementation for interoperability. Over the past decade, social scientific approach has become an important approach in e-Health studies, however, little systematic examination of the aspects of e-Health studied by social scientists have been carried out [10]. The same situation applies to studies in e-health standards.

Exploration of an array of studies in e-Health standards taking an integrated approach is missing from previous research. It is necessary to identify and synthesize dispersed e-Health standards studies found in the fields of medicine, engineering, information science and technology, and social sciences in order to provide a holistic view of the current state of academic research on this topic and understand the dynamics of e-Health standards and standardization. Taking this approach is significant since interests of different stakeholders are not always converged and so are the existing studies that tend to focus on a particular stakeholder group.

What we intend to discover is the role and effect of standards in e-Health instead of merely finding the status of standardization or the designs and solutions to e-Health implementation. This paper, thus, conducts a systematic review of current literature on e-Health standards for the purpose of identifying the role and effect of standards in this interdisciplinary field. In so doing, we find major topical areas and implications for future studies. We aim to provide practical implications that can facilitate future e-Health interventions and policies while addressing challenges associated with standards. In Section 2, we present the methodology, followed by Section 3 which provides an outline of the current literature, and we conclude in Section 4.

2. METHODS

2.1. Search strategy

Systematic reviews adopt a replicable, scientific and transparent process aimed at minimizing bias through exhaustive searches of existing literature [11]. In order to review literature employing a comprehensive and rigorous method, a search was carried out using databases from different disciplines including medical science and healthcare. The review process provided by Petticrew et al. [12] and processes in actual systematic reviews conducted in medical science and healthcare papers are followed for this paper.

A search was performed in three databases including Web of Science, Medline and Embase. Previous studies have concluded that both databases, Medline and Embase, should be searched for a search to be comprehensive in the medical literature [13]. Web of Science (WoS) database core collection was searched to identify references from social sciences, arts and humanities, and sciences and technology. The search was carried out during April and May 2017.

The selected databases have different search options. Therefore, search strategies were adapted for each database utilizing the unique features and maintaining consistency in the search terms at the same time [9]. All terms pertaining to e-Health and standards were used and then combined. These terms include electronic health, mobile health, telemedicine, health information technology, health information system, medical informatics, electronic health record and their variations. It has been pointed out that e-Health and related technologies show a nonstandard use of terminology and lack consensus on taxonomy in the literature [3]. Thesaurus terms referring to e-health were used to mitigate the problems associated with the nonstandard use of e-Health. The search strategy included MeSH or Emtree terms and free text. In order to capture a comprehensive standards landscape, queries have been made using the keywords interoperability, compatibility, regulation, certification and their variations in place of the keyword ‘standard*’.

2.2. Study selection

Studies that describe the use of standards to deliver e-Health services or implement e-Health interventions were included. In other words, studies that are relevant to the research question, which is to identify or further analyze the role and effect of standards in e-Health, were included for review. One of the most important inclusion criteria was that the study should have a standards-related topic. However, if a study had no substantive content or analysis related to standards or had only technical discussions on e-Health standards without socio-technical implications, it was excluded. In addition, articles that use the term “standards” in a broader meaning (e.g. standard practice, standardized patients) have been excluded.

Studies in English were included for review. The type of study was limited to journal articles including systematic reviews. Based on the scoping study to assess the relevance and size of literature, it was found that a considerable amount of letters, editorials and reports exist dealing with the topic of e-Health standards. However, most of them are descriptive about the current status of standardization and recent developments of technologies or present critical viewpoints on issues such as the lack of interoperability that lack academic rigor. Since the purpose of this systematic review is to examine the state of academic research, study types other than journal articles were excluded. Articles applying quantitative and qualitative methodologies were all assessed. Articles for which full text was not accessible were excluded. The time frame searched was between 2000 and 2017. The year 2000 is a significant starting point of
Table 1. Systematic Scoring

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<td>3 points</td>
<td>standard* OR ehealth/e-health in title max. 6 points</td>
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<td>2 points</td>
<td>standard* OR ehealth/e-health in keywords max. 4 points</td>
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In developed countries, standards are highly relevant for e-Health related projects that are promoted at national and regional levels. Literature describes the elements, development process and the outcomes of such projects. The U.S. has been active in initiating projects that involve standards for the exchange of clinical data nationwide and disseminating the project outcomes in the academia. At the federal level, the Strategic Health IT Advanced Research Projects (SHARP) Program developed an open source framework to support the ubiquitous exchange, sharing and reuse of operational clinical data stored in electronic health records, using Consolidated Health Informatics standard terminologies [15]. Similar approaches to the SHAPRn project have been taken in other countries such as Spain [16]. The National Cardiovascular Research Infrastructure (NCRI) project in the U.S. was initiated to convert existing data standards for clinical research and patient care data into appropriate computer-based language structures that could be endorsed as an accepted data standard for public use enabling data exchange across networks [17]. These endeavors have been made to address the issue of standardizing health data from diverse healthcare organizations and providers and establishing infrastructure driven by standards.

In the U.K., early establishment of an information governance initiative to manage data quality of e-health information took place. The initiative is known as the Data Accreditation Programme proposed in 1998 by the National Health Service (NHS), which incorporated information governance standards [18]. At the regional level in Europe, a project solely for e-Health standards, the eStandards project funded by the European Commission, was initiated that was aimed at the regional and global alignment of standards. A recent study shows the results of 19 case studies of e-Health deployment projects carried out as part of the eStandards project, which deal with how to achieve coexistence of competing or overlapping standards in practical terms that ensure sustainability [19]. Europe, in general, presents considerable interest in data protection and harmonization of standards in its e-Health projects.

Literature on national approaches taken by other developed countries such as New Zealand and Canada was discovered. A review of New Zealand’s health ICT standardization showed progress in the establishment of standards and guidelines by government bodies and in the adoption of standards in health information exchanges [20]. Canada introduced the Canadian Health Outcomes for Better Information and Care (C-HOBIC) project involving the use of standardized clinical nursing terminology for patient assessments and implemented it in its provinces’ healthcare systems, which was associated with benefits for continuity of care and aggregation of nursing information [21].

Overall, we found that developed countries have deployed various e-Health projects that are targeted for a specific healthcare setting and purpose, which incorporate standards.
Their main concern does not remain only at the adoption of data exchange or terminology standards but extends to the exchange of health information across networks and the achievement of harmonization or normalization of disparate data standards that facilitates communication across healthcare organizations, regions and also internationally.

Developing countries have been increasingly seeking actions for national and regional standardization on e-Health. A study on the Millennium Villages Project (MVP), a deployment of e-Health architecture running across 14 sites in sub-Saharan Africa, illustrated the development of open source solutions and common standards [22]. In order to achieve Millennium Development Goals that are closely related to healthcare and to develop an accessible and interoperable e-Health system, the study stressed that it is important to use open source technologies and standards. At a country level, Kenya Ministry of Health developed standards and guidelines for electronic medical record systems (EMRs), focusing on the minimum requirements for national roll-out [23]. Conformity to EMR standards (e.g., reporting, security, system features) is significant for such developing countries to manage the functionalities of the system that determine the quality of services related to prevalent HIV.

A common problem that developing countries encounter is the lack of standards and barriers to the adoption of standards. China has adopted standards for vocabulary, classification, coding and messaging, but despite its rapid progress in health informatics, it confronted problems with lacking standards that should be solved to comprehensively utilize hospital information systems [24]. An investigation of tertiary hospitals’ barriers to the adoption of health data standards in Saudi Arabia revealed that technological, organizational and environmental factors as the critical factors influencing the adoption decision [25].

When we compare between e-Health actions that have relevance to standards in developed countries and developing countries, the latter tends to be witnessing developments in more recent timings. Also, they tend to remain centered on the development and adoption of standards such as health data standards. It is most likely that developing countries will face similar issues of interoperability currently being experienced by developed countries, which makes initiatives such as MVP in sub-Saharan Africa more important.

3.2. Types and effects of standards

Literature encompasses a wide array of the types of e-Health standards differentiated by their core functions and healthcare settings. A widely mentioned standard in the searched literature is the HL7 Clinical Document Architecture (CDA), which is a standard that specifies the “structure and semantics of clinical documents for the purpose of exchange between healthcare providers and patients” [26]. HL7 is a not-for-profit, standards development organization that is dedicated to providing a comprehensive framework and related standards for the exchange, integration, sharing and retrieval of electronic health information [46]. CDA is one of its product lines of messaging standards as well as its preponderant v2.x, slowly evolving v3.0 and the emerging Fast Healthcare Interoperability Resources (FHIR). Under the parameters of the HL7 standard, a guide for dental digital imaging reports was developed that can benefit patients, providers, insurers and dentists in terms of increased efficiency and agility with respect to data management, monitoring and treatment [27]. HL7 is said to be an important component of an Electronic Healthcare Record (EHR) along with other relevant EHR standards that structure the clinical content for the purpose of exchange that are developed by formal standardization organizations like CEN and ISO working on Health Informatics or is a de facto standard like the DICOM [28]. Data standards relevant to both research and industry for the capture and exchange of clinical trial information were developed also by a consortium, which is the Clinical Data Interchange Standards Consortium (CDISC) [29]. Data standards come into play in a variety of healthcare settings such as in support of the exchange of health information between emergency departments and poison control centers [30].

As important as data standards are device standards. A family of standards, IEEE 11073 Personal Health Devices (PHD) standards, ensures the transfer of information between medical devices. Such medical device standards are needed to facilitate the development of safe and interoperable medical device systems [31]. We can say that e-Health standards including data standards and device standards that are created by different modes of standardization serve crucial functions like ensuring interoperability, usability, quality, security and privacy. Next, we examine the particular effects that are performed by these standards.

Interoperability is one of the most cited aspects of e-Health when discussing the role of standards and challenges of standardization. Interoperable solutions are needed for advancing continuity of care, providing efficient and effective healthcare services and supporting decisions of stakeholders in healthcare organizations. However, it has been challenging to achieve because of heterogeneous and independent systems in existence. Here, research about ‘why’ and ‘how’ for linking standards to interoperability are found. In the case of radiology, standards such as DICOM and HL7 define formats and protocols of transmitting medical images and signals within and across healthcare organizations. With the increased production of big data, e-Health standards including Virtual Medical Record, DICOM Structured Reporting and HL7 FHIR are becoming a key to data interoperability for the objective of simplifying and speeding up the exchange of patient information [32]. More regarding the question on ‘why’, standards are needed to support cross-border patient summary exchange. The U.S. has set harmonized CDA
implementation guidelines whereas the EU adopted the Patient Summary guideline citing European Patients Smart Open Services (epSOS) guidelines to implement interoperable e-Health systems across borders [33]. The question of ‘how’ standards advance interoperability can be seen in the context of EHR in Korea [34]. To support the implementation of interoperable Clinical Decision Support (CDS) nationwide, standards-based CDS architecture was proposed based on the identification of service features, core components and application architecture in relation to exiting approaches and also supplemented by a survey of major stakeholders in CDS.

In spite of the importance of interoperability clarified in the medical and technological communities, there is a lack of empirical research on the actual impact that standards-based systems have on advancing interoperability. One of them is seen in a case study of Lombardy region in Italy where a fully interoperable healthcare system was enabled through the implementation of international health standards, first at the hospital level that expanded into the regional level [35]. Achieving interoperability is especially difficult in the current situation where we have coexistence of standards and domain-specific processes that create different flavors of a standard.

There are careful considerations for technical features of e-Health systems implemented for ensuring security and privacy. A systematic review on security and privacy of EHR systems used ISO standards on privacy framework and security guidelines to identify key technical features including access control policies and consent mechanisms that are essential for EHR security and privacy [36]. By means of the design and implementation of such features, e-Health standards account for improvement in the quality of care as well as hospital performance. Evidence provides that structured pathology reporting in standardized format for cancer particularly based on international standardization has value in quality improvement for both clinical care and health management at the population-wide level [37]. Compliance with Joint Commission International Accreditation (JCI A) standards, which are standards for the documentation of discharge summaries, provides evidence for better quality of documentation and minimization of unnecessary delay [38]. With regards to hospital performance, a survey of top management of hospitals reveals that e-Health compatibility which is partially explained by IT adaption, defined as the understanding and implementation of IT standards or protocols compatible with hospital resources, has a positive mediating effect on hospital performance [39]. In some occasions, simple adoption of international standards may not guarantee the elimination of flaws. Literature describes that the adoption of Integrating the Healthcare Enterprise (IHE) specifications for authenticating healthcare professionals and assuring patients’ safety reveals security flaw that necessitates modification in the communication protocol in order to establish a secure EHR system [40].

3.3. Implementation of standards

Literature on the role and effects of e-Health standards can be classified under the topic of implementation in terms of the adoption of standards and the application of standards when developing standards-based technical frameworks.

Standards in e-Health have to be put into real life practice to add value to the quality and security of healthcare practices and services. To realize the known effects of e-Health standards, healthcare organizations intend to adopt health data standards. However, the level of adoption is reported to remain low worldwide, especially in developing countries [25]. Some barriers that hinder the adoption of health data standards are the complexity and incompatibility of standards, switching costs, lack of IT infrastructure, lack of adequate policies and plans for data exchange. In other words, interplay of technological, organizational and environmental factors affects adoption decisions of e-Health standards [25]. Through questionnaires, critical factors influencing hospitals’ intention to adopt HL7 in Taiwan were empirically investigated to discover the influence of organizational factors that have been relatively under-examined [41]. The results showed that the critical factors were environmental pressure, top management attitude, staff's technology capability, system integrity, and hospital's scale. Experiences in the U.S. Department of Veterans Affairs showed that the adoption of health data standards is facilitated by internal staff with expertise in standards development and adoption [42]. According to its long history, implementation approaches tailored for different standards in categories of security and privacy, terminology, health information exchange, and modeling tools are needed to translate standards into practice.

There are numerous proprietary solutions for e-Health available in the market that are developed and supplied by individual companies and used by health practitioners in which compliance to standards are not considered. Due to limitations in providing interoperable solutions, academic research is increasing in the development of frameworks applying international standards that work at different levels of applications. HL7 family of standards is frequently applied in these cases. HL7 CDA Release 2 was used as a standard document to propose the architecture aimed at bi-directional exchange of data between EHRs and m-Health apps to promote patient engagement in home monitoring [43]. An earlier study proposed HL7-aware multi-agent system that represents both patient and service information based on HL7 [44]. One of the frameworks was created based on several international standards to transfer health data collected from medical devices to health information systems. Standards include IEEE 11073 for device communication, CEN 13606 for domain modelling, HL7 and IHE profiles for communication with EHRs or PHRs and data storage [45].

Standards that are used globally are being implemented in the process of creating new frameworks for achieving
This is why the adoption and consistent use of standards does not mean that interoperability is guaranteed. Health stakeholders’ activities are missing. Simple use of a standard does not mean that interoperability is guaranteed医科大学文科院. Existing studies tend to be focused up to the point of patient care, hospital performance, and health data. Important variables including quality and security in the areas of patient care, hospital performance, and health data. Our review also found the implementation of standards as one of the major themes that arise in the e-Health literature. Studies present critical factors that influence the adoption of health data standards in the organizational context and applications of international standards for the development of e-Health frameworks and systems. Implementations are the initial step to realize the effects of e-Health standards. However, we also found that there are still research gaps to be filled in these themes. The results that standards-based frameworks and systems bring to the real world of healthcare, such as how they realize interoperability after implementation, is a significant topic that requires academic attention.

Based on the preliminary results of the systematic review, the pool of reviewed studies will be further examined for their quality and divided into more elaborate themes. For instance, the benefits to various stakeholder groups, barriers and adverse outcomes are some themes that are worth surveying as part of this systematic review. Through further synthesis, we expect to derive practical implications that can facilitate future e-Health interventions and policies based on standards while addressing challenges associated with standards.

4. CONCLUSION AND FUTURE WORK

This study explores the divided landscape of standards in e-Health research. The amount of studies under the topic of standards and e-Health has grown during the past decade in diverse disciplines but without an integrated approach to assess the state of academic research and generate common themes. To make academic contributions by bridging the existing gap, we reviewed the literature and found key themes that are linked to the role and effects of standards in e-Health.

Standards are an essential element in building e-Health projects and strategies at national, regional, and international levels. Differences in the depth of projects were found between developed and developing countries. Types of standards vary from health data standards to medical device standards that have influence on interoperability and other important variables including quality and security in the areas of patient care, hospital performance, and health data.

ACKNOWLEDGEMENTS

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INTELLECTUAL PROPERTY LICENSING TENSIONS IN INCORPORATING OPEN SOURCE INTO FORMAL STANDARD SETTING CONTEXT - THE CASE OF APACHE V.2 IN ETSI AS A START

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ABSTRACT

Open Source Software is playing an increasing role in ICT standardizations on future technologies such as 5G and Internet of Things. Formal standard settings organizations (SSOs) are exploring ways to incorporate open source approach. This paper depicts the difference between open source licenses and the current SSOs legal framework in dealing with intellectual property rights, mainly the FRAND license commitment for patented technologies and the distribution for copyrighted software in specifications. Such difference might cause tensions in the two scenarios of interactions between SSO standards and open source: the implementation phase and the standardization activity phase. Some of the tensions are currently hypothetical. However, one recent and concrete example from ETSI, hosting an open source project under Apache v.2, might shed light on how SSOs can (cannot) avoid tensions by making changes to the governing framework.

Keywords—open source software, ICT standardization, IP licenses, ETSI, 5G

1. INTRODUCTION

Future technologies, such as 5G and the Internet of Things (IoTs), present a unique opportunity for new forms of innovation and collaboration in standardization activities. Among other things, open source software (OSS), is increasingly active in shaping technologies such as NFV [1]. Previous research from both academia and the industry have explored possible ways for open source to play a role in Information and Communication Technology (ICT) standards development [2][3]. Questions are often asked in these studies, such as how Intellectual Property rights (IPRs) in the interplay will be dealt with, who will own the copyright and whether patent license commitments are compatible. Several issues have been addressed in some pioneering legal work [4][5][6]. Most of these legal discussions focused on the compatibility between Fair, Reasonable and Non-Discriminatory (FRAND) licensing commitment on Standard Essential Patents (SEPs) and open source licenses (OSLs). Few of them have touched upon legal discussion about the whole picture, given the evolving reality that new technologies keep bringing new scenarios [7][8][9].

Against this background, this paper endeavours to generate an overview on the IPR issues, namely copyright and patent, in the current discussion. Given the complexity of different actors in these potential interplays, we limited our research by taking the perspective of formal standard settings organizations (SSOs). We wish to the following questions: “Whether the current IPRs framework of formal SSOs is adequate to embrace the OSS?” “What are the differences between SSOs’ IPR policy and open source licenses in dealing with IPRs?” “What gaps may arise from such differences?”

In order to explore the answers, we need to first understand the differences in current SSOs policies and open source licenses, by examining the IPR policies for licensing in both SSOs and OSS (Part 2). Such comparisons should not be conducted in a vacuum; instead, we will analyze the tensions in scenarios where open source licenses meet IPRs policies of SSOs, with the help of reference to existing IP laws, legal discussions and court cases (Part 3). In part 4, we will introduce an open source project (OSM) launched by the ETSI in 2016 [10] to reflect on our arguments. Since we limited our stance to the SSOs perspective, we will discuss the scenarios where SSOs take a pro-active role, namely facilitating open source implementation and utilizing open source working process. We admit that other interactions between open source and ICT standards might occur in reality, nevertheless, these are not within the scope of current research such as scenarios where open source products become “de facto” standards. Further, in this preliminary analysis, we mainly discuss policies of three formal SSOs because they have an international influence and are currently active in developing future technology standards. They are the International Telecommunication Union (ITU), the European Telecommunication Standard Institute (ETSI), and the Institute of Electrical and Electronics Engineers (IEEE). Policies of other SSOs will be mentioned if necessary. Similarly, it is not possible to exhaust all OSLs here. We will focus on some typical features represented by the nine licenses that are “popular and widely-used or with strong communities” identified by the Open Source Initiative (OSI) [11].

2. SSO AND OSS: LIBRARIES AND BAZAARS

Perhaps a sense of difference could already be perceived when one looks at the two abbreviations, SSO and OSS.
Built on the term from Raymond\(^1\) and Krechmer compared SSO and OSS “libraries” and “bazaars” [12], respectively, indicating that the values and bases which have evolved in the two contexts are quite different.

The metaphor of “libraries” suggests the value to society of vetted and maintained knowledge that is publicly available. It is common in ICT sectors that companies come together and agree on a single standard, taking the form of an SSO. The ITU, IEEE and ETSI are among formal SSOs that have been recognized by some authorities\(^2\). Technical standards developed by these bodies generally refer to “the establishment of norms and requirements for technical systems, specifying standard engineering criteria, methodologies or processes” [13]. They are relatively stable and establish a common base for the norms for implementation. Technologies embedded in standards are made available through IPRs licenses.

Comparably, the metaphor of “bazaars” represents a marketplace full of new ideas, the freedom to change and evolve [12] [14]. The free software movement started in 1983 with the launch of the GNU project maintained by Free Software Foundation (FSF), as a response to over privatizing software via copyright protection. The OSI was established in 1998, and is an organization that certifies OSLs, which has also certified the General Public Licenses (GPL) maintained by FSF is also included. It is worth mentioning that both the OSI and FSF recognize the four basic freedoms: the freedom to run the software, the freedom to study how the software works, the freedom to distribute the code and any modified version. OSLs have designed terms to guarantee these freedoms. One essential part is to make the source code open, which would otherwise be kept proprietary. Although they have different structures, IPRs are important to both. In the following text, we will discuss how copyright and patent have been structured and made available in these two contexts.

### 2.1. Copyright

#### 2.1.1 SSOs

A "literary work" is entitled to copyright protection when it is the author's own intellectual creation. A Specification produced by SSOs may constitute a literal work. The same with many SSOs, ITU, ETSI and IEEE have claimed in their bylaws that copyright ownership over specifications produced by their working groups.

Depending on the business model, some SSOs such as the ETSI make their specifications available for free, while some such as the ITU and IEEE sell them. Arguably, SSOs value stability over distribution. Distribution of standards is constrained, especially when the document is not free of charge. Distribution of modified versions as standards is strictly prohibited in SSOs, as it would be considered as a threat to the stability of a standard [13].

When code is included in specifications, if not specified, it will be treated the same as the other part of the specifications. For instance, the IEEE bylaws are silent about software in standard specifications. However, some SSOs have raised awareness that software contributed by members or third parties may be referred by standards. Both the ITU and ETSI have introduced software guidelines (rules), according to which additional licenses are demanded from contributors for any code that has been included only for technical purpose, such as describing functionality or testing for conformance. The ITU has three detailed licensing approaches that contributors (members) can choose from, ranging from waiving the copyright to another FRAND commitment on implementation use [16]. Nevertheless, software copyright is not on the priority agenda of SSOs policy yet.

#### 2.1.2 OSS

Although Richard Stallman deliberately created the notion “copyleft” when he started the free software movement, it is now commonly recognized that open source code is subject to copyright protection as other software is [17]. Copyright protection forms the basis for OSLs, in which copyright is defensively reserved to ensure the freedoms and norms valued by OSS [17].

Contributors remain as right owners, while a specific open source license defines how other rights, such as the right to run, to modify and to distribute will be licensed. Making source code open to any recipients who agree to the OSLs is the core difference between OSS and proprietary software. Some other common norms are also mandated by the OSI. Royalties for copyright per se are not permitted, but fees are allowed for physical transactions.

Free distribution is at the heart of open source licenses. Distribution of derivative work is also guaranteed [18]. In some cases, recipients might change the code and develop something that deviates from the original and call it the same name while “forking” the original. As a result, an open source project generally cannot reach the same stability of a technical solution that a standard provides, nor does it value stability over the innovation flow that it keeps, which reflects the value difference we described before. However, this freedom to distribute is only ensured when the recipient agree to other accompanied norms in the licenses. If recipients violate an open source license, copyright infringement will be triggered.

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\(^1\) In his work “Cathedral and Bazaar”, Raymond used the metaphor of “bazaar” to illustrate the software development model of OSS in contrast to proprietary model. See [14].

\(^2\) ITU is the United Nations specialized agency. IEEE is one of the organizations accredited by ANSI to develop US standards. ETSI is recognized by the European Union (EU) to produce EU standards.
One of the well-known norms is the “copyleft”, which is a general method for making a program (or other work) to be licensed under the same open source license. This requirement extends to all modified versions. Five in nine of the most popular OSLs today have this feature, such as the GPL, Mozilla Public License (MPL), or Eclipse Public License (EPL). While among them, GPL family licenses have the strong copyleft that requires modifications to be licensed back “as a whole”, which is argued to have the viral effect that contaminates contributions combined with the license [19]. While the scope of “weak copyleft” feature of licenses such as MPL or EPL is limited to contributions made to the project under the license. Other norms, including approaches toward patent rights, may also be part of an open source license, such as in GPL v.3 and Apache v.2.

2.2. Patent licenses

Perhaps one of the most contentious issues that have been discussed so far in the context of the interaction between standards and open source is the patent granting clause [4][5][20][6]. A patent is an exclusive right granted for an invention of a new way of doing something. Unlike copyright which emphasizes on originality, a patent right went a step further to control the idea behind new inventions. Arguably, it is stronger in terms of exclusivity.

2.2.1 SSOs

As we have learned from recent discussions on SEPs, patent commitment constitutes a significant part of SSO IPR rules. While SSOs maintain the copyright of specifications, patented technologies embedded in standards are on the hands of members (patent right holders). Implementers have to seek a patent license for inter alia SEPs in order to comply with a standard. The value of a patent tends to increase after it has been embedded in a standard thereby enhancing the bargaining power of the patent holder [21]. Hence, it has become a common practice for SSOs to require a license commitment on SEPs by members before including the patented technologies [22]. Common commitment practices include: Fair Reasonable and Non-discrimination (FRAND), Royalty Free (RF) and Non Assertion Covenant (NAC) [23]. FRAND is the most widely used SEPs commitment in terms of both number of technologies and SSOs [24]. For instance, the ITU, IEEE and ETSI require patent holders to commit to negotiate FRAND license terms to make their SEPs available to implementers. SSOs do not specify what terms constitute a FRAND license, leaving parties to negotiate. It is worth noting that, the IEEE took further steps in 2015 on enriching the meaning of FRAND. For example, it specified the smallest saleable unit principle (SSUP), which requires that a reasonable royalty calculation should consider the value of the smallest saleable compliant implementation that practices that patent claim. Nevertheless, as the United States Patent and Trademark Office (USPTO) put it, the FRAND is an effort from SDOs to “reduce the occurrences of opportunistic conduct in the adoption of voluntary consensus standards, while encouraging participants to include the best available technology in standards” [25]. The fact that FRAND is a vague concept leaves room for parties to negotiate, which is a balance between the access to technologies and the interests of patent holders.

2.2.2 OSS

Unlike SSOs that put much attention on patents, copyright-based OSLs did not have patent grant clauses in their early generations. However, with the growing number of software-related patents issued by patent offices worldwide, patents are now pervasive in software innovation industry. Correspondingly, many OSLs today have patent clauses. Six of the nine most popular OSLs have explicit patent clause, and all of them require to grant patent on RF basis. Although the first impression would be that such a RF clause with a specific open source license is clearer than a mere FRAND commitment, norms accompanied by OSLs (the same are applicable to copyright) will influence the actual effect and scope of a patent clause. For instance, patent retaliation clause adopted Apache v.2 specifies that the patent grant is terminated once the recipient initiate a patent litigation against the patent right. Another example is the copyleft feature that we have discussed. GPL v.3 has both RF patent granting and copyleft, which might subject a patent owned by a third party to the same RF clause once it has been combined with OSS released under GPL v.3.

3. PERCEIVED TENSIONS

Having discussed the different values and ways of making copyright and patent available, it should be noted that these differences do not necessitate conflicts; instead, one should consider them in the context of different scenarios. SSOs used to be an arena where proprietary technologies played the main role. However, an empirical study on the RDFa standard and its implementation in the Drupal open source project has shown that “widely deployed standards can benefit from contributions provided by a range of different individuals. Organizations, and types of organizations either directly to a standard or indirectly via an open source project implementing the standard” [26]. With the need of ever fast growing technologies, major formal SSOs such as ITU, ETSI and ANSI in ICT all have recognized the advantages of utilizing OSS [27][7][8] and have started exploring the possible ways to utilize open source working process and potential IPRs risks. A recent study by Lundell and Gamneliesson depicted three basic scenarios based on sequence of standards and open source, namely “standard first”, “software implementation first” and “standard and implementation of standard in parallel” [2]. For the purpose of the current research, we categorized two major clusters from the perspective of SSO, according to the time when an SSO is utilizing OSS: one in the implementation phase and one in the standardization activity phase. It should be noted that, such simplification is only for the explanation of the current paper and variations.
may happen in the real world. Below, Table 1 combines the applicable rules discussed in Part 2 and the tensions argued in the following texts.

<table>
<thead>
<tr>
<th>gap</th>
<th>incompatibility with OSS</th>
<th>license type</th>
<th>possible categories of OSS</th>
<th>implementation scenario</th>
<th>standardization activities</th>
<th>applicable rules and tensions</th>
<th>in major scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSO</td>
<td>FRAND</td>
<td>Ownership of specifications</td>
<td>FRAND, compare with SEPs (ETSI)</td>
<td>NA (MIT…)</td>
<td>contributors own the copyright</td>
<td>contributors own the copyright</td>
<td>RF Patent clause (GPL v.3,…)</td>
</tr>
<tr>
<td>OSS</td>
<td>NA</td>
<td>Free distribution subject to OSLs</td>
<td>Not specified (ITU, IEEE)</td>
<td>contributors own the copyright</td>
<td>contributors own the copyright</td>
<td>contributors own the copyright</td>
<td>RF Patent clause (GPL v.3,…)</td>
</tr>
</tbody>
</table>

3.1. Implementing SSOs standards in OSS

Whether OSS can implement on a standard with SEPs subject to the FRAND commitment has been discussed for years. Some open source opponents argued that FRAND commitment discriminates against OSS implementations[20]. Several previous studies have addressed the compatibility of FRAND licenses with open source licenses. Mitchell QC & Mason classified the OSLs accredited by OSI into three categories and concluded that only projects using GPL family license would have uncertainties when implementing on standards with SEPs under FRAND Kesan’s work reached a similar conclusion [4].

Based on previous work, we now explore the features of OSLs that lead to such (in)compatibility. There are three possible categories: copyleft, patent clause, and other norms. For the first category, an open source license with strong copyleft feature is very likely to be incompatible with a FRAND license, whether it combines with an explicit patent license, e.g. GPL v.3, or not, e.g. GPL v.2. On the other hand, licenses with weak copyleft feature are compatible with FRAND, even if they contain a royalty free patent clause, e.g. the EPL.

Secondly, although the granting of royalty free patent sounds different from royalty-bearing FRAND, it does not render the license compatible with FRAND. Because most of the patent clauses in OSLs, without copyleft, only apply to the “work” or “contribution” from open source.

3 * means whether FRAND applies is not clear, but this is the only patent rule in the current IPRs framework of these three SSOs.

SEPs are therefore still subject to FRAND licenses provided by patent holders. Arguably, SSOs have less concerns for encouraging OSS implementations. Actually, open source implementations on standards are not rare in practice. For example, in the GSM standards developed by the ETSI, there are several OSS projects involved that provide GSM features, e.g. the OpenBTS which develops a base transceiver station. There are also open source projects under GPL v.2 that implement standards that contain FRAND committed SEPs, but many of these are exempted from patent license obligations on the condition that they are not used commercially, e.g. OpenBSC and Open IMS Core [28]. Nevertheless, this does not remove all the risks. Research from Lundell, et al., showed empirical evidence that some organizations controlling patents either cannot be reached or decline to respond, that the effort to obtain a patent license might deter implementations under any open source license in the first place[6].

3.2. Usage of OSS in developing SSOs standards

Perhaps the more complex situation is for SSOs to utilize open source working practice to develop standards. It happens in two sub-scenarios: using source code in specifications directly; and where specifications refer to the same function derive from open source projects.

3.2.1. Direct use of running code

In a situation of a direct use of code, the first thing come into play is the copyright issue over this specification (code included).

Ownership: As we have discussed in part 2, SSOs own the copyright of specifications, while in the open source project, developers remain the right holder. It is uncertain whether SSOs still claim the copyright if code is included as part of the specifications. It should be noted that the definite copyright ownership of specifications by SSOs has aroused debates. A recent case James Elliott Construction Limited v. Irish Asphalt Limited [29], has raised the question of whether European Standardization Organizations can be the right owner for EU standards. However, we also see that a judgement of the Landgericht (Regional Court) Hamburg as of 31 March 2015 confirmed the copyrightability of standards maintained by the German Institute for Standardization (DIN).

Distribution: One may argue that at least in the case of ITU and ETSI, they have software guidelines, which may apply to direct code utilization, if contributors of an open source project agree to these guidelines. This may solve the ownership issue, since these guidelines give the option to contributors to either transfer the ownership or grant a software license. Nevertheless, the problem then lies on distribution. The right granted by such guidelines to copy, modify and distribute are only limited to specific situations listed in those guidelines. Such restrictions obviously contradict the free distribution guaranteed by OSLs.

3
Lack of specific rules: If there is a need for the ITU and ETSI to change the software guidelines, the lack of any IPR rules governing embedded software in the IEEE poses more uncertainties. As a matter of fact, SSOs accredited by the American National Standard Institute (ANSI) may lack a particular clause for code ownership and distribution in specifications, since the ANSI appears to discourage software from being embedded in specifications [24]. In such absence, one can only refer to the copyright rules over specifications, by which the distribution of code embedded in the specification will be substantially restricted, in contrast with the sharing and collaborating practice in the open source community.

3.2.2. Code becomes essential

If the code included becomes essential copyright, it will become more imperative to address the copyright issue we discussed above.

Lack of specific rules: None of the three SSOs so far have a particular clause regarding essential copyright. The ETSI IPR policy even emphasizes that software embedded in specifications shall not be used as mandatory for compliance [16]. Again, SSOs accredited by the ANSI, have been discouraged from including software in standards, let alone letting them be essential.

FRAND commitment: In the absence of specific rules, one may refer to the same clause for patent license. For instance, in the ETSI, the essential claims subject to FRAND license terms use the term “intellectual property rights”, which is broad enough to encompass both copyright and patent rights. Similarly, in the case of SEPs, implementers could seek a FRAND copyright license --- which might bear royalties --- to copy the standard (code). While in the meantime, such code should be licensed under the original OSLs. It is unclear whether FRAND license terms or open source licenses will prevail. In any case, as Bekkers and Updegrove have noted: “...patents and copyrights are sufficiently different that using the same language do address both types of IPRs provides a less than ideal result” [24].

3.2.3. Functions derived from open source code

If not directly using the code as (part of) technical specifications, functions derived from open source code could be adopted in a standard. We have seen large innovation flows in open source projects, it is fair to say some of these patents derived from open source code which may become SEPs.

RF license: If an open source license does not contain any patent clauses, e.g. MIT or BSD, the patent issue could only be left to the policies of a standard body, which might in the end subject to the FRAND commitment. However, if a license contains a patent clause, e.g. the Apache v.2, the patent right is granted on a RF base subject to the open source license. The question would then be whether SSOs can require the right owner who contribute the patent also to the standard to license it under FRAND license even if there is already an open source license with RF patent granting underlining the patent right? We cannot find any entitlements for SSOs to do so in the current SSOs framework.

Different from OSS implementation: It should be noted that this sub-scenario is different from the OSS implementation scenario we discussed in 3.1 in two aspects. Firstly, as we have previously discussed regarding the compatibility between the FRAND license and OSLs, here it is more about which form of patent granting should prevail, the FRAND commitment or the RF granting from OSLs. In the absence of specific rules by SSOs so far, it seems that open source terms are the only clear applicable rule. In this case, RF granting will be the license fee to use the embedded technology. Since the capability to collect royalties on patents are one of the main incentives for many innovators to contribute technologies [30], it is unclear that whether such switch will be embraced by SSO members. Besides the RF granting, perhaps a more troublesome concern is the cascade effects of OSLS. While enjoying the patent for free, implementers have to be bound to other restrictions by an open source license. Some norms are not aligned with the current practice of SSOs. For instance, open source licenses contain a “patent retaliation” clause that generally discourages recipients from bringing patent litigation against the “work” that incorporates the patented contribution, otherwise the patent right will be terminated. This prevents implementers from filing lawful litigation if they find that their patents (included in the same work) have been infringed, which is guaranteed and encouraged by the current framework of SSOs and by competition authorities.

3.3 Conclusion

Having said the above, we find that gaps exist in the current IPRs framework of the ITU, ETSI and IEEE, which pose risks and impede SSOs from utilizing OSS.

In addition, our preliminary legal analysis shows that FRAND licenses do not necessarily conflict with most OSLs (except GPL family licenses). However, in order to encourage OSS implementations, SSOs would benefit from having specific terms to clarify the different applications of the scope of FRAND and OSLS terms to avoid future confusion. Particularly, practices such as patent exemption (e.g. OpenBSC) for research or other non-commercial purposes should be encouraged.

More importantly, software guidelines of SSOs need to change to keep pace with the growing role of software (OSS is only one model). SSOs such as the IEEE that do not have a software guideline would benefit from establishing new rules. For those that have already done some work like the ITU and ETSI, an attentive update will be in order to embrace open source working processes in developing future standards. Although essential copyright is less common than SEPs at the time of writing, we can now find at least one close example in the XML standard, which contains code to the structured information it unifies. Applying the same FRAND rule with SEPs is not the ideal approach. One precedent can be learned from the IETF, in
which the SSO specifies that any source code included in a standard must be made available under the BSD open source license, which applies both to essential and non-essential copyrights in software code.

Similarly, patents built on OSS code must not be ignored either. When standardization activities are closely connected with an open source project, as we learned from an empirical study on RDFa standards and the Drupal open source project, overlapping is very likely to happen in these parallel developing situations, which is proved by the similar proportions of issues raised by the top raisers in W3C RDFa and Drupal RDFs of the contributions [26]. As a result, whether SSOs need a separate patent license policy apart from FRAND on SEPs is an open question that needs to be explored.

However, one should not expect a one-size-fits-all answer. Detailed rules should be warily designed and aligned with goals of a specific SSO on the extent to which it would like to embrace OSS. Nevertheless, a more clarified IPRs policy would help fill the gaps in the current framework.

4. APACHE V.2 WORKS IN THE ETSI

Having discussed these gaps and tensions, a recent case in the ETSI might shed some light on how SSOs might be able to cope while utilizing OSS.

In April 2016, the ETSI, which is one of the key formal SSOs in the telecommunication sector, launched an open source project “OSM” under the open source license Apache v.2, which is aligned with ETSI Network Function Virtualization (NFV) Information Models[10]. In order to answer whether the ETSI is able to (totally or partially) remove concerns in this project, we will analyze the potentially applicable IPRs rules. These documents include: ETSI IRP policies (which have been discussed in parts 2 and 3), the relevant Apache v.2 license clauses, and two specific documents governing the project, including the OSM Terms of Reference (ToR), the Contributor License Agreement (CLA), which has the same copyright and patent license rules with the Apache v.2. Here we draw a simplified chart of the governing documents of IPRs of OSM in Figure1.

**Fig. 1. Governing IPR rules in OSM**

Apache v.2 is among the nine most popular OSLs identified by the OSI, accounting for 15.34% of the open source projects in the records [31]. Major features have been noted in previous texts as well. Succinctly, it is not a copyleft license. It has the so-called “patent retaliation” clause. The core idea is that while granting a RF on patents, receivers are not allowed to initiate patent litigation against any entity (including a cross-claim or counterclaim in a lawsuit) alleging that the Work or a Contribution incorporated within the Work constitutes direct or contributory patent infringement, otherwise the RF granting license will be terminated [32]. The application scope of the patent retaliation clause is defined by the scope of “Work” and “Contribution”. “Work” is not equal to “Contribution”, generally, the scope of “Work” can be broader than “Contribution.” This means that both litigation against “Contribution” that contains the patent in the matter and also other patent contained in the same “Work” will trigger the patent retaliation and deny the patent right that one may have received.

4.1. Limited to implementation

The scope of application of the ETSI IPR policy and the Apache v.2 are essential to our analysis. Boundaries are defined, according to which, the OSM is confined to be an implementation on NFV, and “…[n]either the CR’s nor the OSG OSM Reports will contain code for direct inclusion into an ISG NFV Group Specification”.

A pure implementation seems to be the ETSI’s design for hosting this open source project. Following our discussion in section 3.1, the FRAND commitment and Apache v.2 will apply to SEPs and the OSM, respectively. The two do not necessarily encounter each other in the current phase of OSM. Moreover, we observe that the ETSI MANO is an emerging technology that no party has claimed SEPs on. Hence, there is less risk for open source developers to seek a patent license.

4.2. Potential standardization activities in OSM

Although the ToR went through great lengths to show that deliverables from OSM are not ETSI technical specifications, and that code will not be directly included in specifications, we find some clues in the projects that might not be able to exempt all the possibilities for overlapping easily. One of the functions of OSM stated in the ToR is to “provide practical and essential feedback to the finalization of the ETSI MANO stage two and three specifications.” Such feedback helps formulate the ETSI MANO Standards and the future 5G standards.

Moreover, it is fair to predict that standards that are based on existing OSM implementations are possible. We argue this for two reasons: first, we have seen multi-party de facto standards (implementations) existed before selective process and multi-protocol activities carried out by SSOs such as the IETF or W3C [33][34]. Second, as we have discussed in previous texts, technical sharing between RDFa standard and the Drupal project showed high possibility for overlapping function between SSO standards and an open source project.

Therefore, while direct inclusion of code has been avoided by the ToR, there is still a high possibility that some functions derived from OSM code can be adopted into ETSI NFV standards. Since OSM is a hosting open source project in the ETSI, the patents based on such code are
likely from ETSI members who have signed the CLA. Reflecting on our analysis in section 3.2, if patents turn out to be essential, without clear guidance, Apache v.2, which directly governs the OSM, FRAND will prevail and such patent right will be made royalty free to any recipient that agrees to Apache v.2 in OSM.

Besides the possibility of rendering members’ patents to RF, the “patent retaliation” brings more concerns. As we learned, contributors have to agree not to file patent litigation against the “Work” to avoid triggering patent retaliation. However, as the project continues, the “Work” will grow much larger than it was when first contributed and when the CLA was created. The current ToR did not provide any mechanism to monitor the continuing contributions to the project, which may cause uneasiness when companies decide to participate. Perhaps such uncertainty can explain the number of participants in OSM at the time of this writing, with 65 companies having signed on to the project, 32 of which are ETSI members. Considering that the ETSI has over 800 members, the current participating number is by no means high.

5. DISCUSSION AND CONCLUSION

As we summarized in Part 3, the current legal frameworks on IPRs licensing of SSOs, including the ITU, IEEE and ETSI, have shown gaps for OSS to fit in. By exploring the ETSI OSM case, we further enriched our arguments. First and foremost, although consortia, such as W3C and OASIS, started similar processes, it was conducted mostly in industries where patents were less heavy. For instance, an empirical research about OASIS showed that technical committees on telecommunication sectors were among the two that opted for royalty bearing FRAND commitment other than RF commitment [30] Considering that more than 100,000 SEPs have been declared in the ETSI under FRAND commitments [35], OSM is a pioneering step that other formal SSOs can learn from.

Secondly, the ToR presents the ETSI’s awareness to address some of the tensions we described in Part 3. It clarifies the goal of hosting the OSM, which leads to a clearer scope of application of ETSI IPRs policy (e.g. FRAND commitment and the software guidelines), thus removing some tensions such as in the direct use of cunning code. This in turn confirms our hypothesis on potential tensions if we only rely on the existing framework.

Secondly, we found out that ETSI members might still have a reason for concern as the project develops. Without a clear guidance on the priority of FRAND and Apache v.2, there is a chance for making patents embedded in standards free from royalty charges to a “Work” that is too large to be controlled. One goal of the ETSI is “seeking a balance between the needs of standardization for public use … and the right of the owners of IPRs” [16], which may need further consideration. Besides, other open source projects, e.g., OOCCRAN under AGPL (as of this writing) may also contribute implementations to ETSI MANO. Such ambiguity is by no means an ideal circumstance.

Further, although the ETSI sets an example of how SSOs can utilize OSS, the strict exclusion of OSS code in specifications might also impede full utilization of OSS. The power of code is likely to go up, since there are already questions of whether the industry can rely only on open source to define functions of future technologies instead of formulating a standard [36]. Nevertheless, there is no need for SSOs to panic, as Updegrove said, “code [actually] has been creeping into standards for years, [but] often without the keepers of intellectual property rights policies governing the standards even being aware of it” [37]. What matters is for SSOs to realize the issue, conceive its own goal, and design an optimum mode accordingly.

REFERENCES


GOVERNANCE WITHIN STANDARDS DEVELOPMENT ORGANIZATIONS: WHO OWNS THE GAME?

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ABSTRACT

The past decade has witnessed the rise in prominence of interoperability and Internet standards in the wake of increased digitalization and technological advancement. Typically established by industry-driven association of professionals, often referred to as Standards Development Organizations (SDOs), standards and technical specifications are expected to address the needs of the industry and to benefit society. While SDOs arguably attempt to involve all directly and indirectly affected stakeholders in their standards development, the establishment of organizational rules and procedures, including Patent Policies, is often left to the discretion of the SDOs’ governing bodies and may not necessarily represent consensus of all interested parties. Placing procedural guarantees in the limelight of standardization research, this paper seeks to compare the actors and procedures of different SDOs as regards their standards development, governance processes and dispute resolution. It observes that procedural rules for standard-setting are not per se applicable to the decision-making in the governing bodies of the SDOs, and aims to suggest the possible consequences of this disconnection.\footnote{The author received financial support from Qualcomm Inc., but all ideas are author’s own. All links were updated on 5 October 2017.}

Keywords — Standard-Setting Organizations; Governance in Standardization; Procedural Guarantees

1. INTRODUCTION

Standardization plays a crucial role in the era of emerging technologies and increased digital convergence. Being technical specifications that codify technologies or prescribe methods applied in electronic devices, technical interoperability standards enable the necessary interference, coordinate transmission frequencies and encryption software \cite{1} and provide compatibility between complex electronic mechanisms \cite{2} \cite{3}, creating invisible interconnections between products of different vendors, networks and interfaces. However, standardization goes far beyond the ambit of electrotechnics and engineering. Technological compatibility has a profound impact on the functioning of modern society \cite{4}: anyone who uses electronic devices understands the importance of their interconnection. At the same time, the exchange, retrieval and storage of information is greatly facilitated by Internet standards and protocols and causes major human rights concerns. Although lacking hierarchical authority or any official form of governmental endorsement, technological standards may exert significant normative pull and in a way, constrain our behavior. Hence, by influencing technical infrastructure of the market, standardization affects not only devise manufacturers, network providers and software developers, but also global society, and is of technical, strategic and regulatory importance \cite{4}.

The continuous pace of technological development, together with the emergence of the Internet of Things, raises a number of fundamental legal issues, related to the intellectual property embedded in technological standards, processing and sharing of personal data, and the rights of stakeholders in standards development, the latter often being an underrated and uncharted area in standardization research. As a consensus-based process, standardization should preferably aim to provide a solution that would satisfy all affected parties. Such “compromise deal” can only be clinched after concerns of all stakeholders have been voiced, and derives its legitimacy and validity from effective participation mechanisms \cite{5}.

A major share of standards is developed within the specialized voluntary platforms, commonly referred to as Standards Development Organizations (SDOs). Largely composed of industry representatives and technical experts, while the involvement of governmental authorities or consumer associations is not uncommon, SDOs create a neutral forum for coordination and communication between standardizers. Although their orchestration often follows certain patterns \cite{1} \cite{6}, SDOs may vary in their institutional design from formal associations with a vast repertoire of rules to loosely organized fast-paced industry consortia and specialized interests’ groups \cite{7}. As a general rule, SDOs are expected to serve common interests and to act on behalf of their membership: their standard-setting is a multi-stakeholder process, resulting in drafting of specifications document that is subsequently introduced to the industry.

When formulating a standard, stakeholders follow the rules and procedures prescribed by the SDO in which they chose to collaborate. These rules determine, \textit{inter alia}, membership requirements of an SDO; rights of parties within standards development processes; voting quorum for decision-making within the Working Groups; steps that should be taken prior the final adoption and publication of a standard document;

\footnote{The terms “standard” and “technical specification” are used interchangeable in this paper.}
and requirements concerning the disclosure and licensing of patented technologies essential for the proper functioning of a standard. Procedural rules and policies administering standard-setting processes are drafted by SDOs’ governing bodies. Given that these rules are not considered a part of standardization processes, the governance of SDOs has managed for a long time to escape the legal purview. Against this backdrop, this paper seeks to reinforce the importance of standardization processes and the need of legal analysis of standards development procedures within SDOs. It further suggests that, since the rules issued by SDO are binding upon their affiliates, they constitute a crucial part of standardization activities and should be subject to the similar procedural scrutiny as standards development processes. While providing a brief analysis of standard-setting and governance procedures of five prominent SDOs operating in ICT and telecommunications sector, this paper illustrates a divide between stakeholders developing standards and those setting the rules governing standardization processes, and suggest that such disconnect may have negative implications for technological standardization.

2. GOVERNANCE AND STANDARDS DEVELOPMENT OF SDOs

Standardization is a dynamic, expertise-based process that aims to strike a balance between achieving effective technical solutions and getting all standardizers on the same page. In this regard, standards for technical interoperability and Internet protocols are particularly interesting, as their proper functioning and implementation is often conditional upon proprietary technologies subject to patent claims. A lack of agreement between licensors and licensees, and misinterpretation of rules and policies applicable to standard essential patents, create uncertainty among stakeholders and affect their standards development efforts.

Within the confines of committee-based standardization, the onus is on SDOs and their members to design appropriate rules governing disclosure and licensing of patented technologies. Along similar lines, SDOs adopt procedures for managing participation in and contribution to standard-setting, define the rights and obligations of SDOs’ members and provide mechanisms for mitigating arising conflicts. Institutional architecture and orchestration of SDOs affects coordination ability of standardizers and their incentives to join standards development processes; yet, decisions taken during standards development meetings determine the content and implementation terms of standards document and given that standards often shape modern technologies, are likely to impact an array of stakeholders, ranging from hardware manufacturers and technology vendors to consumers and wider society. It is for this reason that understanding of SDOs functioning and organization is of crucial importance for contemporary standardization research.

Despite the differences in their institutional design, SDOs are often believed to mimic each other’s organizational models [1] [6]. One of the features shared between SDOs is their member-driven character, which implies that the rules and procedures governing activities of an SDO, including its technical decision-making, should be agreed among the SDO’s membership. Within industry consortia, whose informal setting proved attractive for ICT and Internet standardization, rules and procedures are typically developed by a small group of actors – the promoters, and the entire membership is not necessarily represented in SDOs’ governing bodies [7]. Unlike processes of standards development, governance processes are not explicitly regulated in national or international frameworks for standardization activities. The overarching requirements introduced by American National Standards Institute (ANSI), the European legislator or the International Organization for Standardization (ISO) concern openness, consensus and transparency of standard-setting, and balanced, FRAND-based patent policies, without specifying the processes of how the policy is developed and approved.

Nevertheless, the significance attached to governance processes of both formal and informal SDOs should not be underestimated. When signing a membership agreement – or joining a working group of an informal SDO - organizations and individuals become bound by the set of rules within that SDO. Naturally, members also retain a certain degree of autonomy in standard-setting activities and are hardly subjected to any form of “control” by an SDO [9]. Their temporary role of standardizers is executed in the shadow of their main purposes, which may be profit maximization, consumer or environment protection, promulgation of human rights, etc. [10]. Membership of SDOs is completely voluntary, as so is the adoption of their standards; contrariwise, SDOs’ operational rules should in principle be followed as a condition for using their forum.

As standards shape technical infrastructure and coordinate behavior of firms and individuals, SDOs’ governance processes coordinate standards development. The strong connection between the two becomes evident once an SDO modifies its operational rules. Such amendments may affect the willingness of firms to join the processes within a particular SDO, or to offer their technologies for inclusion into a standard, which may have profound consequences for the outcome of standardization processes and even reshape the industry [11]. Accordingly, the design of SDOs’ governance determine the course of standardization activities and by this means, exert considerable impact on development of consensus for approval, revision, reaification, and withdrawal of American National Standards (ANSI).


Sec. 1.0: “These requirements apply to activities related to the
those directly and indirectly affected by standards. Moreover, technology standards, albeit their voluntary nature, can impose de facto rules for a particular sector and hence become coercive. Such transformation is legitimized when standards development respects due process and reflects the interests of all affected stakeholders [12], which in turn increases the chance of standards’ industry-wide acceptance [13]. Given the nexus between SDOs’ governance and the effect their standards produce on the variety of stakeholders, it is reasonable to expect that requirements of transparency, openness and consensus would also apply to rule-and and policy-making processes of SDOs.

In that behalf, the ignorance of governance processes within SDOs is quite astonishing. The idea that the establishment of SDOs’ operational rules should be subject to similar principles as the establishment of standards had not gained much support from the regulators, leaving governance processes a matter of the SDOs’ self-regulatory regime. The exception would have been the principle of “openness” suggested by the Decision of the Technical Barriers to Trade (TBT) Committee of the World Trade Organization (WTO),5 which requires “unrestricted participation in all stage of standards and policy development”, but specifies that meaningful participation opportunities should be guaranteed only for the stages of standards development, rendering the first part of the sentence inutile.

To demonstrate whether there is a disconnect between stakeholders involved in standards development and governance processes, the next section analyzes five prominent SDOs - European Telecommunications Standards Institute (ETSI), Institute of Electrical and Electronics Engineers Standards Association (IEEE-SA), Internet Engineering Task Force (IETF); World Wide Web Consortium (W3C) and Bluetooth Special Interest Group (Bluetooth SIG) - as regards their standard-setting procedures, rule-making and dispute resolution.

3. COMPARISON OF SDOS STANDARD-SETTING AND GOVERNANCE DECISION-MAKING

3.1. Analysis of SDOs’ operational frameworks

The SDOs selected for this study operate in the area of ICT, telecommunications and Internet, and play a considerable role in the digitalized society. The difference in their institutional architecture should be noted from the outset: while ETSI and IEEE-SA fit the definition of formal organizations, IETF represents a “loosely self-organized group of people who contribute to the engineering and evolution of Internet technologies”.6 In turn, both W3C and Bluetooth SIG are examples of industry-driven consortia, managed by a group of founding members/promotors.

European Telecommunications Standards Institute (ETSI)7 ETSI is a non-for-profit association established by the mandate of European Conference of Postal and Telecommunications Administrations (CEPT), with support of the European Commission. It is also one of the three European Standards Organizations (ESOs) mentioned in Annex I of Regulation 1025/2012, and hence entitled to set harmonized European standards (ENs). From the moment of its creation to current days, ETSI has published over 30,000 standards in the areas of radio and Internet technologies, mobile telecommunication and cellular networks. Standards developed by ETSI are offered free of charge. ETSI’s membership is divided into categories, ranging from administrations and NSOs to service providers and manufacturers, and is open only for entities. Once decided on the category, a future ETSI member can chose between full and associate membership, or observership. Observers should fulfil the conditions of full or associate membership, but their participation in ETSI’s activities is rather limited and subject to a lower fee. At the moment of writing, ETSI counts around 800 members from 66 counties.

The main governing body of the ETSI, the General Assembly, is empowered to adopt procedural rules and binding resolutions, approve European Standards, handle membership requests and amend ETSI’s governance documents. The General Assembly also reserves the right to expel a member in case of non-payment of contributions or substantial breach of other membership obligations. When approving a standard document, the General Assembly decides by the Weighted National Voting, whereby a vote is given by the heads of each National Delegation: this implies that private companies, who constitute the most part of ETSI’s membership, are not (directly) represented in the mentioned processes. For ENs’ approval, the balloting occurs after the NSOs have conducted public enquiry. Yet, when amending ETSI’s Statutes and the Rules of Procedure, the General Assembly takes decisions by qualified majority voting, meaning that the votes of all ETSI members – including private companies established outside the CEPT area – are counted. The EC and the European Free Trade Association (EFTA) participate in the meetings of the General Assembly as Counsellors, but have no voting rights. To act on its behalf in daily activities of the ETSI, the General Assembly appoints the Board, which consists of full Members and the Director-General. The Board establishes its own procedural rules, but its decisions can be overruled by the General Assembly. Standardization activities take place in ETSI’s Technical Organization, which in turn encompasses a number of Technical Bodies responsible for the drafting of technical documents. Each Technical Body may establish Working Groups and decide on the rules governing their activities; however, only the Board or the General Assembly can create and dissolve Technical Bodies. If disputes arise between (a) Member(s) against the ETSI,

5 G/TBT/9, Annex 4: Decision on Principles for the Development of International Standards, Guides and Recommendations with Relation to Articles 2, 5 and Annex 3 of the TBT Agreement, issued on 20 November 2000.


parties should exhaust all appeals procedures available under the Institute’s legal framework prior to initiating legal proceedings. While the ETSI does not maintain a specialized dispute resolution body, the General Assembly may facilitate mediation.

IEEE- Standards Association (IEEE-SA)\(^8\)

IEEE-SA is one of the Major Boards of the Institute of Electrical and Electronics Engineers (IEEE), a private, non-for-profit organization and the largest technical professional society, having over 423,000 members in nearly 160 countries. Although in theory, IEEE-SA operates independently from IEEE, it remains accountable to the IEEE’s highest governing body, the Board of Directors, which in turn is empowered to propose amendments for IEEE Constitution approval assessments of IEEE members and sanction members whose conducts are seriously prejudicial to the Institute.

IEEE-SA distinguishes between two types of standards development: individual process, preferred in the most standardization activities, and corporate process. Accordingly, membership can be obtained by individual experts as well as commercial entities or governmental agencies. Standard-setting within IEEE-SA is managed by the Board of Governors (BoG), elected biennially by IEEE voting members, who also hold the membership of the IEEE-SA. The BoG further appoints the other significant body in the realm of IEEE standardization, the IEEE-SA Standards Board, which coordinates standards development processes and approves new projects. The work of the IEEE-SA Standards Board is facilitated by a number of specialized Standing Committees, whose officials are appointed by the IEEE-SA Chair. Members serving at the governing bodies shall not represent the entity of their affiliation and have a fiduciary duty to the IEEE and IEEE-SA.

The BoG and IEEE-SA Standards Board are entitled to amend IEEE-SA Standards Board Bylaws, a main legal document of the IEEE-SA that provides policies for management and creation of IEEE standards. Modifications of IEEE-SA Standards Board Operations Manual, which governs orchestration and working procedures of the Standards Board, are carried out by the Standards Board and do not require approval of the BoG. The general objectives and policies of IEEE standardization are specified in the IEEE-SA Operations Manual, a document created and amended by the BoG. In turn, the IEEE Constitution can only be modified by all IEEE voting members, upon a position resolution of the Boards of Directors; consent of all IEEE members is not required for amendments to the IEEE Bylaws, which govern operation and administration of the Institute, since the approval of the Board of Directors is sufficient. Those who are directly and materially affected by standards may, upon the exhaustion of the appeals procedures of any relevant subordinate committee or working group, appeal procedural actions or inactions to the IEEE-SA Standards Board and, subsequently, to the BoG. Technical appeals are resolved within the relevant Working Groups.

Internet Engineering Task Force (IETF)\(^9\)

IETF establishes Internet standards and specifications, i.e. protocol layers and general applications (i.e. e-mail). Organizational structure of IETF bears little resemblance to formal SDOs, since it has no membership and is not incorporated in any jurisdiction. IETF standardization activity relies on voluntary participation of individual experts, often hardware and software engineers or academics. Since IETF standardization is ideally based on engineering excellence rather than policy and business considerations, experts are not supposed to represent the enterprise of their affiliation. IETF Working Groups typically take form of a mailing list, to which everybody can sign up. Each Working Group is assigned to one of eight IETF areas, coordinated by the Area Directors (ADs). Standardization efforts within the IETF typically result in a document termed a Request for Comments (RFC), which is published free of charge.

Although fairly informal, IETF activities require at least a minimum of coordination. The structure followed by the IETF participants is offered by other organizations. One of the main bodies dealing with the technical work of the IETF is the Internet Engineering Steering Group (IESG), which bears a direct responsibility for the progress of standardization project, including final approval of specifications as Internet Standards and ensuring that the documents are of a sufficient quality. Long-range coordination of IETF activities is entrusted to the Internet Architecture Board (IAB), concerned with the design of Internet and its protocols, review of new IETF Working Groups as regards their architectural consistency and integrity, and approval of the nominees for the IESG. Administrative structure of the IETF Working Groups, IESG and IAB is provided by the IETF Administrative Support Activity (IASA), which also manages financial matters related to IETF meetings. The scope of IASA’s administrative functions is established by the IETF Administrative Oversight Committee (IAOC), who also bears financial and administrative accountability to the IETF community. The Nominating Committee (NomCom), although not directly involved in IETF standardization, plays a key role in the IETF governance by selecting candidates for the IESG, IAB and IAOC. Remarkably, an individual can be a member of multiple boards or committees.

Rules and processes governing standards development within the IETF are established by consensus in dedicated Working Groups and published as Best Current Practices

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RFCs. Patent policy is typically expected to represent the consensus of the IETF community, and is subject to public review and approval by the IESG. Decisions of Working Group chair can be appealed to the Area Director, and subsequently to the IESG. IAB serves as the final appeal board for the decisions of the IESG and IAOC.

The World Wide Web Consortium (W3C)\textsuperscript{10}

W3C is a non-for-profit organization of around 480 members that defines standards and guidelines for Web design and Web applications, which ensure functionality and accessibility of the web on a global scale. Unlike formal SDOs, W3C represents a non-hierarchical cooperation between universities and research facilities. The consortium is managed by a joint agreement among four “host” institutions (Massachusetts Institute of Technology, European Research Consortium for Informatics and Mathematics, Keio University and Beihang University). W3C standards are defined in the Working Groups of the W3C community and, similarly to the IETF, published in the form of Recommendations.

The membership of W3C is open only to organizations, but all members enjoy equal benefits, irrespective of their nature, orchestration or incorporation. Participation of general public in W3C activities is possible through Community and Business Groups, which unlike Working Groups, are open to non-members; likewise, interested parties may take part in specifications reviews and tests and provide implementation feedback. Individuals may join W3C forum either as Affiliate Members or as “invited experts” upon the approval by the Working Group Chair and the Team, the latter comprised of the Director, CEO and W3C paid staff and fellows. As non-members, the four host organizations are subject to a different set of privileges and obligations, and are entitled to amend the Member Agreement.

The main governing body is the Advisory Committee, comprised of all W3C Members. It reviews proposals for working groups’ charters, recommendations and process documents, and elects the Advisory Board and Technical Architecture Group (TAG) members. In turn, the Advisory Board deals with legal and management matters, oversees the evolution of the standard document and drafts technical rules and procedures, which in turn require approval of all W3C members. The TAG deals with technical issues around Web architecture and coordinating cross-technology developments within and outside W3C. Members who disagree with decisions of the Working Group (including those as the result of a vote), should file a formal objection with the Working Group’s Chair. Appeals are typically handled by the Advisory Board and the TAG. Matters that cannot be resolved through the dialogue or internal appeals procedure are settled by arbitration tribunals.

Bluetooth Special Interest Group (Bluetooth SIG)\textsuperscript{11}

Bluetooth SIG is a non-for profit and non-stock corporation dedicated to the development of specifications for wireless connectivity solutions and low-power wireless connectivity technologies. The membership of the Bluetooth SIG can only be acquired by entities, and is divided in three classes: Promoters, Associate Members and Adopter Members. Being the only voting members, Promoters and are entitled to appoint a representative to the Board of Directors, the main governing body of the consortium. Promoter membership is granted upon the unanimous consent of other Promoters. Adopter Members may implement specifications and participate in certain committees of the Bluetooth SIG. Adopter Members can also be promoted to Associate Membership, which grants them right to participate in working groups and access relevant information. In total, Bluetooth SIG has more than 400 members at the moment of writing.

The Board of Directors reviews membership applications, adopts final versions of all Bluetooth specifications, oversees qualification and testing programs and establishes committees and working groups, whose activities it also can veto. The Board of Directors is composed of one representative appointed by each Promoter for unlimited time and, subject to the unanimous approval of the Promoters, representatives of up to four Associate Member Directors, appointed for a two-years term. All other members may participate at the meetings of the Board of Directors as observers. Guidelines established by the Board of Directors serve as default procedural rules, but working groups may draft their own procedures in their charters. Bylaws of Bluetooth SIG may only be amended by unanimous approval of the Promoters. The consortium does not provide any appeal mechanism: disputes are resolved exclusively by the state and federal courts of New York.

3.2. Findings and Explanations

As expected, all five SDOs are dominated by industry and private sector representatives. Depending on the SDO, governments and public society enjoy a certain level of participation, either by directly contributing to the activities of Working Groups (ETSI, IEEE-SA, IETF), or by engaging in public review processes (IEEE-SA, W3C). Working and Study Groups of SDOs have a discretion to adopt their own procedures and charters, as long as those do not contradict the rules of the SDO under which they operate. Due account must be taken of the fact that each of the discussed SDOs administers different types of standards and operates in a different setting, and thus they can only be compared to a very limited extent.

Despite these constraints, the findings of this paper, although still very preliminary, illustrate that the governance of “consensus-based standardization” is not always build on consensus between all stakeholders. For instance, in a complex web of governing bodies in the IEEE and its


\textsuperscript{11} Bylaws of Bluetooth SIG, Inc. (June 2015) retrieved from https://www.bluetooth.com/membership-working-groups/membership-types-levels/membership-agreements.
Standards Association, a crucial role is performed by the BOG, whose members are selected by IEEE members following a rigorous process. In contrast, any update of the W3C Process Document and its Patent Policy requires approval of the entire membership, and the Advisory Board, entrusted with amendments of operational framework, is selected by all W3C members in the Advisory Committee. Likewise, ETSI membership is consulted when developing and modifying Institute’s procedural rules and facilitating settlement of disputes, since both activities are performed by the General Assembly. Modifications of IETF’s standard-setting procedures are carried out by a Working Group, rather than by a governing body or its committees. In the absence of definite membership, any estimation of the extent to which IETF standardizers are represented in the decision-making of its governance is hardly possible. An interesting observation can be made as regards the IETF patent policy that, unlike it was the case in other SDOs, was offered for public review. In contrast to these four SDOs, governance and standard-setting processes within Bluetooth SIG are mainly driven by a small group of companies: contributions from other members are permitted for as long as they are approved by Promoters.

4. POSSIBLE CONSEQUENCES OF THE DISCONNECT BETWEEN GOVERNANCE AND STANDARD-SETTING

As self-regulatory bodies, SDOs by all means enjoy a high degree of autonomy when designing their governance models. In the long run, all five SDOs have proved to develop successful standards and still remain attractive platforms for various types of stakeholders, irrespective of their governance mechanisms. Challenges arise when (a group of) standardizer(s) sharply disagrees with the methods underlying the adoption of a standard but is not provided with means to voice their concerns. Such type of situation undermines the achievement of consensus between affected stakeholders and is likely to affect the quality and market acceptance of a standard in question, not to mention the fairness and openness of standardization process.

Modern history of technological standardization is rich in cases where procedural guarantees of SDOs’ members were at stake. The amendments of IEEE-SA Patent policy in 2015 received much critique with respect to its drafting process [14] [15]. The strong dissent of patent-holders against the policy resulted in their lack of compliance with the new rules and fueled uncertainty within the Working Groups [16]. Few years earlier, TruePosition Inc., a US-based developer of high accuracy location products for radio access networks, accused Ericsson, Qualcomm Inc. and Alcatel-Lucent in conspiring with 3GPP and ETSI, who was later dismissed from the action, to hijack standardization of Uplink Time Difference of Arrival (U-TDOA) technology for LTE wireless networks. TruePosition argued that since the defendants’ affiliates were in control of the key committees of the SDOs, they had the power to manipulate standards development processes and offer their own technologies for inclusion into technical specifications, while eliminating competition from other vendors [17]. The litigation process ended with a settlement between Ericsson and TruePosition. The most recent example of disagreement among the SDO’s membership is the process of approving Encrypted Media Extensions (EME) recommendation within the W3C, and the subsequent resignation of the Electronic Frontier Foundation (EFF) from the W3C membership. Adoption of an EME recommendation by W3C has been subject of a lengthy discussion among W3C members. Opponents of EME asserted that the recommendation will run afoul of the W3C main principle of the open web, and may even risk legal consequences. In turn, those in favor of the recommendation suggested that it’s adoption will guarantee security and accessibility and offer a better user experience, but most importantly, allow W3C to regain control over a practice that has already been widely adopted and implemented by web-browsers. Pursuant to the opposing members, their objections have been continuously ignored during the drafting and approval processes, and any attempt from their side to reach a compromise with EME proponents resulted in failure [18].

The work on recommendation continued despite the lack of consensus and a clear divide between the membership. In July 2017, the EME was promoted to the W3C recommendation by the decision of the W3C Director, which was taken following the procedure defined in the W3C Process Document [14]. This decision was promptly appealed by the opposing members, who stated that the overruling of formal objections to EME by the Director was improper since the W3C membership has not been consulted on negotiation of a covenant to protect EME’s users against anti-circumvention regulation [15]. The decision to publish EME recommendation was upheld in the appeal by 58.4% of membership (108 members voted in favor, 57 opposed and 20 abstained) which, despite the positive result for EME proponents, marks a departure from consensus. In September 2017, the EFF - one of the main opponents of the EMA - announced its withdrawal from the W3C as a consequence its “collapse of confidence in the W3C process”, which paved the way for procedural abuse by a certain group of stakeholders [18].

Each party of the aforementioned disputes certainly has strong reasons to defend its position. That being said, the paper does not aim to reconstruct all controversies between stakeholders affected by SDOs’ decisions, and nor does it attempt to suggest which of the parties were “wrong” or “right”. Rather, the three examples demonstrate that the

12 This is evident from the increased number of negative Letters of Assurance submitted after new policy took effect.
13 See also the e-mail from Harry Halpin of 9 July 2017 regarding the Disposition of Comments for Encrypted Media Extensions and Director’s decision, retrieved from the W3C public mailing list https://lists.w3.org/Archives/Public/public-html-media/2017Jul/0003.html.
14 Article 6.6 and Article 7.1.2 W3C Process Document. See also the e-mail of Philippe Le Hégarët of 6 July 2017.
15 See the e-mail of Cory Doctorow of 12 July 2017.
SDOs’ operational frameworks, appeals mechanisms and composition of their bodies play a significant role in its standardization activities. Designing operational rules that would satisfy all affected by a standard is a utopian task: for this reason, standardization processes are based on consensus, concessions and compromises. Yet, governance models that open avenues for conspiracy and abuse of processes, and do not guarantee consideration of all objections, are likely to tilt the balance towards a single group of stakeholders and abandon consensus-based nature of standardization. Such situation may not only result in costly and lengthy litigation, as it was the case for the ETSI and TruePosition, but may also incentivize members’ withdrawal from organization or even lead to delays in standards development, and hence jeopardize the efficiency and market acceptance of standards. Transparent, open and consensus-based governance processes, which give due considerations to the views of all stakeholders, are the key to successful standards.

5. CONCLUSIONS AND FUTURE RESEARCH

Despite out tendency to believe the opposite, standardization remains a political process, fraught with conflicting interests and tensions between its stakeholders [12]. Even if governance processes of an SDO in theory seem to accommodate a broad range of interests, the practice is not always straightforward and may demonstrate different outcomes. The unwritten rule of every SDO is that standards are not established in the Working Groups, but “during the coffee breaks or hallway conversations”.17 Does the same logic apply to governance processes? The answer, if there is any, lies within an array of extensive empirical studies, which this paper aims to encourage.

The overall contribution of this paper to the existing body of research is its exposure of SDOs’ orchestration and governance processes and the consecutive observation of a disconnect between stakeholders involved in standards development and those defining the rules and procedures of SDOs. Considering the effect of SDOs’ operational frameworks on the outcome of standardization processes, and the expectations of SDOs to act on behalf of their members, this paper claims that procedural guarantees should be respected in SDO procedures-drafting and dispute resolution. It further suggests that inclusive governance processes that take into account the views of all stakeholders contribute to consensus-building in standards development groups and as such, improve the quality and general acceptance of standards.

6. REFERENCES


17 Remarks made at the conference ‘Decision-making in Standard Developing Organisations for the Internet’ organized by the University of Exeter, University of Salford, University of Warwick and Economic & Social Research Council on 25 April 2017.
Fig. 1. Comparison table of governance processes, dispute settlement and standard-setting of ETSI, IEEE-SA, IETF, W3C and Bluetooth SIG
THE STANDARDS REVOLUTION:
WHO WILL FIRST PUT THIS NEW KID ON THE BLOCKCHAIN?

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ABSTRACT

Blockchain is here to stay. Some affirm that it is the next big thing after the Internet. Blockchain is a network-based technology that rewards participants to assemble transactions which will next configure blocks and later be part of a chain. Blockchain guarantees immutability and integrity of data without the need of a third surveilling party. It is therefore a revolution in current systems of trust. It also brings automation and self-execution of processes thanks to its embedded smart contracts functionality. Current standards drafting and development processes can definitively benefit from blockchain technology, and perhaps see the standardization domain revolutionize, like it already happened in the fintech and insurtech arenas [1]. In this paper, we explain what these advantages are. And, before new standard drafting models emerge from the disruptive blockchain community, challenging traditional standard development models -with this paper-, we want to inspire and give tools to established standardization bodies for them to take the lead and initiate a transformation towards ‘Blockchained Standards’ so that they can keep their authority and leadership in the field going forward.

Keywords— Blockchain; Distributed Ledgers; Standards Development; adoption mechanisms; accountability systems

1. INTRODUCTION: GETTING TO KNOW THE BASICS OF BLOCKCHAIN TECHNOLOGY

Blockchain is a novel technology enabling new forms of distributed software architectures, where components can find agreements on their shared states for decentralized and transactional data sharing across a large network of untrusted participants, without relying on a central integration point that should be trusted by every component within the system. The blockchain data structure is a time-stamped list of blocks, which records and aggregates data about transactions that have ever occurred within the blockchain network. Thus, the blockchain provides an immutable data storage, which only allows inserting transactions without updating or deleting any existing transaction on the blockchain to prevent tampering and revision [2].

Blockchain technology is now where the Internet was in 1992 but its hype is as of the Internet in 1998. Why this? Partially because there is a lot of noise and confusion around the technology itself. Let’s thus, before discovering how the technology would work for standards, shed some light to help us distinguish between pure manifestations of the blockchain technology and its placebos.

Most well-known blockchain application is Bitcoin1 cryptocurrency. Other renowned cryptocurrency examples are Dash2 and Litecoin3, amongst the six-hundred plus cryptocurrencies existing nowadays4. Ethereum5 is the more ‘complete’ example of a blockchain per se, which means it has the cryptocurrency function (and its corresponding token to remunerate transaction mining, the so-called Ether) as well as additional blockchain functionalities such as smart contracts. Another example of a blockchain that goes beyond cryptocurrency is NEM6, which has the XEM as token and a MultiSig contract functionality.

Hyperledger7 and Everledger8 are distributed ledger technologies (DLT) but not blockchains. This is because they do not have blocks, nor a token to remunerate transaction mining. All blockchains are DLT as well but with the addition of a rewards system to remunerate the mining efforts of nodes creating the blocks. Blockchains are public, open to anyone, borderless, uncensored. Blockchains are novel systems of trust not depending on central authorities to validate transactions but on their network of nodes. In DLTs (also incorrectly named as ‘private’ or ‘permissioned’ blockchains) all nodes are known and therefore transaction mining is not required but their simple signature instead.

The main characteristic of blockchains is their ability to operate in a decentralized way without having to trust a central authority. The distributed characteristic of blockchains comes from the network of peers (or nodes), in which one relies to verify transactions. Moreover, besides decentralized and distributed, blockchains are disruptive since they allow participants to verify everything by themselves without depending on a middleman or intermediary party. Therefore, we can assert blockchains are changing the paradigm of current systems of trust.

1 https://bitcoin.org/
2 https://www.dash.org/
3 https://litecoin.org/
4 https://coinmarketcap.com/
5 https://ethereum.org/
6 https://nem.io/
7 https://www.hyperledger.org/
8 https://www.everledger.io/
It is the absence of disruption what really differentiates DLTs from blockchains. DLTs are decentralized and distributed, yes; but are not disruptive since peers in the network are permissioned and therefore known. This means that blocks do not exist but a ledger of signed transactions instead. In DLTs, the network transforms into a kind of consortium where controlled participants will sign transactions rather than competing in an open market to validate and assemble them to create blocks under a “Proof of Work (PoW)” security model (such as in Bitcoin or Ethereum) or in a “Proof of Stake (PoS)”. Ethereum has plans to move to PoS in the near future since it is becoming too expensive to use PoW as the network grows.

Both PoS and PoW are consensus algorithms and constitute the security element in blockchain networks. PoW requires mining in stricto sensu, needing powerful mining hardware and therefore involving huge expenditures of electricity. PoW hardware and electricity expenses impose a cost on miners. This is used as means to secure the network and prevent the so-called “51% attack”, by making it too expensive for attackers since they would have to gather the equivalent of 51% of hardware and electricity power sustaining the network to succeed in their attack. On the other hand, the idea behind PoS is to use deposits of cryptocurrency to create the disincentive. In PoS, there is less hardware involved and subsequently lower electricity expenditure but miners have to commit a certain amount of cryptocurrency into a smart contract, in a kind of bond or mining fee. In an eventual 51% attach to a PoS blockchain, attackers would have to commit a large amount of their own cryptocurrency to succeed, which they would lose forever.

In DLTs, PoW or PoS are meaningless because participants know and trust each other. It is therefore not needed to assemble transactions in blocks. And, the chain is not necessary either because there is no immutability threat, what makes the token-based system of incentives to write and assemble transactions in blocks, unnecessary. In DLTs there are no blocks and there is no chain. But DLTs arrived long before the blockchain. We find the first DLT examples in the late nineties whereas the first blockchain arrived in 2008 from the mysterious Satoshi Nakamoto. In 1999 Liebman [3] publishes an article to explain why US Baltimore Gas and Electric (BGE) switched to a pioneering intranet-based IT ledger. This change was to gain control of their distributed assets and to reduce costs, both envisioned as key strategies to compete in an open market. As regulated monopoly, the way costs were managed in BGE - and new IT introduced-, was much different than in other companies in competitive markets. BGE representatives explained that the implementation of these in-house intranet-based IT ledgers entailed a cultural change, which resulted in a shift to a competitive stance. This was triggered by the adoption of novel IT since IT always responds to market requirements and, secondly, distributed ledgers made everyone in the company more conscious of keeping the costs of implementing and owning these technologies over time and under control.

From this early -intranet only- DLT implementation we distill that first DLTs were essentially distributed databases. We can find the first examples of internet-based IT ledgers a little bit later, in the early two-thousands, like in Ohmori [4], where the author proposes an Internet accounting system where transactions are entered on the spot and business data is created by the distribution of transactions. This internet-based IT ledger consists of three elements: a web structure, an accounting system and database servers. The accounting system provides complete accounting functions including general ledger, accounts payable and receivable, purchase and sales order, inventory management, fixed assets, temporary payment, multi-users, multi-currencies, multi-companies and multi-languages. These allow customer and partner relation management, supply chain management and performance analysis.

From these two examples, we can identify that in later/ internet-based DLTs, data bases were substituted by accountability systems. Current DLTs are still these internet-based distributed and decentralized accountability systems.

2. WHAT GOT LOST BETWEEN THE FIRST INTERNET AND ITS CURRENT VERSION, AND HOW BLOCKCHAIN WILL BRING IT BACK TO US

Some authors define blockchain as the ‘internet of value’ [5], or the rewards layer that the internet never had [6]. Other authors focus on its social aspect and argue that the blockchain can re-decentralize the Internet [7]. It is worth elaborating on the later as it will help us to visualize blockchain’s user empowerment capabilities in comparison with the Internet.

The Internet was conceived as a distributed system (no permission should be needed from a central authority to post anything on the Web), decentralized (there is no third-party managing nodes and so no single point of failure), and universal (this requires all computers involved to speak the same language). Unfortunately, part of the commercial success that many companies had with the Internet came thanks to avoiding the last two principles of decentralization and universality. In this respect, the effects of the domination of a few companies -thanks to their de facto monopolistic position-, does not promote equal access to the Internet market place to all IT business participants. Furthermore, from a data privacy perspective, each of the dominants holds a disproportionate amount of personal information about individuals, threatening our digital sovereignty.

Finally, there is the element of trust. In this monopolistic environment, when two parties make a transaction, they have to rely on the dominant central authority to execute the transaction for them, and surrender to their guarantees about its validity. Additionally, they will have to trust their notification of successful completion and agree with their procedures on what to do in case of error. Unfortunately, if this central figure fails or gets compromised, the transaction cannot proceed or will go wrongly. Since these issues have been identified, many voices have been raised advocating for decentralization and universality to be brought back to the Web [5]. The blockchain has the potential to reboot our
current Internet and return decentralization to the Web. As shown in Table 1, blockchain enhances Internet’s original data commons potential thanks to its rewards system and improves Web’s security in P2P exchanges through its embedded encrypted cryptographic identities.

Table 1. Internet-based technologies. Features comparison (Source: Author’s elaboration)

<table>
<thead>
<tr>
<th>Features</th>
<th>Internet 1990</th>
<th>DLT 1999</th>
<th>Blockchain 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Universal</strong></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>[all nodes speak the same language]</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Platform</strong></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>[commons with no single point of failure]</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td><strong>Decentralized</strong></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>[no centralized control of nodes]</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Network</strong></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>[secure and trustful P2P exchanges]</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Distributed</strong></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>[no central permission to post anything]</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Ledgered</strong></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>[immutable and integral record keeping]</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Disruptive</strong></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>[incentives-based network of trust]</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Blockchain is a P2P network that sits on top of the Internet. The Transmission Control Protocol/Internet Protocol (TCP/IP), with its appearance in 1992, unlocked new economic value of connectivity by dramatically lowering the cost of connections [8]. The blockchain will not only greatly reduce the cost of transactions -and make them safer-, it will also uncompromise identity since transactions are encrypted trough cryptographic private keys.

In European history, the Commons were lands to be shared freely by all members of an agrarian community [9]. However, not all experiences of the Commons have been successful as anticipated by William Foster Lloyd, with the concept Tragedy of the Commons [10]. According to his 1833 essay, where he laid out the concept, individual users in a group, acting independently according to their own self-interest, will behave contrary to the common good of all users by depleting or spoiling the shared resource through their collective action. As later advised by Rifkin [11], any institution of the Commons works best with initiatives that have near zero marginal cost, what Rifkin defines as where the production of additional copies of an item is almost cost-free once the initial production of costs have been paid. With the arrival of the Internet, the concept of the Commons was applied to data that people would voluntarily share on the web (e.g.: Open Source software, Wikipedia, etc). This was named Data Commons. Although the Data Commons initiative is closer to Rifkin’s theory than historical implementations of the Commons, there is still a ‘tragedy of the Data Commons’. The Tragedy of the data Commons has been defined as the failure to anonymize data shared on the internet to safely build a common wealth of information [12]. It is argued that, under current internet protocols, malefactors can reverse-engineer shared data and identify individuals within data sets or even claim ownership to economically benefit from common data. With blockchain this will no longer exist since privacy and reward mechanisms native to the technology allow for a safe and remunerated sharing of data that will incentivize proprietary-knowledge exchange actions and therefore make information even more accessible, trustable and of higher quality. Here is where, mostly, the following proposal on blockchain for standards leverages on.

3. PRIMARY ROLE OF STANDARDS IS SUPPORTING TRADE OF GOODS AND SERVICES. CAN THIS BE BETTER SUPPORTED WITH A BLOCKCHAIN-BASED MODEL?

Indeed, blockchain can bring the anticipatory and market predictive capacities that current standards development do not have. For long time, the standards community has been pledging for standards harmonization and integration with policies and regulations. At International level, the WTO Agreement on Technical Barriers to Trade (TBT)9 and the EU New Approach10 initiative, are efforts in this direction. However, current standardization development models in both SDOs11 and NSOs12 are ‘permissioned’ -only opened to paying or accredited members-, which limits standards harmonization and integration capabilities since expert knowledge from external stakeholders cannot be included (and it can be very necessary at a particular point during standards development, to delve into a specific knowledge area of the standard).

In order to make standards development less restrictive and not to limit expert knowledge participation, we propose a blockchain-based model for standards drafting which will

9 https://www.wto.org/english/tratop_e/tbt_e/tbt_e.htm
10 http://www.newapproach.org/
11 SDOs stands for Standards Development Organizations and includes the three international standards bodies, the ISO (International Standards Organization), the IEC (International Electrotechnical Commission) and the ITU (International Telecommunications Union). Within the SDOs, a distinction is made for the ESOs (European Standards Organizations), which include the following: CEN (Comité Européen de Normalisation), the CENELEC (Comité Européen de Normalisation Electrotechnique), and the ETSI (European Telecommunications Standards Institute).
12 The National Standards Organizations (NSOs) are standardization bodies of different countries.
have its corresponding token to administer open participation. The current permissioned nature of SDOs and NSOs would make DLTs more suitable but, as the same DLT-based Hyperledger’s Chief says “DLTs have to be a shared asset rather than a technology controlled by a single vendor. We want Hyperledger to be a home for many different blockchain technologies” [13]. It is therefore acknowledged by the DLT community that stakeholder empowerment capacities offered by blockchains are to be promoted by eventually having blockchains sitting on top of DLTs. This actually connects quite well with ITU’s standards development model and places UN’s standards organization as the most suited of all SDOs to pioneer blockchain work.

The ITU typically investigates a new standardization domain by first setting up a Focus Group (FG). To capture the maximum expertise, participation in FG is free of charge and open to any stakeholder. If and when FG work is successfully completed, then a Study Group (SG) will be created to develop standards based on FG’s elaborations. Participation in SG is subject to fees, either paid by national governments who will appoint representatives, or paid by participants representing their private organizations. The proposal made here is for ITU to test our blockchain-based standardization model in one of the new FG working on blockchain-related topics (e.g in the FG on Digital Currency including Digital Fiat Currency13, or in the FG on Application of Distributed Ledger Technology14), to next continue with standardization activities under the same FG scheme and/or eventually reimagining the SG structure to accommodate this proposal.

Moreover, since blockchains are typically bottom-up community-promoted initiatives, we can expect the emergence of a standards development DAO (Decentralized Autonomous Organization) sooner than later, filling the still opportunity gap of a blockchain-based virtual standards development organization. It is therefore, not only strategic but necessary, for SDOs and NSOs to embrace the technology without delay to keep their established leadership positions in standards development.

As mentioned by Davidson [14], anything that requires ‘proof of something’ can benefit from being on the blockchain. Thinking of how a blockchain-based standards development process could work, we did some literature research on alternatives to Proof-of-Work (PoW) and Proof-of-Stake (PoS) to find examples that leverage on knowledge to build their consensus algorithms. For instance, Swan [15] proposes Proof-of-Intelligence (PoI) as a reputational qualifier to manage consensus in their DAC (Decentralized Autonomous Corporation) -which is similar to a DAO-, a model to create organizations that emulates the brain to take decisions. Koop [16] suggests Proof of Retrieval (PoR) for their Distributed File Storage system. And Dimitru [17] creates Proof of Trust (PoT) -with resemblances to credit scoring-, to elaborate consensus in their proposal of Trusted Data Marketplaces. Inspired in these knowledge-based alternatives to Proof-of-Work (PoW) and Proof-of-Stake (PoS), already available as published research, we propose the Proof-of-KnowHow (PoKH) as the consensus algorithm for blockchain-based standards drafting and the KHnow as its token.

As mentioned earlier, the proposed blockchain-based standards development will allow for the participation of key expert knowledge during standards drafting that under the current process is being left outside. A possible strategy for this more inclusive standards development proposition would be the transformation of current Technical Committees (TC) into Expert Collaboratories [18]. Each former TC would become an Expert Collaboratory (EC) on the blockchain. Not in typical TCs or SGs but ITU’s FGs are quite close to the proposed ECs, although this blockchain-based standards development model would still require the inclusion of certain groups currently left behind. Besides the well-established groups participating in today’s traditional TCs -Supply side and Demand side-, ECs will also include the Innovators, typically unrepresented in current standards development processes (see Figure 1). Innovators will bring thematic expertise from the following minorities, but not limited to: Innovation and Growth Hubs, LEPs (Local Enterprise Partnerships), PPPs (Public, Private, Partnerships), PPPPs (PPP+People), Charities and NGOs, Accelerators, Incubators. The inclusion of the Innovators will allow for the development of novel standards able to anticipate future needs of goods and services.

Moreover, in order to creatively raise funds for the development of new standards, and inspired in the recent very successful fundraising experiences of several blockchain ICOs (Initial Coin Offerings), Innovators would also include funding bodies such as: Venture Capitalists (VC), AG (Angel Groups), Social Banks, alternative funding platforms (crowd-funding, micro-funding, etc.)). In connection with blockchain’s ability to raise fresh funds and skill to “proof-everything”, one of the novel advancements of the proposed blockchain-based standards will be their ‘proof of fit-for-purpose’ through embedded tests and trialing before they get published and go to market. This is explained in the next and last section.

4. MAIN CHALLENGE FOR STANDARDS IS TO INCREASE IMPLEMENTATION AND UPTAKE. CAN THIS BE IMPROVED WITH BLOCKCHAIN-ENABLED STANDARDS?

Definitively, adoption of standards can be improved by using blockchain for development purposes. Standardization communities, especially de facto groups13,14.
have realized the importance of trialing and testing as means to improve implementation and uptake of standards. In this regard, it is worth highlighting some international experiences such as the BuildingSMART Tetralogy of BIM\textsuperscript{16} in the USA or the EU Fiware IoT Ready Program\textsuperscript{17}, as examples for BIM and IoT de facto standards respectively developed in a trailing environment.

Taking into consideration how Maxwell \textsuperscript{[19]} reinvents traditional storytelling through blockchain, to convert reporting into a process of value, we reboot the standards narrative by adding testing and trialing activities, as capitalizations that will increase benefit realization of using standards and therefore their market value. As part of the blockchain-based standards drafting process, these trialing and testing experiences will be included in the standard. Our Proof of Know How (PoKH) consensus algorithm will make sure that at least one implementation of a proposed piece of guidance is made before it is added to the standard. The more and better tests a participant node can proof, the more PoKH will be awarded with (Figure 2). Moreover, this pioneering inclusion of implementations conforming with the standard will also have a positive impact in market uptake and implementation of standards since practical exemplification is the best way to promote adoption.

16 \url{https://www.nationalbimstandard.org/tetralogyofbim}
17 \url{https://catalogue.fiware.org/iot_ready}

Fig. 1. EC’s organic network growth

Fig. 2. Blockchain-based standards drafting.

Different transaction stages in the process of building a block, corresponding to phase $n$ of an EC network (see Figure 1). In Alfa stage, nodes started ‘transacting guidance’ to create a block containing that piece of guidance that, once finished, would be added to the blockchain containing the standard. The consensus algorithm Proof-of-KnowHow (PoKH) ensures that no block is closed until an implementation exemplifying the
guidance is added. In Beta stage, nodes continue transacting guidance but none of the transactions includes an implementation yet therefore the block remains open. Later, in Gamma stage, one of the innovator nodes (i³) brings an implementation in. This creates the block and closes transactions for that specific piece of guidance, which will be included in the blockchain forming standard. The innovator node that mined the implementation closing the block will be awarded an amount of KHnow. Further implementations for that particular piece of guidance or a new one can be added and will create new blocks, which will also be remunerated with KHnow. (Source: Author’s elaboration)

Some authors argue that blockchain use is not democratic since it is only accessible to a small techy elite [20]. This is partly true if we focus on cryptocurrencies and on blockchain software development. But the smart contracts functionality enabled by programmable blockchains -such as Ethereum- eliminates that barrier as it allows for self-execution, meaning that blockchains can be used to store executable binding code that can be triggered by a simple user’s mouse click.

In our standards reimagina, smart contracts will help gain critical mass in the adoption of the standard once it is published and released to the market: instead of having the standard presented as some sixty pages report like today, it will be turned into an executable tool upon which the users will input their own performance data and therefore be self-assessed in meeting the standard. In other words, blockchain-enabled standards will empower the user with compliance capabilities to adopt a self-conformity role. This eliminates the need for a third-party certification organization.

The use of blockchain in standards development and drafting will result in fully tested standards, elaborated in an ecosystem of stakeholders which will include innovators amongst whom there will be fundraisers that will ensure the kick-off of the standard as well as its maintenance over time through regular updates brought by new use cases.

Lastly, in author’s opinion, standards development would benefit from a more architectural construction such as the 3C Meta-standard [21]. In the 3C Meta-standard, the key words and key terms that will configure the standard are distributed in a framework architecture that is presented to the user as a single matrix. The standard, as today’s report, disappears and is substituted by a very intuitive grid of cells each containing a piece of guidance. The different 3C Meta-standard use cases have proven that the more visual representation of the standard in a framework architecture improves users’ adoption.

The addition of blockchain functionalities to the 3C Meta-standard architecture would not only bring the well-known blockchain’s capabilities of data integrity and immutable recordkeeping [22] but facilitate experts’ participation since these could be distributed in specialized groups, each taking responsibility of thematic blocks (related key words in the matrix cells) which will be integrating the blockchain as long as implementations are being transacted.

5. CONCLUSIONS: STRENGTHS AND WEAKNESSES OF BLOCKCHAINED STANDARDS

We have outlined a model for standards development using blockchain. As way to conclude this research piece, the advantages and inconveniences of using blockchain technology for standards development are presented in turn, by means of a comparison exercise between standards developed with and without blockchain:

-- Automation: by using blockchain, the process of standards drafting becomes fully automated and less time consuming compared to current practices, what allows releasing standards to the market sooner.

-- Transparency: the immutability of records plus the standard becoming a replicated ledger mean that standardization consensus rules and the overall process are fully disclosed. In traditional standards drafting there are parts of the process that remain undisclosed and non-accessible to participants.

-- Contents’ collective awareness: having the standard decentralized in multiple replicated ledgers ensures not to lose focus in the scope of the standard.

-- Real time progress: blockchain allows for the visualization of changes as a result of approved transactions in an average time elapse of 10-15 seconds. Work-in-progress updates can take months under current procedures.

-- Decentralized governance: the standard is not governed by a single authority (Secretariat) but by the network (EC participants)

-- Distributed ownership: compilation and consolidation work of the standard are no longer a solo responsibility of the Rapporteur but of the network (EC participants)

-- Weighted vote: blockchain takes elements of Agent technology such as trust and reputation. Consensus rules for these can be created by the Secretariat to weight participants’ votes to approve transactions according to specific strategies and interests for each standard.

-- Larger turnout participation: since blockchain allows for a total digitalization of the process, f2f meetings become optional which is an advantage to get in stakeholders who were not participating due to time or travel constraints.

-- No stakeholder left behind: digitalized consensus of the standardization process will have a positive impact in enlarging participation numbers which will turn the standard into a more complete and representative instrument.

-- Meetings can focus on discussions: since the bureaucracy of approving changes and updates can be fully transferred and ran on the blockchain, f2f meetings –if any- can be released from these administrative tasks and focus on an expert discussion to better inform the standard.

-- More practical and user-friendly standards: the fact that the community developing the standard, the EC network, operates virtually allows for the addition of use cases and examples as soon as they become available. The inclusion
of these implementations will have a positive impact in the adoption and uptake of the standard.

--Performance monitoring: the addition of uses cases and examples will allow identifying what data is required to inform the different recommendations given by the standard and document the guidance offered. This will help users to objectively monitor their performance when implementing the standard in projects and solutions

--“Executable standards”: blockchained standards are programmed standards that can be installed in any computer and users, by imputing the required data against the executable standard, will get a self-assessment on the compliance and conformity of their projects, solutions, or products with that given standard.

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REFERENCES


Challenges for a data-driven society
SESSION 3

ACCELERATING SUSTAINABLE DEVELOPMENT THROUGH DATA

S3.1 Capability maturity models towards improved quality of the Sustainable Development Goals indicators data

S3.2 Advanced data enrichment and data analysis in manufacturing industry by an example of laser drilling process*

S3.3 Small data and sustainable development - individuals at the center of data-driven societies
CAPABILITY MATURITY MODELS TOWARDS IMPROVED QUALITY OF THE SUSTAINABLE DEVELOPMENT GOALS INDICATORS DATA

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ABSTRACT

Achieving the Sustainable Development Goals (SDGs) demands coping with the data revolution for sustainable development: the integration of new and traditional data to produce high-quality information that is detailed, timely, and relevant for multiple purposes and to a variety of users. The quality of this information, defined by its completeness, uniqueness, timeliness, validity, accuracy, and consistency, is crucial for appropriate decision making; which leads to improvements in advancing national development imperatives for reaching the goals and targets of the sustainable development agenda. In this paper, we posit that the more mature the organizations within the national data ecosystems are, the higher the quality of data that they produce. The paper motivates for the adoption and mainstreaming of organizational Capability Maturity Models within the SDGs activities. It also presents the preliminary formulation of a multidimensional prescriptive Capability Maturity Model to assess and improve the maturity of organizations within national data ecosystems and, therefore, the effective monitoring of the progress on the SDG targets through the production of better quality indicators data. Furthermore, the paper provides recommendation towards addressing the challenges within the increasingly data-driven domain of social indicators monitoring.

Keywords — Sustainable Development Goals, Capability Maturity Model, Data Revolution, Institutional Capacity

1. INTRODUCTION

In September 2015, leaders of 193 countries agreed on seventeen Global Goals for Sustainable Development which set off a world-wide call to protect the planet and ensure peace and prosperity for all people by the year 2030. These goals, known as the SDGs, define the global development agenda for the upcoming years and present challenging objectives that must balance the three pillars of sustainable development: social inclusion, economic development, and environmental sustainability. The SDGs build on the success of the Millennium Development Goals (MDGs), a set of time-bound and quantified targets agreed in September of 2000 during the UN Millennium Declaration [1]. In particular, SDGs prioritize areas not considered before such as climate change, economic inequality, innovation, sustainable consumption, peace, and justice [2]. The seventeen goals aim at reaching 169 targets, which will be monitored and evaluated through 230 indicators. The UN Statistical Commission [3] is the body within the UN system responsible for the development of a global indicator framework for monitoring the progress towards the achievement of the SDGs. The current measurement framework divides the 230 indicators into three tiers: Tier I comprising indicators for which statistical methodologies are agreed and global data are regularly available; Tier II comprising indicators with clear statistical methodologies, but little available data; and Tier III for indicators with no agreed standards or methodology, and no data. The latter represents 32% of the total number of indicators. On top of this, 15 indicators have yet to be assigned to a tier [4].

A crucial component of the SDGs agenda is the monitoring of progress towards the achievement of the targets, as well as the development of suitable technology tools and platforms to support the activities of the different stakeholders [5]. It is expected that the monitoring of the SDG indicators will demand further efforts to take advantage of the achievements of MDGs and to produce reliable and high-quality data that can cover the new subjects, while ensuring that ‘nobody is left behind’ [6]. However, there are deep-rooted capacity challenges for many countries in measuring progress on the proposed SDGs [7]. The capacity of key players in the data ecosystem, including governments, institutions, and individuals, also needs to be enhanced to be able to deliver and take advantage of this data. There is, therefore, a universal imperative to ensure that all countries have an effective national statistical system, capable of measuring and producing high-quality statistics in line with global standards and expectations [6].
High-quality data is critical for transforming the SDGs into useful tools for problem-solving and for proper decision-making. Without timely and reliable data, the design, tracking, and assessment of policies are almost impossible. For these reasons, data is one of the key elements of the accountability framework for the SDGs. High-quality data that can be transformed into information that reflects the progress, monitors the allocation of resources, informs policy making, and assesses the impacts of policy and programs, is fundamental for accountability and monitoring of the 2030 Agenda.

Notwithstanding the inherent complexity of the national data ecosystems, this research adopts an organization thinking approach to explore the potential interventions towards improving the capacity of organizations within the national data ecosystem to be more effective in producing high-quality data and therefore in monitoring the SDG indicators.

The rest of the paper is organized as follows. Section 2 discusses the unfolding data revolution especially in the context of social indicators monitoring for SDGs. Section 3 presents an extensive review of the current initiatives on improving the quality of statistical data. Section 4 motivates for the use of Capability Maturity Models (CMM) within the SDG indicators framework for improved quality of SDG indicators data. This is followed by a presentation of a preliminary multidimensional prescriptive CMM in Section 5. Sections 6 and 7 provide recommendations and a conclusion to the paper (respectively).

2. THE DATA REVOLUTION

The volume of data in the world is increasing exponentially. One estimate is that 90% of the data in the world has been created in the last two years [6]. The volume and types of data available nowadays have increased exponentially due to the evolution of technology and its impact on the social behavior. All players in the ecosystem, including governments, companies, academia, and civil society, need to adapt to this new reality and need to be prepared to continue adapting to a world that produces more and more data, generated at a faster speed, and coming from new sources. This new reality has been defined as the data revolution.

The concept of data revolution was coined in 2013 in the report of the High-Level Panel of Eminent Persons on the post-2015 Development Agenda [8] and it is defined as “an explosion in the volume of data, the speed in which data is produced, the number of producers of data, the dissemination of data, and the range of things on which there is data, coming from new technologies such as mobile phones and the Internet of Things, and from other sources, such as qualitative data, citizen-generated data and perception data” [6, p. 6].

Applying a data revolution perspective to SDGs involves the integration of new data (e.g. crowd-sourced data, citizen-generated data, etc.) with traditional data (e.g. census information) to produce high-quality information that is more detailed, timely and relevant for many purposes and users, especially to foster and monitor sustainable development [6]. Traditional statistics entities must therefore not only engage with new data sources but also with new technologies and data analysis tools. Supporting the evolution and modernization of the statistics production systems is also demanded by the large number of indicators for which novel and innovative data sources and methodologies are needed [5].

National Statistical Offices (NSOs), the traditional guardians of data for the public good remain central to the government efforts to harness the data revolution for sustainable development. To fill this role, however, they need to change more quickly than in the past. To be able to adapt to the constant changes, they need to abandon expensive and inefficient production processes, incorporate new data sources, and ensure that the data cycle matches the decision cycle. However, many NSOs lack sufficient capacity and funding, and remain vulnerable to political and interest group influence. Data quality should be protected and improved by strengthening NSOs, and ensuring they are functionally autonomous, independent of sector ministries and political influence. Their transparency and accountability must be improved, including their direct communication with the public they serve [6].

The data revolution, as any transformation, raises new risks. One of the main challenges for monitoring SDGs is to minimize the risks and maximize the opportunities that come from the data revolution for sustainable development. Among them, the enlargement of the data divide (i.e. the gap between those who have ready access data and information, and those who do not) is one of the riskiest. Inequalities in the access and use of information must be tackled to reduce the breach between information-rich and information-poor countries. A way of managing risks and exploring opportunities is by enhancing national capabilities in data science. National and international support and resources are needed, especially in developing countries, to achieve high-quality official statistics that are required for the data revolution to contribute to sustainable development.

Several efforts and important investments have been made for monitoring MDGs. Some of those efforts have been successful and have improved the way data for monitoring and accountability is used. Consequently, there is now a much better understanding of the realities of the world, including the ones of the people that need more help. However, and in spite of this significant progress, some big challenges still need to be tackled:
Many people and groups are still ignored – some ethnicities, for instance, are being left further behind.

There are data and knowledge gaps – new science, technology and innovation (among others) are needed to fill such gaps.

There is not enough high-quality data – many countries cannot rely on their data because it is outdated, incomplete, or it simply does not represent the reality accurately.

Lots of data that is unused or are unusable – many countries still have data that is of insufficient quality to be used to make informed decisions, for governments to be accountable or to fostering innovation.

These challenges limit governments’ ability to act properly towards the achievement of the SDGs.

A key role of the UN and other international organizations is to set up principles and standards, and to lead the actions according to common norms. Mobilizing the data revolution for achieving sustainable development urgently requires actions such a raising awareness, improving capacity, setting standards, and building on existing initiatives in various domains, among others. In particular, initiatives built over previous foundations should consider the data production ecosystem to understand the multi-stakeholder engagement issues related to data sharing, ownership, risks, and responsibilities. Such initiatives are indispensable to enable data to play its essential role in the implementation of the development agenda.

The Independent Expert Advisory Group on a Data Revolution for Sustainable Development calls for “international and regional organizations to work with other stakeholders to set and enforce common standards for data collection, production, anonymization, sharing and use to ensure that new data flows are safely and ethically transformed into global public goods, and maintain a system of quality control and audit for all systems and all data producers and users” [6, p. 18]. Towards this aim, efforts must be made to support countries in empowering their statistical system to be resourced and independent in order to be able to respond to new realities of data, and to produce and use high-quality data in quantitative and qualitative ways.

3. STATISTICS DATA QUALITY INITIATIVES

The importance of the role of the national statistics entities in the production of official statistics for the monitoring and implementation of the development agenda, and the importance of high-quality statistics have been described in literature [9]. In order to serve sustainable and inclusive development, statistics should be obtained from high-quality, timely, easily accessible, reliable and disaggregated data. Data disaggregation, in particular, is key to achieve the principle of leaving no one behind [10].

From an extensive literature review, a wide set of initiatives aimed at improving the functioning and the results generated by the national statistics entities have been identified – including models, standards, frameworks, processes and programs, enterprise architectures, and readiness studies. Figure 1 shows some existing efforts grouped by categories.

![Fig. 1: Initiatives for improving quality in statistics generation](chart)

Among the frameworks for data or statistics, the following can be highlighted:


- **Frameworks for National Statistics** – define the status and governance framework for official statistics. For example, the one developed by the UK Statistics Authority [12] focuses on economy and society.

- **Statistics Quality Frameworks (SQF)** – set forth main quality principles and elements guiding the production of statistics. An example is The European Central Bank Statistics Quality Framework [13].

- **Monitoring and Evaluation Frameworks** – aim at identifying trends, measuring changes and capturing knowledge to improve programs’ performance and increased transparency. For example, the SDG Fund Secretariat [14] has established a Monitoring and Evaluation framework with key indicators that allows to obtain a comprehensive overview of the contribution to sustainable development.
• **Process Quality Frameworks** – the framework for process quality in national statistical institutes [15] proposes a structured framework for the quality of the statistical processes used to produce official statistics.

• **Quality Management Frameworks** – for example, the one implemented in the Central Statistics Office in Ireland [16] is an extensive and long-term program of activities aiming at ensuring that statistical production meets the highest standards as regards quality and efficiency.

• **Quality Frameworks** – provide a systematic mechanism for ongoing identification and resolution of quality problems and increased transparency to the processes used to assure quality. An example is the Quality Framework and Guidelines for Economic Co-operation and Development (OECD) Statistical Activities, developed by the OECD in 2012 [17].

• **Data Quality Assessment Framework** – evaluates the data quality of statistics. For example, the International Monetary Fund created a data quality assessment framework [18] for comprehensive assessments of countries’ data quality. It defines five dimensions and it covers institutional environments, statistical processes, and characteristics of the statistical products.

• **Statistical Quality Management Framework** – aims at setting out clearly and succinctly an organization’s commitment to quality in respect of particular statistical outputs, and to describe the steps that it will take to meet its quality aims [19].

**Enterprise Architectures** (EA) are formal descriptions of the structure and function of organizational components, the relationships between such components as well as the principles and recommendations for their creation and development over time [20]. Some EA applications to official statistics include:

• **Enterprise Architecture Reference Frameworks (EARF)** – aim at helping countries (in particular, EU member states) with the production of statistics that respond more quickly and cost-effectively to new statistical business needs [21].

• **Common Statistical Production Architecture (CSPA)** – provides support for the whole span of statistical production process and gives a framework for collaborating and sharing effectively [22].

Koskimäki and Koskinen [23] discuss Statistical Enterprise Architectures as tools for modernizing the national statistical systems by identifying the gaps and overlaps between CSPA and EARF from the point of view of the National Statistics Institutes.

**Readiness** studies analyze the conditions in a country, city or sector to see if data initiatives are likely to be successful and, at the same time, they seek out suitable areas and identify challenges that may exist when implementing such policies [24]. Some readiness studies in the domain include:

• **Readiness Assessments** – are used to determine the existing environment and the preparedness for change. UNDP has developed a prototype tool – the Rapid Integrated Assessment (RIA) – to support countries in assessing their readiness for SDG implementation. RIA reviews the current national development plans and relevant sector strategies, and provides an indicative overview of the level of alignment with the SDG targets.

• **Common Assessments** – useful for assessing and promoting common approaches towards objectives involving multiple stakeholders. The Common Country Assessment (CCA) prepared by UNDP informs the design of UN policies and programs at the country level based on the review of context-specific data that correspond to the SDGs and targets of the 2030 Agenda [25]. The CCA assists in identifying links among goals and targets in order to effectively determine mutually reinforcing priorities and catalytic opportunities for implementation of the new agenda as a whole.

• **Data Readiness** – a tool to assess an organization’s ability to produce and report data. In [26], a design-reality gap model is applied for the assessment of big-data-for-development readiness, barriers and risks. This kind of tools could similarly be applied to assess readiness for monitoring the progress towards the achievement of the SDGs.

**Processes and standards.** A statistical process is defined as the collection, processing, compilation and dissemination of statistics for the same area and with the same periodicity [27]. A statistical standard provides a comprehensive set of guidelines for surveys and administrative sources collecting information on a particular topic [28]. The following are some processes and standards for statistics:

• **Quality Assessment Process** – their purpose is to define the steps to process data in such a way that quality is preserved. The quality assessment process for Big Data developed by the OECD [29] presents a data quality assessment process which includes a dynamic feedback mechanism to adapt to the characteristics of big data, and define the tasks that should be conducted at early stages to improve quality.

• **Codes of Practice (CoP)** – the European Statistics Code of Practice aims to ensure that statistics produced are not only relevant, timely and accurate but also comply with principles of professional independence, impartiality and objectivity [15]. Similarly, the UK National Statistics Code of Practice sets out conditions and procedures which govern access to data, including access to data for research purposes, and appropriate actions for unauthorized data disclosure [30].
There are also models to represent information, activities, capabilities, business processes, and modernization of statistical organizations. Examples of such models are:

- **Generic Statistical Information Model (GSIM)** – a reference framework of internationally agreed definitions, attributes and relationships that describe the pieces of information that are used in the production of official statistics [31]. It describes the information objects and flow within the statistical business process.

- **Generic Statistical Business Process Model (GSBPM)** – describes and defines the set of business processes needed to produce official statistics [32]. It covers all the activities undertaken by producers of official statistics – at both national and international levels – which result in data outputs. It is designed to be independent of the data source, so it can be used for the description and quality assessment of processes based on surveys, censuses, administrative records, and other non-statistical or mixed sources.

- **Generic Activity Models for Statistical Organizations (GAMSO)** – describes and defines the activities that take place within a typical statistical organization. It extends and complements GSBPM by adding additional activities needed to support statistical production. It is useful to assess the readiness of organizations to implement different aspects of modernization.

- **Modernization Maturity Models (MMM)** – self-evaluation tools to assess the level of organizational maturity against a set of pre-defined criteria. The United Nations Economic Commission for Europe (UNECE) defined a MMM that considers multiple aspects of maturity and distinct dimensions in the context of modernization [33]. The model defines maturity levels allowing identifying the organizational maturity, which can be compared between organizations, and between statistical domains/business units within an organization.

**4. IMPROVING THE QUALITY OF SDG INDICATORS DATA**

While most of the existing work focuses on assessing and improving the quality of the information produced, we believe the way that such information is produced is equal or even more important. To be able to monitor progress, make governments accountable, and advance sustainable development, having strong institutions able to fulfill the rapidly changing demand for high-quality information is utterly important. It is also imperative for the improvement of the capability of the national data ecosystem that frameworks, models, and standards are formulated to support the adoption of best practices for improving the monitoring of SDGs.

The capability of national data ecosystems (focusing particularly on organizational capacity) can be improved through the formulation of a new multidimensional prescriptive CMM to assess and leverage the capacity of the entities responsible for reporting on the progress of the SDGs at the national level – typically, the NSOs – in collecting, analyzing, processing, and reporting data about the SDGs.

Maturity reflects a level of organizational development which can be used to determine the capability of organizations to perform certain activities. Maturity models are an important tool to assess the quality and effectiveness of processes. Evaluating maturity became popular with the introduction of the CMM for software defined by the Software Engineering Institute at Carnegie Mellon University [34]. Maturity models can be used to identify organizational strengths and weaknesses, and as tools for benchmarking information [35].

Prescriptive models surpass descriptive ones since they are good not only for assessing the here-and-now (also known as the “as-is” situation) but also to indicate the way to improve the level maturity by enabling organizations to develop a roadmap for improvement [36]. Organizations applying these types of models benefit from the ability to measure and assess their capabilities at a given point in time and to have guidelines on improvement measures.

Some of the statistics data quality initiatives (as discussed in Section 3) stand to make a contribution to improving the quality of the data produced by the NSOs. However, it remains that none of these initiatives are specifically aimed at improving the quality (defined by its completeness, uniqueness, timeliness, validity, accuracy, and consistency [37]) of the data generated for the monitoring of the SDGs, and at assessing the capability maturity of such entities and the processes they use to produce SDGs statistics. The closest initiative would be the MMM as it can be used to identify the maturity of statistical organizations and it helps them to modernize the way they produce official statistics. Nevertheless, the most critical difference with the model presented in this paper relies on the focus: while the CMM targets specifically the process that informs the progress towards the SDGs, the MMM focuses on the approach followed by statistical organizations to modernize the way they produce official statistics as a whole. The evolution of the model is also different; while the CMM is descriptive, the MMM is prescriptive. Defined as a "self-evaluation tool to assess the level of organizational maturity against a set of pre-defined criteria" [33, p. 1], the MMM is complemented by a roadmap where the guidelines to reach higher levels of organizational maturity are defined. The CCA by UNDP can also be a useful input to the CMM since it holds the potential for ensuring that the support provided by UN agencies as a whole in a country is coherent and complementary, drawing from each agency’s expertise, resources, and mandate. Other existing efforts, like GAMSO and CSPA, could also inform the CMM.
5. PRELIMINARY CAPABILITY MATURITY MODEL FOR SDG INDICATORS MONITORING

The initial/preliminary CMM explored in this research uses the activities (also called phases) defined by the GSBPM [32] and classifies maturity according to a five-point scale. The model is multidimensional, as each phase includes a number of dimensions. A simplified, high-level view of the model is shown in Figure 2.

![Fig. 2: Capability Maturity Model](image)

The diagram does not show (due to space limitations) the fact that each phase is composed, in turn, by a set of sub-processes. The sub-processes are crosscut by each dimension. For example, the Analyze phase consists of five sub-processes – 1) prepare draft outputs, 2) validate outputs, 3) interpret and explain outputs, 4) apply disclosure control, and 5) finalize outputs. The following dimensions are analyzed for each of the sub-processes: a) guidelines, processes and methodologies for preparing draft outputs; b) tools, platforms, and systems for preparing draft outputs; and c) research, experience, and information sharing for preparing draft outputs.

Figure 3 shows the levels of maturity: *Ad-hoc* (less mature), *Supported*, *Managed*, *Proficient* and *Optimizing* (more mature). Organizations in the *Ad-hoc* level are expected to deliver low-quality information because their processes are unclear; they rely primarily on manual practices and isolated efforts; and they have an inaccurate, partial, or incomplete representation of the ecosystem. Organizations in the *Supported* level have tools, platforms, and systems in place but have a poor representation of the ecosystem; the quality of data they produce is expected to be moderate. *Managed* organizations have guidelines, processes, and methodologies in place; have a good understanding of the ecosystem and the quality of information they produce is expected to be high and accurate. Organizations in the Managed level of maturity are trustworthy for decision making. Organizations are considered *Proficient* when they incorporate standards, best practices, and trends in their activities; have a complete and accurate view of the reality and the information produced is of high-quality. Proficient organizations are at a level of maturity that enables them to take advantage of data exchange and information sharing. The *Optimizing* level of maturity is reached when organizations adapt and react fast and easily to changes in the ecosystem. Such organizations offer the most accurate representation of the ecosystem and the information they offer has an impact on policy.

![Fig. 3: Maturity Levels](image)

Figure 4 illustrates the direct relationship between capability maturity and the expected quality of data. Hence, promoting capability maturity of the entities responsible for reporting the progress on the SDGs contributes to higher quality of information, and therefore, to better monitoring of the global development agenda.
6. DISCUSSION AND RECOMMENDATIONS

There is a clear need for reliable information within the international statistical community, and there have been a number of efforts to ensure quality and accuracy of data. However, the process is long and technology is changing rapidly, directly affecting the lives of human beings and in turn, the data they produce. Therefore, reliability must be safeguarded by robust and mature organizations which are independent of their employees, and the current and future administrations. To this end, national statistical systems must be empowered to quickly and easily adapt to the new reality of data.

International organizations play an important role in supporting countries in being able to produce reliable and efficient indicators, and in providing them with adequate tools for achieving so. For instance, UNECE is making great contributions with the development of GAMSO, GSBPM, GSIM, CSP. There is space however, for other organizations to also make a contribution.

Every country, regardless of their advancement and level of development can benefit from the CMM. While developed countries tend to lead the way and have more resources for improvement and innovation, developing countries can benefit greatly from the efforts and experience gained from those leading the way. The achievement of the global development agenda is not a competition among countries and it depends on every member to be able to achieve its goals and targets. One of the beliefs and principles of the SDGs states that "The United Nations member states work together with a high level of cooperation to improve the circumstances of all people in the world, and place them at the core of future development" [38, p. 1].

The model proposed in this paper is targeted to the SDGs in particular, and to the social indicators for the public good in general. Practices and solutions taken from the private sector have to be analyzed and adapted carefully since their priorities and goals are different. As an example, while developmental indicators pay attention to inclusion (no one should be invisible) and respect for the privacy of individuals and their communities, the private sector solutions may have other priorities.

Other efforts for monitoring social indicators exist and can be taken advantage of. For instance, big investments have been made in improving data for monitoring and accountability for the MDGs. Similarly, UN member states have been reporting for over ten years on human rights in compliance with the Universal Periodic Reviews. All such efforts (and in particular, their results) have to be standardized and considered to develop the synergies that they can facilitate.

Data has to include everyone and has to be useful for everyone. The trend shows that businesses and governments are increasingly relying on big data and the associated analytics. While businesses use big data to inform business decisions and strategy, governments use big data to provide better service delivery and citizen engagement [39]. Initiatives on small data (in which data, instead of being aggregated is processed at the same unit as it was sampled [40]) are also important to make sure nobody is left out. The model proposed in this paper integrates both, the big and the small data approaches to promote inclusiveness.

7. CONCLUSIONS

This paper advocates the achievement of the sustainable development agenda through interventions towards improving the capabilities of the entities within the national data ecosystem responsible for monitoring its progress. By the adoption of an organization thinking approach, this research motivates for the adoption and mainstreaming of CMMs within the SDGs activities.

The main contributions of this paper are: a thorough definition and the problematization of a space where research and actions are urgently needed, the preliminary formulation of a multidimensional prescriptive CMM to assess and improve the maturity of organizations within national data ecosystems, and a set of recommendations towards addressing the challenges within the increasingly data-driven domain of social indicators monitoring. Furthermore, and aiming at reaching globally accepted standards, an extensive review that describes the landscape of the current initiatives on improving social statistics was also presented. This contribution can be helpful for informing statistics institutions of the domain of tools and platforms available. Gaps and overlaps were also identified, and the lack of integration among these efforts, leading to a poor utilization of current and previous investments, was highlighted.

Future work includes an in-depth review of case studies to identify best practices for the production of statistics for development, and further development of the CMM by integration the findings of this survey.

REFERENCES


ADVANCED DATA ENRICHMENT AND DATA ANALYSIS IN MANUFACTURING INDUSTRY BY AN EXAMPLE OF LASER DRILLING PROCESS

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ABSTRACT

Nowadays, the internet of things and industry 4.0 from Germany are all focused on the application of data analytics and Artificial Intelligence to build the succeeding generation of manufacturing industry. In manufacturing planning and iterative designing process, the data-driven issues exist in the context of the purpose for approaching the optimal design and generating an explicit knowledge. The multi-physical phenomena, the time consuming comprehensive numerical simulation, and a limited number of experiments lead to the so-called sparse data problems or “curse of dimensionality”. In this work, an advanced technique using reduced models to enrich sparse data is proposed and discussed. The validated reduced models, which are created by several model reduction techniques, are able to generate dense data within an acceptable time. Afterwards, machine learning and data analytics techniques are applied to extract unknown but useful knowledge from the dense data in the Virtual Production Intelligence (VPI) platform. The demonstrated example is a typical case from laser drilling process.

Keywords— sparse data problems, data analytics, machine learning, virtual production intelligence, model reduction

1. INTRODUCTION

Presently, production companies in the high-wage countries have to overwhelm the challenges of rapid responding to variant market demands, individual customer necessities and increasing labor costs. The rising complexity in the production processes motivates the generation of more reliable, efficient and flexible production planning and scheduling steps. The process parameter identification, knowledge extraction, iterative and communicative process design and multidisciplinary optimization are vital fields for production planning and decision making. Since a large amount of data are generated from machines, sensors, orders etc. in manufacturing industry, the developed data-driven methods and methodology can be applied in manufacturing decision making processes [1]. However, the data density is not enough for extracting knowledge because the evident parameter dimensionality is not enough and “the number of experiments” is limited by time or costs.

In this work, a methodology to enrich sparse data by fast and frugal reduced models is introduced. Several typical model reduction methods such as mathematical methods, numerical methods and data-driven methods for generating reduced models are reviewed. After obtaining sufficient and dense data, machine learning methods such as clustering and classification are applied to conduct the data analysis and knowledge extraction. The example case is a laser drilling process. The detailed enrichment of the data and the data-driven decision making process are demonstrated in this example.

2. SPARSE DATA PROBLEMS IN MANUFACTURING INDUSTRY

The processes in manufacturing industry are characterized by multi-parameter models with high resolution. Moreover, the solvability of the process is considerably to be restricted by the complexity of physics. From a data analytics perspective, two main barriers are addressed in this paper, which slow down the process to extract knowledge from manufacturing processes.

The first reason is that the required number of sampling points is enormous. When the dimensionality of parameters increases, the volume of sampling space increases exponentially. That means a large amount of parameters combination is needed and the existing available data becomes sparse. Especially, in manufacturing industry, the data from different process domains becomes heterogeneous and sparse within the high dimensional parameter space.

The second reason is that the sampling process can be time consuming. The sampling process is a process of selecting or generating the dataset which can be used in knowledge extraction. The sampling points can be collected from the real experiments or the computer aided calculations. The number of real experiments is not only limited by the time restriction but also limited by the boundary of the
performance of machines or sensors. The computer aided calculation, also known as numerical simulation, is a powerful tool to generate sampling datasets. However, the complex numerical simulation could be time-consuming because of the high resolution and complex process physics.

3. ENRICHING SPARSE DATA BY REDUCED MODELS

Generally speaking, the reduced models can enrich the sparse data from two aspects. On the one hand, the reduced models decrease the required data volume dramatically. The “sparse data” become “dense data” because of the compendious dimensionality. On the other hand, the reduced models are also characterized by their convenient solvability, millions of datasets can be generated from reduced models in acceptable duration.

The workflow to enrich sparse data into dense data are shown in Figure 1. Firstly, the data is extracted from divergent sources in real manufacturing processes and experimental measurements. Different types of sensors, diagnosis techniques and design of experiments are intensively operated to accumulate the original sparse data. At this stage, the data are featured by its high volume, insufficient dimensionality, heterogeneous distribution and irregular data format. Thereafter, the massive mathematical and physical modelling work for the complex manufacturing process is performed and validated by the sparse data in the first stage. From the well-built complicated models, the full dimensional parameters will be involved and the data generated from multifarious models is equipped with standard data format. Since the sampling process by complex models is time consuming, model reduction techniques are applied to generate the fast and frugal reduced models and avoid the unnecessary complexity. The reduced models are derived to avoid any unnecessary complexity and to reduce the computation time of large-scale dynamical systems by inducing approximations of much lower dimensions which can produce nearly the same input-output response characteristics. Meanwhile, to ensure the accuracy and the applicability on the specific context, the reduced models are also calibrated and validated by the measured sparse data. These reduced models can simulate the complex system by preventing redundant calculation, so the sparse data can be enriched dense enough for data-driven decision making extraction within a short phase.

The model reduction procedure adopts a top-to-down approach and starts from the original partial differential equations and derives approximated analytical solutions or a set of ordinary equations using many mathematical approaches, physical and phenomenological approaches, numerical approaches and data driven model reduction methods. Especially, there are several model reduction techniques which are convenient enough to use and worth reviewing.

3.1 Perturbation analysis

The objective of perturbation theory is to determine the behavior of the solution when one variable tends to be very small, which can lead to the split of two part of solutions for complex system. One part is the temporal solution and another part is the long term asymptotic solution. This separation of system solutions result in the reduction for the models. The typical application of this perturbation theory lies in the fields involving differential equations as well as a series of engineering problems [2] [3]. Vossen et al. used the perturbation and asymptotic analysis to describe the dynamical behaviors of the free boundaries of the melt during the laser cutting process considering the spatially distributed laser radiation. A reduced model which can generate results at real time scale was derived by perturbation analysis for the purpose of predicting the product roughness [4].

3.2 Inertia and central Manifold analysis

The inertial manifolds are connected with the long term behavior of the solutions of dissipative dynamical systems. The reduced phase space of ordinary differential equations and partial differential equations in the long time limit is named as central or inertial manifold. Schulz et al. derived a reduced model by applying inertial manifold method. This reduced model can calculate the thermal behavior in laser manufacturing processes very fast [5, 6].

3.3 Buckingham Pi theory
The Buckingham Pi theory is used to find the dimensionless groups from relevant input and output parameters. The dimensionality of the original parameters is sharply decreased and simplified by applying the dimensionless groups [7]. The major steps to perform the model reduction with assistance of Buckingham Pi theory are as following:

Step 1: Finding the dimension matrix;
Step 2: Determining the rank of the dimensions of full-space parameters;
Step 3: Finding the vectors spanning the full-space parameters;
Step 4: Finding the reference meta-models which include the dimensionless parameter groups;
Step 5: Data-driven modelling by calibration sparse data and reference meta-models;

Schulz et al. derived a reduced model by applying the Buckingham Pi theory and the steps listed above. This reduced model can calculate the heat conduction losses in laser sheet metal cutting processes rapidly [8].

3.4 Proper Orthogonal Decomposition

Proper Orthogonal Decomposition (POD) is a numeric method by searching for a low-dimensional approximate representation of the large scale dynamical systems, such as signal analysis, turbulent fluid flow and large dataset like image processing [9,10]. POD generates a set of orthonormal basis of dimensions, which minimizes the error from approximating the snapshots. It can generally give a good approximation with substantially lower dimensionality [11].

4. EXAMPLE FOR LASER DRILLING MANUFACTURING

As an example to illustrate the data enrichment by reduced models and data visualization, an advanced reduced model for sheet metal drilling has been developed by Nonlinear Dynamics of Laser Manufacturing Processes Instruction and Research Department (NLD) in RWTH Aachen University. Using this model, the final shape of the drilling holes can be calculated and described. Inside the formula (see Figure 2), the term $F$ is the local laser fluency, $z$ and $x$ represent the position along $z$ and $x$ axis respectively, the term $F_{th}$ is based on the heuristic concept of an ablation threshold and material dependency. The only one unknown parameter has to be calibrated and determined with experimental sparse data. Afterwards, this reduced model can be used to calculate the final shape of the drilling hole by laser sheet metal drilling. Not only the final shape of drilling hole but also the feasibility for each parameter can be indicated accurately by this reduced model.

Table 1. Example of parameters and their range in laser drilling processes

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</thead>
<tbody>
<tr>
<td>Pulse Duration [(t_p)]</td>
<td>0.1-1.5 [ms]</td>
</tr>
<tr>
<td>Laser Power [(P_L)]</td>
<td>3-10 [kW]</td>
</tr>
<tr>
<td>Focal Position [(z_0)]</td>
<td>-8-8 [mm]</td>
</tr>
<tr>
<td>Beam Radius [(w_0)]</td>
<td>50-350 [(\mu)m]</td>
</tr>
<tr>
<td>Rayleigh length [(z_R)]</td>
<td>3-35 [mm]</td>
</tr>
<tr>
<td>Workpiece Thickness [(d)]</td>
<td>0.2-5 [mm]</td>
</tr>
</tbody>
</table>

After the sparse data is enriched into dense data by asymptotic reduced model, the machine learning techniques are applied to conduct data analytics. Thereby the data analytics process including appropriate data visualization methods are implemented within a Virtual Production Intelligence (VPI) platform [12]. The process is described in detail in [13]. It implemented a hybrid data analytics approach with clustering and classification tree to identify parameters of the manufacturing process that result in desired outputs. The approach is shown in Figure 3.

Fig. 2. The procedures to generate asymptotic drill reduced model

As a consequence, the whole asymptotic shape of the drilling hole is calculated and is illustrated. Finally, classification of sheet metal drilling can be performed by identification of the parameter region where the drilling hole achieves its asymptotic shape.

Fig. 3. Data analytics process to analyze dense data [13]
First of all, clustering is used to divide the output data of the reduced model into different regions (clusters). Thus, the user is able to select a cluster that represents desired process results. After that, the classification trees are used to identify regions of the parameters space (see also Table 1) which lead to these process result.

The output of the asymptotic drill reduced model represents the shape of the drilling hole and thus consists of three dimensions: the widths at the top and the bottom of the hole as well as the conicity. In order to depict and analyze this multi-dimensional data, a visualization technique named parallel coordinates is utilized. Figure 4 shows its implementation in the VPI platform for 10,000 laser drilling sampling points, whereas the data is generated with the fast reduce model. In the next step, the data are divided with a clustering algorithm into 4 clusters. The following Figure 5 illustrates the clustering results of the K-means algorithm.

Having identified the good (i.e. desired) output spaces as well as the bad ones, the next step is to transform the problem into a binary classification problem and to build a classification tree that is used to predict the process outcome (good/bad) on the basis of the laser drilling process parameters (see Table 1).

The following Figure 7 shows a classification tree for the desired clusters (high conicity).

The tree shows that there are mainly two parameter space regions that lead to the desired results (good leaves). These two regions can be defined by the following rules (extracted from the tree):

- \( \text{Laser Power} \leq 170 \) & \( \text{Thickness} \leq 0.0023 \) & \( \text{Beam Radius} > 0.00064 \)
- \( \text{Laser Power} \leq 140 \) & \( \text{Thickness} > 0.0026 \) & \( \text{Beam Radius} \) between 0.00046 and 0.00064

These results show that the hybrid data analytics approach on the top of the reduced model data provides an intuitive and interpretable decision support for the laser drilling process planner. The gained knowledge, especially the identified parameter regions, can subsequently be used to further optimize the process.

**6. OUTLOOK**

In this paper, the methodology to enrich sparse data to dense data and analyze acquired dense data is demonstrated. In order to fully utilize the advantages of the reduced models, a...
large amount of efforts should be made to generate more useful reduced models. Besides, different reduced models have different domain space, the exploration of the boundary for each reduced model is necessary for generating reliable and high quality process knowledge. These regime conditions can be determined by physical driven or data driven methods.

The comprehensive use of data from reduced models can extract the global and local knowledge of the manufacturing process. The interesting topics can be robustness analysis, global and local sensitivity analysis.

REFERENCES

SMALL DATA AND SUSTAINABLE DEVELOPMENT - INDIVIDUALS AT THE CENTER OF DATA-DRIVEN SOCIETIES

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ABSTRACT

At the centre of data-driven societies are individuals and end-users who not only generate data, but also benefit from the outcomes of the data-driven development. Extensive work has been undertaken to understand and explore the challenges and potential impact of data, in particular Big Data, for the private as well as the public sectors. Similarly work has been undertaken within the domains of Personal Informatics and life-logging, which has investigated the role of data, and specifically personal physical activity and health data towards improving the wellbeing of individuals. In this research we investigate the engagement of individuals in the use of data towards the achievement of the sustainable development imperatives as articulated in the 2030 Agenda for Sustainable Development. The paper presents: the awareness levels of the participants with regards to the Sustainable Development Goals; their attitudes and perceptions around monitoring of social indicators; key considerations associated with data ownership, privacy and confidentiality of data, as well as sharing of data within the data ecosystem. The paper subsequently discusses how these finding could inform the implementation of small data tools to support the active engagement of individuals in data-driven societies.

Keywords— Small Data, Sustainable Development, Data Driven Development

1. INTRODUCTION

Data is increasingly pervasive and ubiquitous in the 21st century data-driven societies, and the use of data stands to increase and to permeate more societal domains. Advancements are being seen in the use of data, in particular Big Data, for supporting businesses and the corporate sector towards improved decision-making and effectiveness in areas such as Business Intelligence and Analytics (BIA)[1] as well as management [2], [3]. Similarly the public sector use of data can be noted towards improved policy development [4], and service delivery, where “governments expect big data to enhance their ability to serve their citizens and address major national challenges involving the economy, health care, job creation, natural disasters, and terrorism” [5]. The increasing ubiquity of data in society is not only seen in the increased use in organizations but also in: increased data use by individuals in areas such as life-logging [6], [7], associated with the proliferation of activity trackers and mobile devices; as well as in the embedding of digital infrastructures and ‘everyware’ [8] within smart cities initiatives [9].

At the global level, there has been recognition of the role of data towards supporting the achievement of the global development imperatives as articulated in the 2030 Agenda for Sustainable Development. The United Nations Sustainable Development Goals (SDGs) resolution highlights, within Goal 17, technology as an explicit Means of Implementation towards the achievement of the goals [10]. Further, the role of the indicators data within the SDG programme has also been well articulated [11], [12]. The focus within the social indicators monitoring domain has largely been about using data for the purposes of Planning, Monitoring and Evaluation at the national and sub-national levels. Extensive research has been undertaken exploring the potential for data in this regard [12]-[14]. Social indicators monitoring in this context is typically driven by the work of the statistics community, in particular the National Statistics Offices, government departments, as well as multilateral organizations.

Beyond supporting the national-level and multi-lateral stakeholders, the use of data can be towards supporting individuals and community-level actors (e.g. Non-Governmental Organization, and Community-Based Organizations). There has been increasing efforts and research around the use of data for informing individual wellbeing goals and imperatives. The growing field of Personal Informatics, quantified-self, and lived informatics represent this interest and focus on data that is collected by individuals for the ultimate utility that accrues towards the individuals [15]. Within these domains work has been undertaken that explores data for supporting social sense-making [16], using personal data for improving patient-provider communication in the healthcare sector, and using quantified-self data for cancer rehabilitation.

Mortier et al have suggested that, with the growing amount of ubiquity and pervasiveness of data, there is a need to explicitly consider Human Data Interaction (HDI), which they define as being constituted of three key themes and domains: legibility, agency and negotiability [17]. Legibility regards ensuring the comprehensibility of data and the associated algorithms, so that the individuals are aware of their data and the implications of its use; agency in this context is about allowing individuals the freedom and capacity to act within the data ecosystems; and negotiability concerns the dynamic relationships that emanate from the individuals’ interaction with the data. These three themes provide a suitable initial framing of the key concerns for
consideration in the role and engagement of individuals in data-driven societies.

In this research we investigate the engagement of individuals in the use of data towards the achievement of the sustainable development imperatives as articulated in the 2030 Agenda for Sustainable Development. Section 2 provides a theoretical articulation of dynamics of data for development and also provides a characterization of small data. This is followed in section 3 by a presentation of the survey that was undertaken to understand participants’ attitudes and practice towards collection and sharing social indicators data. Section 4 and 5 provides a discussion informed by the findings of the research, and section 6 concludes the paper.

2. SMALL DATA AND DEVELOPMENT

While there is a tendency to consider data generally and broadly, different types (e.g. Big Data, open data, citizen generated data, small data, real-time data) of data stand to play varied roles within the 21st century data ecosystem. For example, the dynamics associated with the use of Big Data by governments are very different from the dynamics of open data, wherein the former could be associated with citizens disempowerment through increased surveillance and collection of citizens data, while the latter could be associated with empowerment of the citizenry through the increased openness and transparency of government towards the citizens. Similarly citizen generated data could play a more elevated role towards better describing grassroots social development phenomenon, while small data could lead to individuals being connected to more actionable and relevant insights.

Small data, which is of main focus in this research, is increasingly being conceptualized and defined in very distinct terms. Small data has been articulated: as the digital traces around an individual [18]; as data from an ethnographic and human-centric investigation of a social phenomenon [19]; and as an approach to analyzing data at the same unit of sampling [20]. In this research we adopt the characterization of small data for development as “an approach to data processing that focuses on the individual as the locus of data collection, analysis, and utilization towards increasing their capabilities and freedom to achieve their desired functioning” [21]. This definition focuses on the individual and their associated interactions within the data ecosystem, and from this perspective the emphasis in the consideration of data for development is about connecting individuals with the relevant data (including personal data, big data, open data, real-time data) towards their development and wellbeing.

The value proposition for data for development follows the traditional information value chain, wherein data that is converted to relevant information, informs decision making and has an impact on life (Figure 1). This basic information value chain however oversimplifies a complex and much more nuanced process that typically unfolds at the interplay of individual’s agency and the structural context. Using Sen’s capability approach can help to unpack this process in a more generalized manner wherein the data that people have access to is simply a resource that potentially increases individuals’ capabilities set, and therefore one that individuals can use to achieve their desired functionings [22]. This process can be further enunciated by identifying one of the mechanisms through which collected social indicators data is utilized, which is for facilitating individuals’ reflection and critical awareness of their own life and circumstances [23].

![Fig. 1. Expounded information value chain](image)

The notion of using data, in particular personal data, for reflection is also noted as an explicit phase in the Stage-based model of Personal Informatics Systems which consists of the stages of [15]: preparation – establishing motivations for tracking data and identifying which data is of interest; collection – the actual collection of the identified data; integration – processing of the data, which involves analysis, combination and transformation; reflection – when users engage with the data for the purposes of sense-making and meaning-making; and action – which is the stage at which individual actively chose a particular course of action informed by the reflection on the data collected.

The motivation, within the preparation phase in the Stage-Based Model of Personal Informatics Systems, for people to collect information about themselves is usually to advance self-knowledge, self-insight and to promote positive attitudes and behaviors [24]. Rooskby et al identify what they term “styles” of personal information tracking which are [6]: Directive tracking – wherein individuals record and track personal information towards a goal achievement. For example, measuring and monitoring
the number of steps taken towards reaching the goal of 10,000 steps a day; Documentary tracking – this is the recording of personal information for the purposes of documenting their lives, in a manner not different from journaling about one’s daily activities; Diagnostic tracking – this is where the recording of personal information is done with the goal of identifying links between various phenomena. For example, to diagnose the link between diet and the occurrence of stomach ailments; Collecting rewards – this is for cases where individuals undertake recording of personal information towards receiving a specific value reward; and Fetishised tracking – in this case the allure and the pull of the technology is the main motivation for individuals to measure and monitor their personal data.

Individuals play varied and diverse roles within the data ecosystem such as data producers, collectors, curators, and consumers. Illustratively one can note examples of individuals playing the role of being data producers, not only in personal informatics domain but also through the myriad of mechanisms, such as using social media tools and also through what has in recent times been termed digital traces.

3. INDIVIDUALS ENGAGEMENT IN THE SDG DATA ECOSYSTEM

The methodological design of this research is framed around three lines of inquiry: to contribute better understanding of participants’ attitudes and values towards social indicators monitoring, their current practice towards social indicators monitoring, as well as the use of technology to support social indicators monitoring. This investigation is framed in the context of the Sustainable Development Goal 3, which aims to “ensure healthy lives and promote wellbeing for all at all ages”.

A survey instrument has been used in this research for quantitative data collection for: informing an understanding of the participants (i.e. in terms of basic demographics), for the high level identification of their values and attitudes towards monitoring and tracking of individually relevant social indicators data, and for understanding the current practice around monitoring of relevant social indicators. The survey is framed to inform a non-probabilistic descriptive understanding of these issues for the specific individual participants in the research, without making wider population group generalizations. This survey instrument was administered online and the recruitment of the participants was done through email invitations, social media channels and virtual snowballing techniques.

In total 53 people started the survey and 37 of those completed the survey. The bulk (58.2%) of the respondents are young people within the 25 – 34 age group, with the other big groups being 35 – 44 age group at 27.6%, and 45 – 54 age group at 9.8%. The participants are mostly educated and technology-savvy with 94.1% holding a university degree; and with technology ownership at 96% and 88% for smart-phones and laptops/computers respectively.

The key findings from the survey are presented hereafter through the analytical lens of the Stage-Based model of Personal Informatics Systems to highlight and map the insights from the survey against the five phases of information flow within this model [15].

3.1. Awareness of SDGs

The Sustainable Development Goals form the backdrop against which the consideration of individuals’ contribution and participation in the data-driven society is considered in this research. The awareness and knowledge of the SDGs by the participants varies widely from 29.8% of the participants indicating not knowing the SDGs, and 25.5% indicating to have heard about the SDGs; to 6.4% who indicated that they know all the SDGs in detail (Figure 2).

![Fig. 2. Knowledge and awareness of the SDGs](image)

Further evaluation was undertaken to understand the importance that the participants ascribe to the different developmental issues as articulated in the SDGs narratives. On a five star (1 – 5) rating of the importance of the various goals, the average rating across all the SDGs was 4.45. The lowest average rating at 4.06 was for SDG 14 (“Conserve and sustainably use the oceans, seas and marine resources for sustainable development”) and the highest average rating at 4.79 was for SDG2 (“End hunger, achieve food security and improved nutrition to promote sustainable agriculture”). For the rankings for SDG3 (“ensure healthy lives and promote wellbeing for all ages”), which is of particular focus in this research, the finding is that the majority (80.9%) of participants considered this a very important goal at 5 stars.

The importance of awareness as a step towards reaching the SDGs targets can be alluded from literature wherein a high correlation was found between the level of public awareness of the Millennium Development Goals (MDGs) and the likely achievement of the MDG indicators [25]. As such building and increasing public awareness around the SDGs remains an important initial step towards garnering public support and engagement in contributing data towards the monitoring of the SDGs.
3.2. Motivations and incentives for data use

During the preparation stage, individuals' motivation for collecting and using data are considered. At this stage individuals also make decisions regarding not only the data that they intend to monitor, but also the associated tools that they use for the monitoring.

In economic theory and social psychology, motivations are typically considered to either be intrinsic or extrinsic [26]. In the case of intrinsic motivation, the benefits of undertaking an action accrue directly and immediately to the individual in a form of enjoyment-based or obligation-based satisfaction. Extrinsic motivations on the other hand involve an indirect reward, such as money. While the terms “motivation” and “incentive” are sometimes used interchangeably, a distinction is sometimes made where motivations are considered more intrinsic while incentives are more extrinsic to individuals [27]. There is an interplay between motivations and incentives towards influencing individuals decisions and actions, where phenomenon such a “crowding out” can occur due to extrinsic incentives eroding intrinsic motivations [26]. There has been research undertaken that explores incentivizing individual’s participation in data related activities, such as participating in online surveys [28], however there is a gap in literature on incentives for data contribution in the context of the sustainable development agenda.

This research investigated the extent to which the participants would be incentivized to record and share their data, both personal health data and information that they had access to, such as water and air quality data (Figure 3).

![Fig. 3. Motivations and incentives for data collection and information sharing](image)

The motivations and incentives for recording and sharing of social indicators data are observed to be both intrinsic and extrinsic. The majority of the respondents highlighted the intrinsic socially framed motivation of undertaking the monitoring and sharing “if it’s part of a community effort”. The extrinsic motivations of “monetary benefit”, “cellphone credit” and “a chance of winning a price” are observed to be the least influential for motivating the participants towards monitoring and sharing of data.

3.3. Data collection and monitoring

From the preparation stage, once individuals have established the motivations for monitoring and collecting data, and having identified the relevant tools, they progress to undertake the actual collection and recording of the data.

From the participants in the survey the use of fitness / activity trackers is observed at 18.75% for daily use, 6.25% for weekly use, 2.08% for monthly use, 10.42% for seldom use, and 62.5% for never used. While the use of fitness / activity trackers is specifically for tracking personal health metrics, increasingly individuals are also making use of the smart phone apps and smart watches for monitoring and tracking of personal health metrics. From the survey 87.5% of the people indicated that they never used smart watches, while 10.42% and 2.08% use their smart watches daily and weekly respectively. The use of smart phones is high as expected at 95.83% of individual claiming daily use, 2.08% for seldom use and 2.08% for having never used a smart phone before. This captures the general use of smart phones by the participants and not just specifically for self tracking and monitoring.

3.4. Data utility, sharing, and social sense-making

The conversion of monitored and collected individual data into developmental action is decomposed by Li et al into two distinct processes of integration and reflection [15]. Integration primarily consists of processing and manipulating the data in order to feed into the next process of reflection. Reflection as a cognitive technique for meaning and sense making has been studied and expounded on in various fields including education [29], psychology, and human computer interaction [30]. In the field of Personal Informatics, recent work has explored supporting reflection and behavior change through sharing of personal data [31], [32], and through social sense-making [16].

![Fig. 4. Sharing of personal health information with different stakeholders](image)

In the context of the sustainable development data ecosystem or that of future data-driven societies, the sharing of personal data needs to be considered not only within individuals’ personal social circles but also with other stakeholders within the wider data ecosystem. As such this research explored the participants attitudes towards sharing of their personal data within the sustainable development agenda.
development data ecosystem, exploring both the willingness of the participants to share their data with specific stakeholders, as well as the factors that would inform their willingness to share (or not to share) their personal data.

Using a continuous scale from 1 to 7 at “low willingness to share” and “high willingness to share” respectively, the participants are most (mean 6.58) willing to share their personal health data with their doctors, and least (mean 3.24) willing to share their data with pharmaceutical companies (Figure 4).

Further analysis was undertaken to understand how the participants’ attitudes towards sharing their personal data correlates across the different stakeholders. For this analysis a Spearman correlation matrix was derived and subsequently agglomerative hierarchical clustering (complete linkages method), using the Euclidian distance between the correlation scores, undertaken to understand the main clusters for the different stakeholders (Figure 5).

From this analysis three primary clusters of stakeholders are noted (cutting the dendrogram in Figure 5 at the height of 1.5) and these are: Cluster 1 - individual’s doctor; Cluster 2 – NGO working on health issues, national Department of Health, National Statistics Department, a pharmaceutical company, and the World Health Organization; and Cluster 3 - family members and friends. Clear characterization emanates from these clusters, based on the relationship between the stakeholders and the individual, and the nature of the utility that accrues to the individual, as follows:

- Cluster 1 is a stakeholder that is able to use the shared personal health data towards the provisioning of an immediate health service, wherein the data can be used for health monitoring or to inform diagnosis of medical ailments. This therefore represents a direct (and future) benefit to the individual.
- Cluster 2 are organizational entities within the wider health sector with clear sub-clusters of governmental, non-governmental, and international/multinational organizations. The benefits that accrue to the individual from sharing data with these entities are indirect and generally not immediate.
- Cluster 3 are entities with a high social proximity to the individual, where the sharing of the personal health data could be more towards the associated social benefits, such as sense-making [16], and social support [32].

The findings from the survey are that these initial clusters of stakeholders not only highlight the need for differentiated data sharing arrangements with entities within the data ecosystem, but also point to the willingness of the participants to consider sharing their data across the ecosystem.

The advent of social media has meant that individuals are increasingly used to sharing their data. However a lot of the voluntary and active sharing of data is typically in the context of the social networks that the individuals have. Currently a lot of individuals’ data is collected, without their full awareness and complicity, from individuals’ digital traces and from tracking of individuals online through surveillance. Solove suggest a taxonomy that identifies four basic activities around which violation of individuals’ privacy violation can occur, and these are [33]:

- information collection – in which activities such as surveillance and interrogation can be employed (by data holders) to gather information about individuals (the data subjects);
- information processing – through the processing of the data involving aggregation and analysis;
- information dissemination – encapsulates activities such as breach of confidentiality, disclosure, exploration, blackmail and distortion, which would contribute towards violating individuals’ privacy; and lastly invasion – which is not about individuals’ information but rather about violating privacy associated with individuals personhood. The contention and opposition to the practice of mass collection of individuals’ data is growing, and increasingly there is push back from civil society to have increased privacy and confidentiality of their data, to have control over who collects the data, what data is collected, and how the data is used (i.e. increased data legibility [17]).

As such, beyond just understanding the participants’ attitudes towards sharing data with specific stakeholders, this research also sought to investigate the factors that affect the willingness of participants to share data, based on 10 pre-selected factors and an evaluation using a continuous scale of between 1 (for low influence) and 7 (for high influence).
The factor that scored the highest (mean 6.16) on influencing individuals to share (or not to share) their personal health information is the privacy of the information, with the lowest being the individuals’ right to be left alone. A subsequent clustering of these factors was undertaken, using hierarchical clustering based on the Euclidian distance off the Spearman correlation matrix of the factors (Figure 6), and using the complete linkages agglomeration method to find similar factor clusters (Figure 7).

Three key categories emanate from the clustering exercise undertaken, and these have been labeled: 1) the intrinsic value based factors – which reflects internally held individuals beliefs about the values and attributes of the data; 2) intrinsic personal factors – which are factors centered around the individual and their interaction with their data; and 3) extrinsic factors – these are factors that are associated with externally-oriented use of the individuals’ data. Table 1 lists these categories and the associated mean scores for the factors and across the categories.

Table 1. Influence factor clusters and means

<table>
<thead>
<tr>
<th>Key</th>
<th>Description</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic value based</td>
<td>The confidentiality of the information</td>
<td>5.64</td>
</tr>
<tr>
<td>X9_confidential</td>
<td>The secrecy of the information</td>
<td>5.11</td>
</tr>
<tr>
<td>X9_privacy</td>
<td>The privacy of the information</td>
<td>6.16</td>
</tr>
<tr>
<td>Intrinsic personal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X9_benefit</td>
<td>That the information is used for my direct benefit and wellbeing</td>
<td>5.7</td>
</tr>
<tr>
<td>X9_control</td>
<td>The need to control access to personal information</td>
<td>5.26</td>
</tr>
<tr>
<td>X9_alone</td>
<td>My right to be left alone</td>
<td>3.84</td>
</tr>
<tr>
<td>Extrinsic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X9_UN</td>
<td>Assisting the UN to compare quality of health across different countries</td>
<td>4.48</td>
</tr>
<tr>
<td>X9_reporting</td>
<td>Assisting government to report on quality of health in the country</td>
<td>4.34</td>
</tr>
<tr>
<td>X9_industry</td>
<td>Contributing to improving the health industry through better medicines</td>
<td>4.84</td>
</tr>
<tr>
<td>X9_national</td>
<td>That the information is used for national health policies</td>
<td>4.74</td>
</tr>
</tbody>
</table>

On average the factors that the participants point to as having the highest influence on their willingness to share their personal health information are those associated with the privacy, confidentiality and secrecy aspects of the personal data. These three concepts are of course tightly coupled and represent varied conceptualizations of the notion of privacy [34]. The factors associated with the external use (e.g. contribution to the national or UN-level social indicators efforts) of the individuals data in general are of lower influence on the participants towards them sharing their data.

The two broad findings, on the clustered differentiation of the entities within the data ecosystem that the participants are happy to share their data with, as well as on the clusters of factors that influence individuals to collect and share their personal data, give further insights on the strategies for engagement of individuals within the sustainable development data ecosystem.

4. DISCUSSION

Mortier et al have suggested that legibility, agency and negotiability are three of the core themes for consideration in Human Data Interaction [17]. These three themes are associated with amplifying the capability of individuals to engage meaningfully and actively with their data. This research has engaged with these concepts from the perspective of small data to support the individuals’ participation within the sustainable development data ecosystem. The formulation of small data for development in section 2, which is framed around the Capabilities Approach, emphasizes individuals’ freedom and agency to use data to achieve the development ends that they desire. Recognition is given to the fact that data, including small data, has the potential both to restrict and to expand individuals’ substantive freedoms towards their development and wellbeing, as such the individuals participation and engagement within the 21st century data-driven societies needs to be critically considered from this...
In the use of data towards development and wellbeing, individuals employ both reflection [31] and social sense-making [16] as techniques towards converting the data into actionable insights. Beyond sharing data within their immediate social circle, there are opportunities for increased effectiveness (e.g. for better understanding of various social phenomena) within the sustainable development ecosystem from sharing of data widely with other stakeholders. The findings from the participants in this research identify three clear groups of stakeholders for consideration in data sharing. The first is associated with entities that are able to provide immediate benefit and service to the participants (in this case, the doctors), the second represents the close social relationships, and the last broadly represents organizational entities. These clusters not only highlight the need for differentiated data sharing strategies, policies, and systems, but also provide an initial encapsulation of the different requirements for data sharing.

Beyond the identification of the participants’ attitudes towards sharing personal data with specific stakeholders, the investigation of the factors that affect participants’ willingness to share their data reveals the high importance of data privacy, secrecy and confidentiality. This suggests a need for explicit data security mechanisms within the systems that are implemented for processing of personal data. While the factors that are associated with external use of personal data had a low influence on individuals collecting and sharing of their data, it still remains that at a mean of 4.48 (out of 7) these factors are still taken into consideration at some level by the individuals. The three clusters that emanate from this investigation also provide an encapsulation of concerns to inform the development of relevant system policies or functionalities.

Research has been undertaken to explore the role and effectiveness of incentives for influencing individuals towards data sharing, in the context of participating in web surveys [28]. The findings from the participants in this research, with regards to factors that would motivate their collection and sharing of data is that both intrinsic motivations and extrinsic incentives would be considered and relevant, however the indication of the highest incentive as “if it’s part of a community effort” puts even greater emphasis on the potential of intrinsic obligation-based motivations. Linking this motivation with the observations around social sense-making also suggests the potential of collective (e.g. at a community level, or social grouping level) engagement in data for sustainable development initiatives. This would thereby be towards not only encouraging social sense-making, and providing incentives, but also expanding the collective capabilities of the individuals [35].

5. INFORMING THE IMPLEMENTATION OF SMALL DATA TOOLS

This research is undertaken in the context of a larger exploration of the role of Information and Communication Technologies to support individuals and community based organizations towards the achievement of the sustainable development goals. The findings from this research stand to inform the development of the associated small data tools towards supporting individuals’ use of data for their health and wellbeing (SDG3) as follows:

- The tools need to allow for a targeted, differentiated and secure sharing of data with specific individuals and stakeholders.
- There is a requirement for data provenance preservation, associated with expression of concern by the participants to have control over their data, and also to maintain the confidentiality of the data.
- The general high level of use of smart-phones presents an opportunity for varied kinds of data (e.g. recorded, derived, and observed) to be processed, taking into consideration the privacy concerns.
- While it might be necessary to incorporate mechanisms for extrinsic rewarding within the tools for user contribution of data, there is also a potential to facilitate community building and collective engaging between the users of the tools.

6. CONCLUSION

The ubiquity and pervasiveness of data is growing and the use of data to drive efficiencies, achievement of goals, and improved decision making is increasingly permeating all societal domains. This data revolution is characteristic of the 21st century data-driven society and it presents numerous opportunities and risks not only to individuals, but also to organizations and governments. Extensive research has been undertaken that explores these opportunities and challenges, in particular within the context of the 2030 Agenda for Sustainable Development goals.

This paper has explored the engagement of individuals within the sustainable data ecosystem, by investigating through a non-probabilistic survey and presenting through a descriptive analysis: the awareness levels of the participants with regards to the Sustainable Development Goals; their attitudes and perceptions around monitoring of social indicators; key considerations associated with data ownership, privacy and confidentiality of data, as well as sharing of data within the data ecosystem. While the results from the survey are specific to the participants and cannot be immediately generalized to wider populations (due to the non-probabilistic sampling), the findings highlight important considerations that not only stand to inform the development and implementation of further small data solutions in this research, but also contribute to the general discussions around data ownership, data sharing, data provenance, and incentives and motivations for sustainable development data.
The role of individuals in data-driven societies is paramount and the necessity to support individuals’ active involvement and participation in the associated data ecosystem is critical. This paper has presented research that’s part of an ongoing effort towards ensuring the benefits of the data revolution accrue to all, without leaving anyone behind.

REFERENCES


SESSION 4

SMARTENING UP SOCIETY WITH DATA AND NEW APPLICATIONS

S4.1 Fostering smart city development in developing nations: A crime series data analytics approach*
S4.2 Toward the data-driven "smart" and "green" hospital-care*
S4.3 Socio-economics and educational case study with cost-effective IoT campus by the use of wearable, tablet, cloud and open e-learning services*
S4.4 Drone readiness index
FOSTERING SMART CITY DEVELOPMENT IN DEVELOPING NATIONS: A CRIME SERIES DATA ANALYTICS APPROACH

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ABSTRACT

Crime remains a challenge in many parts of the world. This is compounded in low-resource settings where police are short-staffed and there are not enough technological solutions in place to assist security agencies with knowledge-driven decision support. While most smart city initiatives have placed emphasis on the use of modern technology such as armed weapons for fighting crime, this may not be sufficient to achieve a sustainable safe and smart city in resource constrained environments, such as in Africa. In particular, crime series which is a set of crimes considered to have been committed by the same offender is currently less explored in developing nations despite its importance for public safety improvement. This research presents a novel crime clustering model, CriClust, based on a dual threshold scheme for crime series pattern (CSP) detection and mapping to derive useful knowledge from a crime dataset. Based on analysis of 5500 (rape) crime records across 40 locations (suburbs) in Western Cape, CriClust led to the identification of up to three series at some of the locations investigated. We present an effective web-based system that security agencies can use for timely CSP identification to aid strategic and viable means of combating crime in low resource settings.

Keywords— Public safety, Low-resource settings, Crime series

1. INTRODUCTION

South Africa (SA) is one of the countries with the highest crime rates around the world [1]. Therefore, the government’s vision is to invent new strategies for improved public safety outcome [2]. Tackling crime effectively is more challenging in resource constrained settings, where crime intelligence experts and police are limited and not enough technological solutions are in place to meet up with daily operational safety needs. This is the case in most developing nations where local police stations still adopt the traditional (manual) means of crime data collection and by extension limited analysis for knowledge support, which hinders strategic and tactical crime interventions. Moreover, this limited data analysis for knowledge support does not align with the smart city goal focused at improving the “quality and efficiency” of the services rendered by government entities and decision makers [3].

Security agencies (particularly in developing nations) need to adopt more reliable and promising crime mining solutions to realise better tactical and strategic ways of dealing with crime. One of such ways is through the timely identification of a crime series pattern (CSP) as depicted in Figure 1, which is a set of crimes considered to have been committed by the same offender [4]. However, our findings reveal that police do not currently have an automated means of identifying CSP.

Fig. 1. A depiction of serial predator in related crime scenarios in a city

In promoting the identification of crime series, we present CriClust, a model for revealing CSP information in crime data. In this research, a user-centred system was developed to elucidate how security agencies in low-resource settings can be assisted in achieving tactical and strategic interventions. A related study (by the authors) is focusing on how to integrate crowd-sourcing and mobile phones to promote crime knowledge support. This can enhance operational planning with deep insights from crime data.

The rest of the paper is structured as follows: Section 2 provides a general background to current practices in South Africa and presents a summary of gaps and opportunities that have been identified in the current system and approach to knowledge support for crime control. The key contribution of this paper is described in sections 3, 4, 5 in terms of the methodology, results, the web-based system and contribution to smart city development. Finally, section 6 presents the conclusion and possible extension to the research.

The authors gratefully acknowledge the financial support from the National Research Foundation (NRF), South Africa.
2. CRIME CONTROL IN SOUTH AFRICA

The South African Police Service (SAPS) is the national police force of the Republic of South Africa, with about 1,138 police stations. These stations are divided according to the 9 provincial borders, and a Provincial Commissioner is appointed in each province [2]. A major responsibility stipulated by the country’s constitution is that SAPS should prevent, combat and investigate crime. However, containing crime remains a never-ending concern in South Africa (SA), as suggested by the victim of crime survey 1. In recent times, there has been a significant increase in the crime rate in South Africa, and this has been a major motivation for this research.

2.1. Crime Control - Current Practice

In SA, crime reporting is typically done at the police station using traditional (manual) approach. This information is later captured onto the system at the local police stations and stored for (future) processing at a provincial level, where a domain expert analyses the information for knowledge support. This is typically the case because existing software (e.g. Analyst’s Notebook) that could reveal pattern in crime data are very expensive to purchase and requires critical training or a domain expert, which poses serious constraints on developing nations. Our findings indicate that such tool is only available at the headquarters/provincial level in SA. Thus, local stations only make use of basic Excel software for filtering data and identifying patterns, which is cumbersome, error prone and time consuming. This is a great hindrance to effective policing.

2.2. Crime Control - The Gaps

According to report 2, the South African police: citizen ratio is currently 1:347; that is one police officer for every 347 citizens, or around 288 police officers per 100,000 people. This report positions the country in the lower-middle end of policing when compared to countries across the world. While the police is determined to “squeeze crime to zero” [2], there exists some challenges that may hinder their effort in combating crime. The following four main gaps were identified in the current approach to crime control:

2.2.1. Limitation on Crime Data Acquisition

The crime data provided by SAPS may suffer from omission and inaccuracies since it is still manually captured by the police. These inaccuracies could hinder crime mitigation measures. A related study (by the authors) aims to address some of these challenges by use of a context-aware application that integrates crowd-sourcing, mobile phones and internet-crawling to extract crime data that will assist real-time information capture, as well as automated and timely documentation of crime information.

2.2.2. Limitation on Knowledge Acquisition

The usefulness of the information supplied by the current system (e.g. Crime Hub 3) to stakeholders and community policing authorities is rather wanting. The summary crime statistics usually reported by SAPS are at best only able to provide a rough indication of deterioration or improvement within different suburbs in South Africa or between police districts. It would for example be more desirable to report on exact attributes or the peculiar (characterising) features of a crime trend, which can assist actionable knowledge support. For example, it is not sufficient to report that; “1700 sexual assaults cases were recorded in western province in 2016”; rather, a report stating that, “out of 1700 sexual assaults cases recorded in western province in 2016, 500 of the cases have been identified to involve repeat offender(s), who mostly operates at night (between 7-9 pm) at the city-centre and captures young females between ages 12 to 25 as victims”. The latter report reveals more information about the spatial, nature and sensitivity of crime attributes involved in such series. Hence, can aid actionable knowledge (e.g. suspect prioritisation) for crime deterrence in resource constrained settings.

2.2.3. Potential Delay in Crime Information Dissemination

Considering the current practice in SA, there is high tendency for delay in crime mitigation practices, leading to poor interventions and policing strategies. This is evident as local stations typically transfer crime data accumulated over a period of time to the provincial authority for analysis, since there are few domain experts that can handle such analysis and that is where a more advanced tool is available. This is a great limitation to effective policing because if at local levels, police are able to derive patterns in a timeous manner, then they can act to stop such patterns. However, in situations where they will have to wait a couple of days or weeks to get the analysed pattern from provincial level, crime could have worsened during the waiting period. This gap can be fixed by deploying at local levels cost-effective user-centred tools (e.g CriClust), which can present understandable structures, patterns or trends to stakeholders in a timeous manner.

2.2.4. Non-Proximity Centred Analysis

The aim of data analytics is to transform data into “smart statistics” (i.e. non-trivial and useful information) to gain insight for knowledge support. Crime patterns often differ and have their unique Modus Operandi (MO), since the opportunities available to potential offenders vary across different spatial space due to differences in spatial factors [5]. Hence, a spatial framework with features and instances embedded

1http://www.statssa.gov.za/publications/P0341/
3https://www.issafrica.org/crimehub/
within the framework is central to deriving a useful spatial analysis. This means that when crime data from a spatial region is analysed alongside other spatial data (from another region/province), there is tendency for over-fitting or under-fitting in the emerging model or pattern, leading to poor predictions on new data sets. Thus, the spatial characteristics of data within a specified proximity is crucial during analysis. The proximity centred analysis can be achieved if local stations are empowered to effectively analyse data from their region or suburb.

2.3. Paucity of Research in Crime Series Identification in Developing Nations

Over the past decade, there have been a significant research effort on crime mining, for example, in the area of hotspots and spatio-temporal related research [6],[7],[8], but there is a paucity of research in crime series identification particularly in developing nations [9]. Moreover, while research on crime series identification seems to be gaining attention by researchers in the advanced part of the world such as the USA [10],[11], its exploration in developing nations is insignificant, despite its critical importance for public safety improvement in a smart city development.

Crime series analysis focuses on crimes thought to have been committed by the same individual or offenders, and may not necessarily happen at hotspot locations [4]. Experience has shown that many crimes are due to repeat offenders [10],[11], [12]. However, our findings reveal that the crime intelligence unit in most of the developing nations (e.g., South Africa) do not currently have an automated means of identifying these similar attributes or incidents. Hence this research focuses on the development of a crime series mining model, CriClust, augmented with a dual-threshold scheme, which applies established theoretical concepts from clustering (highly connected sub-graph and similarity ranking) [13] to derive useful evidence to security agencies as a way to improve public safety outcomes in developing nations.

3. CRICLUST MODEL FORMULATION

3.1. Data Used: Rape Database

This work serves to assist in identifying CSP in a rape data, however it can be extended to other forms of crime. The motivation for considering rape crime is the fact that despite the heightened sensitivity and understanding about sexual assault and violence, South African communities happen to be a place where rape, assault and murder of people (and particularly women and children) is of great concern.

Table 1 presents a description of some features and subjects considered in this research. The prefix on gender information (e.g., I-male, B-female) represents the different racial population categories in SA.

3.2. Problem Definition and Analysis

The proposition in this study is that most crime patterns exhibit at least a \( k \) minimum principal set that characterise the MO of the offender(s) behaviour. This minimum principal set induces a similarity graph of crime objects and has the capability to reveal specific and general crime trends. To identify crime series in a (rape) crime database, a hybrid model called CriClust, which combines similarity concepts, geometric projection, and graph connectivity (highly connected subgraphs), was adopted. CriClust is augmented with a dual threshold scheme. Firstly, a crime similarity function was derived which is used to connect crime instances that share related attribute information, based on the dual threshold scheme. The similar objects are then modelled into a graphical structure, to learn a similarity graph that is based on established graph-theoretic model which is then partitioned into highly connected sub-graphs of related crimes [13].

Let \( C \) be a set of crime items or objects, where each crime object, say \( C_i \), is defined by a set of attributes \( A(C_i) \), with cardinality \( F \). Our interest lies in crime objects that exhibit a coherent pattern on a subset of attributes of \( A \). This requires understanding the different characteristics of a data set and prioritising features that will promote the goal of the analysis. The measure used in this work identifies similarity attribute between crimes \( C_i \) and \( C_j \) based on two important thresholds \( S \) and \( P \), for sufficiently high (strict) coherence; where \( S \) is the interest similarity support measure (significance threshold), and \( P \) is the prevalence support threshold. Therefore, the following definitions follow:

**Definition 1.** (Instance Feature (IF)) Consider a crime \( C_i \in C \), and a feature \( f \). Let \( I_f(C_i) \) be the value of the \( f^{(th)} \) feature in \( C_i \). For example, if the crime \( C_2 \) occurs on a Monday, then \( I_{\text{day}}(C_2) = \text{Monday} \).

We define a binary feature similarity function \( S_f \) using the Kronecker delta function, where \( S_f(c_i, c_j) \) takes on values in

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http://rapecrisis.org.za/
\[ S_f(C_i, C_j) = \begin{cases} 
1 & \text{if } P_f(C_i) = P_f(C_j) \\
0 & \text{otherwise} 
\end{cases} \]

**Definition 2. (Coherence)** The coherence of a set of crime \( C_i, C_j \) is defined as the sum of their pairwise similarities:

\[
\text{Coherence}(C_i, C_j) = \sum_{f=1}^{F} S_f(C_i, C_j). \tag{1}
\]

**Definition 3. (Significance Threshold (\( S \)))** The significance threshold \( S \) for a set of crimes, \( C \), in the feature space is defined as the coherence threshold for two crime objects \( C_i \) and \( C_j \) to be considered similar. That is if the two crimes exhibit sufficient related attributes in common, then we define crime similarity (\( S \)) as follows:

\[
\Theta(C_i, C_j) = \begin{cases} 
1 & \text{if } \text{Coherence}(C_i, C_j) \geq S \\
0 & \text{otherwise} 
\end{cases} 
\]

The crime similarity for any non-null crime object reference(s) has the following properties:

1. \( \Theta(C_i, C_i) = \text{true} \) (i.e. 1); [reflexive].
2. \( \Theta(C_i, C_j) = \text{true} \iff \Theta(C_j, C_i) = \text{true} \); [symmetry].
3. \( \Theta(C_i, C_j) \geq 0 \); [non-negativity].
4. \( \Theta(C_i, C_j) = 0, \iff C_i \text{ and } C_j \text{ are independent} \) [well-defined].
5. \( (\Theta(C_i, C_j) = 0) \lor (\Theta(C_i, C_j) = 1) \); [consistency].

Our threshold is computed based on a sound mathematical principle and crime expert recommendations. The significance and prevalence thresholds measure the interest similarity support, and helps to conceptualise the underlying graphical structure, and ensures that a link ensues between two crimes if and only if the support of the similarity attributes is greater than or equal to parameters \( S_1 = 5 \) and \( P \). While the parameter \( S \) come from crime intelligence experts as was also done in previous research [5], the coefficient \( P \) is a parameter we learn from the data. The prevalence threshold considers attributes relating to “day”, “time” and “location” information of a crime incident. These features are considered because of their potential characteristics in assisting the analysis as a series will happen within a close space-timeproximity. While the significance threshold helps to eliminate the first level of uncertainty between two crime objects, that is knowing whether the crime objects, say \( C_i, C_j \), are sufficiently similar to be considered for further analysis, the prevalence characteristics (threshold \( P \)) further affirms the proximity condition. In learning a suitable value for parameter \( P \), we consider the data set derived for analysis as shown in Table 2 so that distance apart can be derived. In computing the distance measure to capture the information for the prevalence threshold, our approach adopts key principles of basic geometry and extends them to the current research in achieving the 2-D components for the day and time attributes. The location (loc) attribute typically has the longitude (long) and latitude (lat) as its (2-D) components \( (X, Y) \), while that of day and time is computed using the standard geometry concept.

<table>
<thead>
<tr>
<th>Geo</th>
<th>Loc</th>
<th>Day</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_1 )</td>
<td>(long, lat)</td>
<td>(x, y)</td>
<td>(x, y)</td>
</tr>
<tr>
<td>( C_2 )</td>
<td>(long, lat)</td>
<td>(x, y)</td>
<td>(x, y)</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

More formally, \( P \) is set to the 3rd quartile among the set of values computed in the following manner: Consider a crime object \( C_i \in C \), we form the 6-component vector \( A^i \) using the 2-D co-ordinates of \( P_{\text{day}}(C_i), P_{\text{loc}}(C_i), P_{\text{time}}(C_i) \). Thus,

\[
A^i = (P_{\text{day}}(C_i), P_{\text{loc}}(C_i), P_{\text{time}}(C_i)).
\]

If \( \text{Coherence}(C_i, C_j) \) exceeds \( S \) (the significance threshold), we compute the 6D Euclidean distance \( d_{ij} \) between \( A^i \) and \( A^j \). If the distance is within range, that is not greater than the threshold \( P \), then \( (C_i, C_j) \) are connected in the similarity graph. \( P \) is set to the 3rd quartile of the \( d_{ij} \)'s, on the advice of crime experts.

**Definition 4. (Similarity Graph)** A similarity graph is an undirected graph \( G = (V, E) \), where \( V \) depicts the set of vertices, \( E \) depicts the set of edges. \( E = \{(v_i, v_j) : \Lambda(v_i, v_j) \geq S_1, v_i \neq v_j \} \). \( \Lambda(v_i, v_j) = \sum_{f=1}^{F} S_f(v_i, v_j) \).

\[
\Lambda(v_i, v_j) = \sum_{f=1}^{F} S_f(v_i, v_j). \tag{2}
\]

**Fig. 2.** Identifying sufficiently connected nodes in a crime similarity graph (red edges are min-cut)

The underlying crime incidents dependency structure can be modelled using a graphical approach as shown in Figure 2,
3.3. CriClust Problem Specification

- Specifying the Similarity Graph

For a crime object $C$, let $L_d(C)$ denote the 2-D (x, y) component of day attribute, $L_t(C)$ - the 2-D (x, y) component of time attribute, and $L_l(C)$ - the 2-D (longitude, latitude) component of location attribute. Moreover, let $L_i(C)$ be the $i^{th}$ attribute of the crime object $C$. The specification for CriClust model is as follows:

$m : \mathbb{N}$ \quad \sim \text{number of attributes (\geq 9)}

$S : \mathbb{N}$ \quad \sim \text{significance threshold (\geq 7)}

$P : \mathbb{N}$ \quad \sim \text{prevalence threshold (\leq 11)}

$N : \mathbb{N}$ \quad \sim \text{number of crime objects}

$C : \mathbb{R}^m$ \quad \sim \text{crime objects with } m \text{ features each}

$G : \text{array} \{N, N\} \times \mathbb{R}^m \quad \sim \text{similarity graph (originally empty)}$

For $C^q, C'^q \in C$

if \{i : L_i(C^q) = L_i(C'^q)\} \geq S \quad \sim \text{sufficiently similar crime objects}

$A^q := (L_d(C^q), L_t(C^q), L_l(C^q))$

$A'^q := (L_d(C'^q), L_t(C'^q), L_l(C'^q))$

if Euclid-dist$(A^q, A'^q) \leq P$

$G^+ = (C^q, C'^q)$

Return $G$ \quad \sim \text{similarity graph}

- Specifying the Minimum Cut (min-cut) using Karger’s algorithm [14] on a graph $G = (V, E)$

$$\text{minCut}(G = (V, E))$$

$$G_0 \leftarrow G$$

$j = 0$

While $G_j$ has $|V| > 2$

pick an edge $e_j$ from $G_j$ at random

$G_{j+1} \leftarrow G_j \setminus e_j$

$j \leftarrow j + 1$

$\{T, V \setminus T\}$ is the cut in the original graph that corresponds to the min-cut of $G_j$

- Specifying the Highly Connected Sub-graph (HCS)

For a graph $G$, let $E(G)$ be the edge set, $V(G)$ be the vertex set and $C$ be a minimum cut \footnote{A minimum cut, $C$, is the minimum number of edges which separates $G$ into sub-graphs $H$ and $\tilde{H}$.} $\text{HCS}(G(V, E))$

begin

$\{H, \tilde{H}, C\} \leftarrow \text{minCut}(G)$

if $G$ is highly connected then return ($G$)

else

$HCS(H)$

$HCS(\tilde{H})$

end if

end

The correctness and completeness of the approach considered in this research can be seen as a direct consequence of the correctness and completeness of the methods and algorithms utilised for achieving the target task [13],[14].

4. CRICLUST WEB-BASED KNOWLEDGE SUPPORT SYSTEM

It is important to stress that while this research explores a rape database for identifying crime series, the idea considered in this study can be extended to other forms of crime. We carefully and deliberately try to focus our analysis on relevant attributes that will assist the analysis according to crime expert advice.

4.1. System Overview

The experimental set-up was implemented using Java NetBeans platform with multi-threading, Apache Derby Network Server 10.10.2.0., with security manager installed using the basic server security policy. The experiment was conducted on an Inspiron-7347 DELL machine, Intel(R) Core(TM) i5-4210U CPU @ 1.70GH. The data considered for the experiment consist of 5500 rape crime records across 40 locations (suburbs) in Western Cape, South Africa, comprising of 13 attributes of relevant features as prescribed by the crime intelligence unit. In what follows, we present some results to show the potential usefulness and reliability of the CriClust model.

**Fig. 3.** CriClust selection interface for data processing features

Figure 3 shows the process selection interface for data processing features. Upon successful login, the functionalities of the system use this interface for flexible feature selection. Other features from the view include “crime forms” tab that allows users to capture crime data. There is also an added...
feature that allows importation of crime data from an existing file for processing (“process data” tab).

4.2. Identified Series Information Across Locations

CriClust uniquely presents cluster information in a manner that can be understood by a novice public safety personnel, with no expert domain knowledge. Figure 4 presents the identified locations with at least one series. This gives a quick high level insightful information on areas with repeat offenders. However, it is worth mentioning that the map is able to reveal more information about the series clusters as seen in Figure 5. The graduated colour map can show the following for any suburb:

- the number of series at a particular location (as seen in Figure 4).
- proportion difference evaluation (PDE) across series identified at a specific location (i.e a pie chart with % per series), that is the propagation effect of each series.
- pattern space enumeration (PSE), revealing attribute information and the peculiar features that characterise a particular series as seen in Figure 5—“Series Information”.

![Fig. 4. The locations of crimes series](image)

![Fig. 5. Visualisation of series information at Wynberg](image)

Figure 5 shows an instance of three series identified at Wynberg location, with PDEs 26 %, 34 % and 40 % respectively.

Note that Figure 5 reveals a section of raw-data information (PSE) for an instance of the highlighted series. Generally, clicking the series PDE information (that is the pie chart) reveals the pattern space information of the corresponding (PDE) series at that location. The pattern space enumeration (PSE) gives much more in-depth information about attribute values characterising a series.

5. RESULTS AND DISCUSSION

This paper presents a novel crime clustering model, CriClust, for crime series pattern (CSP) detection and mapping to derive useful knowledge from a crime dataset. The analysis is augmented using a dual-threshold model, and pattern prevalence information is encoded in similarity graphs. The system reveals underlying strong correlations and defining features for a series, which can promote actionable knowledge.

Furthermore, we note that when the crime records increases the number of series identified across most of the locations remains as it was (2 or 3 series). This means that increase in crime record does not necessarily always imply increase in the number of identified series at the locations or emergence of a new series, as depicted in Figure 6. Table 3 describes the peculiar features that characterise each series, denoted (S1, S2, S3). The markers “1” (presence) and “0” (absence) respectively denote emergence or disappearance of a corresponding feature. “Disappearance” in this context means a scenario where the value of the feature is relatively “undefined” or not consistent enough to be considered as a characterising feature for the series. The emergence of a feature does not necessarily mean that the feature has the same “value” across all the series highlighted in Table 3 as the opportunities available to potential offenders vary across different spatial space. Thus having the indicator “1” for lines (S/N) 1 and 2 for the “Day” attribute does not mean S1 and S2 at Mowbray always happen on the same day as they are two different series, but emerging at the same locality. Furthermore, the suspect frame (SFr) attribute emerges for both S1 and S2 at Mowbray, but actually with unique values “moderate” and “slender” respectively. Also note that the “motivation” (Mot) feature emerges for S2 but did not emerge for S1. Hence, this feature has the indicators “0”
Table 3. A depiction of the characterising (peculiar) features emerging for each series ($S_i$).

<table>
<thead>
<tr>
<th>S/N</th>
<th>Location</th>
<th>PDE(%)</th>
<th>Day</th>
<th>Time</th>
<th>Vic</th>
<th>Sus</th>
<th>VAge</th>
<th>SAge</th>
<th>SFr</th>
<th>Mot</th>
<th>MO</th>
<th>HCol</th>
<th>Mask</th>
<th>Sub-Ab</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mowbray</td>
<td>35 (S1)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>CapeTown</td>
<td>65 (S2)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Central</td>
<td>50 (S1)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Mowbray</td>
<td>50 (S2)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Wynberg</td>
<td>40 (S1)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>CapeTown</td>
<td>34 (S2)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Mowbray</td>
<td>26 (S3)</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>Grassypark</td>
<td>21 (S1)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>Sub-Aberdeen</td>
<td>79 (S2)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
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</tbody>
</table>

It is clear from Table 3 that the operating times for the series and the capture method (called MO in the data as this is the term police use for it) are features that are highly consistent throughout the identified series, which is as anticipated, while some other features such as motivation (Mot) and Victim age (VAge) are not very consistent across series clusters. These varying observations agree with the fact that each series is likely different and has its unique MO, since the opportunities available to potential offenders vary across different spatial space due to differences in spatial factors. While the capture method emerges across all the series, it is also interesting to note that the corresponding feature values vary for different series. For example, the method for victim capture is through “kidnapping” in one instance and “substance-influence” in some other series. The usefulness of this research in terms of clusters generated, various forms of visualisations, and relative scalability can only be appreciated if one considers the challenge crime analysts usually have to go through if they were to identify crime series clusters in even hundreds of records using Excel, a common tool currently in most SA police stations. This would otherwise be tedious, error-prone and time-consuming if not assisted with effective models such as CriClust.

Figure 7 reveals the runtime performance of CriClust as dataset size increases. These times are averages over multiple runs against each dataset. We note that run-time increases approximately linearly as the data size increases, which is typical of most data dependent applications. The time to deploy indicates the time it takes for the application to establish connection with the database and to be ready for cluster processing, while the runtime indicates the actual time it takes to process the clusters.

In summary the following are the key benefits of the CriClust system:

- Timely series pattern discovery: security agencies can stop a crime if they timeously identify the pattern of such crime, leveraging these to inform and influence actionable safety goals or targets.

- Statistically interpretable patterns and visualisation: CriClust pays special attention to systematically presenting series information such that a novice (public safety personnel) in the crime mining field can easily understand what the trend is saying. This is achieved using the Google map application programming interface (GMAP), which helps to enhance visualisation of locations where series activities are prevalent. Furthermore, the notion of the PDE and PSE information which reveals the propagation effect (dominance) of a series and characterising feature for a series, aid actionable knowledge support. The propagation effect tells us which of the series has a high dominating power (dominant series) at a particular locality. This measure can help to guide decisions as to which series to track down first.

5.1 Contribution to Smart City Development in Developing Nations

Smart city development is an emerging phenomenon that is driving much information and communication technology (ICT) research in recent times. This phenomenon is also currently a major focus in most developing nations of the world, and has varying interpretations by different researchers [3]. While smart city generally focuses on transforming existing cities into better and more intelligent ones, its development is specifically concerned with two major objectives, which are: (i) increase or promote the quality of life of people; and...
(ii) improve the quality and efficiency of the services rendered by government entities and decision makers. CriClust focuses on point (ii) above [15], which has a direct positive impact on point (i). If crime pattern is not delivered timeously then crime control is hampered, coupled with little or no capital outlay to acquire armed weapons and related materials aggravates the challenge of crime. While we have not presented smart data analysis or the CriClust system as a panacea, the solution presented in this research is more than a case study and is applicable to other crime domains. This can help in pro-actively improving public safety, particularly in resource-constrained settings such as in developing nations.

6. CONCLUSION AND FUTURE WORK

The motivation for this research is the incessant challenge to tackle crime faced by public safety agencies, particularly in resource constrained settings such as in developing nations, which is an impediment to realising smart city development targets. This research has successfully demonstrated that the appropriate use of a cost-effective user-centred software solution (e.g CriClust) could significantly assist crime reduction in resource constrained settings. CriClust can assist analysts in suspect prioritisation, predicting and responding to patterns that anticipate crime before it happens. This will consequently help to tackle under-performance in certain core responsibilities of the police and help to develop evidence-based policies.

As future research, the CriClust web-based knowledge support system could consider combining mining of text and visual information, following a more extensive consideration for promoting effective investigative solution. For instance, attributes relating to suspect information (e.g tattoo, masked) could perhaps be translated into visual information (identikit) to mine suspect information and gain better insight into the crime data. Further improvements are in form of incorporating the use of crowd-sourcing, mobile phones and Wireless Sensor Networks (WSNs) to improve the automation of crime data collection and analysis.

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TOWARD THE DATA-DRIVEN "SMART" AND "GREEN" HOSPITAL-CARE

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\section*{ABSTRACT}

The Hospital is the most complex and representative establishment of the society and nowadays, among the most costly ones. ICTs may rationalize personnel-efforts and reduce energy and material-wasting, to enable health-care coverage, of unprivileged social-groups. The aim of the paper is to present the most effective and efficient means and tools, reducing unnecessary cost, as Mobile IP-network, Service-oriented architecture, provided to other components, through a communication protocol, over a network, Ubiquitous-computing, Femtocells, small, low-power cellular base-stations, typically designed for use in a hospital-department, ward-room or unit, Wireless mesh-networks, made-up of radio-nodes, organized in a mesh-topology, supporting intra-hospital data-exchange, training Multimedia-sharing over wireless networks, for real-time or compressed data-streaming over IP/wireless-networks for communication or archiving. Green-computing in wireless-networks, are limiting people and material intra-hospital “circulation” and, thus, they are enabling the necessary environmentally friendly and smooth procedures. Standardization, policies and regulations for green communications and computing, in “green” Hospitals are indispensable and ICTs enable procedures optimization, solving energy- and material-waste problems, reducing the overall operational-cost, in the emerging “smart, green and networked” Hospital, in favor of the people in need.

\textbf{Keywords—} ICTs, Mobile IP-networks, Service-oriented architecture, Ubiquitous-computing, Femtocells, Wireless mesh-networks, Standardization and regulation, Green-computing, Green smart Hospital.

\section{1. INTRODUCTION}

This paper presents some important perspectives on “Green ICTs” [1], focused on the contemporary Hospital, by discussing its various facets and showing how they could be implemented, in order to reduce personnel efforts and superfluous costs. It examines various ways and means of making ICTs “smarter” and “greener” [2], by using Information Technology, as a tool and an actuator, to improve and promote environmental and economical sustainability aspects, in the modern networked Health-care. Indicative aspects of “green” technologies in Health-care are described, as design, standards, maturity, adoption etc. “Green” manufacturing and proper employment of Medical equipment, reagents, medicaments and disposal of various wastes, are also briefly addressed.

The Hospital is an ancient, complex, though representative establishment of the society, and nowadays it constitutes the most multifarious, multifaceted and costly one. ICTs may rationalize the personnel-efforts [3] and reduce energy and material-wasting [4], to enable health-care coverage, of unprivileged social-groups. The aim of the paper is twofold:

\begin{itemize}
  \item To briefly present the most effective and efficient ICTs means and tools, reducing unnecessary cost.
  \item To “match” the available appropriate tools and methods to the needs of the corresponding Hospital Departments, Clinics, Laboratories and Services.
\end{itemize}

Methodologically, this task is being accomplished, by monitoring and evaluating the relevant to the subject-matter recent scientific publications and published Industrial Property Documents (IP-Docs), predicting the near future. Finally, a cardinal aspect of a successful accomplishment of such an endeavor is the meticulous planning, for each involved Institution, of the procurement methods, i.e. the actions of obtaining or procuring ICTs, Biomedical Technology (BMT) Equipment, Services and Innovation.

Pre-Commercial Procurement (PCP) [5], challenges industry from the demand side, to develop innovative solutions, for example covering some Hospital needs. It provides a first customer reference that allows companies to create competitive advantage on the market. PCP enables public procurers to compare alternative potential approaches and filter-out the best possible solutions that the market can deliver, to address a specific public need.

Public Procurement of Innovative (PPI) solutions facilitates a wide diffusion of innovation in the market [6]. PPI provides a large enough demand, to provide the incentives for the industry to invest. Expecting wide commercialization, the providers hope to bring innovative technologies to the market, with the quality and the price needed, for mass market deployment. This enables the public sector to modernize public services, as Hospitals, Universities, R&D Facilities etc. with better value for money technology and creates the opportunity for growth for the involved companies.
2. THE 5G-WIRELESS MOBILE-NETWORK AND THE INTERNET OF THINGS

The disrupting fifth-generation wireless mobile-network technology (5G) [7] and the way it will gradually affect the Health-services, supported and automated by the Internet of Things (IoT), constitutes undoubtedly [8], [9] the most important challenge for the next decade.

Future 5G networks will be about 100 times faster, non-loss of communication should be their central feature and their major-goal, beyond the dramatically enhanced inter-connection of people, is the interoperable and automated interlacing of any devices, within the same network.

In this part, we shall attempt to present briefly, some of the existing or emerging effective and efficient methods, means and tools, reducing unnecessary cost and facilitating the smooth integration into a new technological era, related to the IoT and the achieving of a globally 5G mobile culture.

2.1. Mobile IP

Mobile IP (MIP) is an Internet Engineering Task Force (IETF) standard communications protocol that is designed to allow mobile device users to move from one network to another while maintaining a permanent IP address.

Mobile IP for IPv4 is described in IETF RFC 5944, and extensions are defined in IETF RFC 4721. Mobile IPv6, the IP mobility implementation for the next generation of the Internet Protocol, IPv6, is described in RFC 6275 [10].

2.2. Service-oriented architectures

A service-oriented architecture (SOA) is a style of software design where services are provided to the other components by application components, through a communication protocol over a network [11]. The basic principles of service oriented architecture are independence of vendors, products and technologies.

A service is a discrete unit of functionality that can be accessed remotely and acted upon and updated independently, such as retrieving a credit card statement online.

A service has four properties, according to one of many definitions of SOA [11]:

- It logically represents a business activity with a specified outcome.
- It is self-contained.
- It is a black-box for its consumers.
- It may consist of other underlying services.

2.3. Ubiquitous-computing

Ubiquitous-computing (or pervasive computing etc.) [12] appears anytime and everywhere, by embedding microprocessors into objects, allowing communication and task-performing.

In contrast to desktop computing, ubiquitous computing can occur using any device, in any location, and in any format. A user interacts with the computer, which can exist in many different forms, including laptop computers, tablets and terminals in everyday objects such as a fridge or a pair of glasses. The underlying technologies to support ubiquitous computing include Internet, advanced middleware, operating system, mobile code, sensors, microprocessors, new I/O and user interfaces, networks, mobile protocols, location and positioning and new materials.

2.4. Femtocells

Femtocells are small, low-power cellular base-stations [13]. It is a wireless access point that improves cellular reception inside a home, office or even in a Medical Praxis. The device, which resembles a wireless router, essentially acts as a repeater.

The device communicates with the mobile phone and converts voice calls into voice over IP (VoIP) packets. The packets are then transmitted over a broadband connection to the mobile operator's servers.

2.5. Wireless mesh-networks

A wireless mesh network (WMN) is a communications network made up of radio nodes organized in a mesh topology. It is also a form of wireless ad hoc network. A mesh refers to rich interconnection among devices or nodes. Wireless mesh networks often consist of mesh clients, mesh routers and gateways [14].

2.6. Multimedia-sharing over wireless networks

Multimedia-sharing over wireless networks for real-time or compressed (PACS, ICU, Lab etc.) data-streaming, over IP/wireless-networks, for communication or archiving. The availability of low-cost hardware has fostered the development of Wireless Multimedia Sensor Networks (WMSNs). These networks of wirelessly interconnected devices are able to ubiquitously retrieve multimedia content such as video and audio streams, still images, and scalar sensor data from the “environment” [15].

2.7. “Green-computing” in wireless-networks

Green-computing [16] in wireless-networks mobile cloud-computing, are limiting useless people and material intra-hospital “circulation”, enabling environmentally friendly and smooth procedures. Standardization, policies and regulation, for green communications and computing, are inevitable, for an ordered and productive employment. ICTs for “green” buildings enable procedures optimization, solving energy- and material-waste problems, reducing the
overall operational-cost, in the emerging “green networked Hospital”, in favor of the people in need.

2.8. Toward “smart green Hospitals”

Concerning the Health and Medical systems, in a Hospital or in a Medical center, monitoring and diagnosis data need to be processed and transmitted from one room or a building to another, for various purposes. Data transmission should be usually broadband, since high resolution medical images and other monitoring information can easily produce a constant and large volume of data. Traditional wired networks can only provide limited network access to certain fixed medical devices [17].

![Figure 1. An overview of the wireless world toward the 5G of wireless/mobile broadband [8]. 5G on the Horizon](https://www.researchgate.net/publication/300484775_Leveraging_SDN_for_the_5G_Networks/figures?lo=1)

WiFi-based networks must rely on the existence of Ethernet connections, which may cause high system cost and complexity, without, however, the ability to eliminate dead spots. However, these issues do not exist in WMNs. Certainly, the 5G technology and the Internet of Things will upgrade Health-care services, both, in Hospital and in Home-care. The IoT i.e. the inter-networking of physical devices, vehicles, buildings, and other entities, embedded with electronics, software, sensors, actuators, and network connectivity which enable these objects to collect and exchange data[18]-[20].

In 2013 the Global Standards Initiative on Internet of Things (IoT-GSI) defined the IoT 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"[20].

The emerging 5G wireless-world incorporates gradually the existing technologies and follows several technical directions, aiming to the provision of cost-efficient resources, for an augmented collective intelligence, of the emerging wireless world.

Global system for mobile communications (GSM), general packet radio service (GPRS), enhanced data rates for GSM evolution (EDGE), universal mobile telecommunications system (UMTS), high-speed packet access (HSPA) etc. contribute, not without drawbacks, to the gradual maturity of a “global technical smart and green alliance”. ICTs have already formed an extended, complicated and global “ecosystem”. Green-computing offers the most convincing strategical alternative to slow-down the climatic change and to adequately reverse the global environmental degradation.

Health-care and its “Temple”, the modern Hospital, forms, another very important “ecosystem”. Technology interacts with Medicine for Centuries and this interface leads gradually to an approach between these two “ecosystems”, especially after the invention of CT (Nobel Prize Medicine 1979, A. M. Cormack and G. N. Hounsfield) and the entry of Medicine in the “digital world”. The emerging “green smart Hospital” of the near future, originates eventually from this successful “marriage”. 
3. THE ICT-ECOSYSTEM MEETS-UP HEALTH-CARE

The modern Hospital includes five major areas that will be directly affected.

- The Emergency and Outpatient Departments.
- The Imaging and Radiotherapy Departments.
- The Surgical Departments, the Intensive Care Units (ICU/CCU, NICU etc.) and the Wards.
- The in vitro Diagnostics, Hematology, Transfusion Medicine, Cell Therapy Laboratories and Units.
- The various Supporting Facilities (e.g. Sterilization, Laundry, Food-services, Building Engineering etc.).

Home-care and Health self-inspection will be increasingly employed for caring about major social groups, as the ageing population and people physically and/or mentally impaired. This task is being accomplished, by retrieving and evaluating relevant recent Publications and published Industrial Property Documents (IP-Docs), attempting to predict the expected progress.

3.1. The Emergency and the Outpatient Departments

The Emergency Department (ED) includes schematically a sequence of acting, starting by receiving of an Emergency call or another notification, of an incoming emergency patient. An “IoT-device” can accelerate the identification and the registration of the patient, by transmitting a first standard message, including for instance a SSN ID-string (Social Security Number) and eventually, a codified preliminary short-description, based for instance on one or two WHO ICD-10 assumed codes, over the IoT-device IP, during the transportation. The second cardinal step is the “triage”, based on the collection of in Vitro diagnostic (IVD) data, either on site by employing Point of Care Testing (PoCT), or transmitted from central Lab over the Autoanalyzer’s IP-address.

The collection of relevant electrical and non-electrical Biosignals, acquired on site, digitized and transmitted wirelessly and simultaneously to the patient-record and to a Decision Supporting Module (DSM), accelerating the triage-procedure and finally to the ED-records [20], [21].

In between Medical Imaging (US, CT, MRI etc.) examinations are performed on site or elsewhere, and the data are transmitted wirelessly to the Radiology Information System (RIS) and to the Picture Archiving and Communication system (PACS), contributing to the final Diagnosis and to the appropriate treatment, of the ED-patient.

The IoT devices are useful, because they are able to participate fast and actively to the “reconstruction” of the distributed parts of the patient’s record, and provide in a limited time-interval, a more complete medical history of the patient, facilitating a rush progress of the acute patient’s treatment.

The Outpatient Department (Ambulatorium) offers usually more comfort, privacy and a little bit more time for the patients, however, the complexity and the severity of the procedures leading to a correct Diagnosis and Treatment, is not much less pressing, compared to ED. Therefore, the employment of the IoT will bring all the advantages mentioned previously, providing more time and lower cost. However, additional advantages that can be provided in the very near future, will be the practically full automation of the Continuity of Care record and the advantages brought, by the use of semantically enriched XML; it will reduce the paper-work load and will “create” more time for the physicians and the nurses, to be spent for the patients, making medical practice, a little bit more reasonable.

Synopsising, we could remark that, as far as, the technical aspects are taken into consideration, the crucial aspects related, to the difficulty degree of this transformation, the ED and the Outpatient Department (OPT), posses a high heterogeneity and scalability degree, due to the multiplicity of the ED-and OPT-devices, ranging from numerous minor devices, such as pumps, disposable catheters, O₂-saturation monitors etc. to medium-sized monitors and ventilators, up to expensive Imaging Systems and Anesthesia Machines.

As far as Self-organization, Interoperability and Security are concerned, the tasks to be performed can be analyzed in standardized steps and the combination of this approach, with Semantics, lead to a rather acceptable quality. Finally, the Low Energy Data exchange and Tracking, is easily provided in the present hi-tec environment, which is not the case, in home-care or patient’s shelf-inspection settings.

3.2. The Imaging and Radiotherapy Departments

A “Medical Imaging IoT” can be traced-back over 20 years ago, since the concept of connecting and monitoring medical imaging equipment, via remote servers over the Internet is not new. It has been the corner-stone of the remote servicing capabilities that medical imaging vendors started to offer many years ago. Remote connectivity [21] has allowed for efficiency in equipment maintenance and support functions to a service model, adopting proactive and preventative service. Most Medical Imaging customers acquire remote services by vendors that allow for, early symptoms spotting of an approaching breakdown, minimizing, thus, downtime.

Concerning the major “Medical imaging manufacturers”, they are taking serious steps towards the “next generation” of the Internet of “Medical Imaging Things” [21]-[28].

*GE Healthcare* intents to connect 500,000 Imaging Machines, on the new GE Health Cloud, as announced at 101st RSNA, on Nov. 29th 2015, to help clinicians deliver better outcomes.

*Siemens Healthcare* is based on its developed remote monitoring of equipment technology (Lifenet and Siemens Remote Services, Microsoft Azure), and has made significant progress, in developing the “Teamplay” IoT platform for Medical Imaging.
**Philips Healthcare's “HealthSuite” Digital Platform** forms the base of its Medical imaging IoT strategy.

Finally, **Toshiba** intends to Collaborate with GE on a common Industrial IoT Pilot Project. Today, a huge amount of Radiology Data are acquired, providing the opportunity to analyze images and associated clinical data, far more sophisticated and accurate, in order to improve diagnosis. The IoT could contribute essentially, to the automation of the evaluation of the accumulated data and their processing, to reach a more accurate and individualized Diagnosis. Further, appropriate arrays of IoT-devices (cyberactuators) could involve Radiology more actively in Epidemiological studies, by re-evaluating big amounts of Anonymized data, from around the world and by “comparing” within them, details of Medical Images, associated or assumed to be associated, with specific diseases.

The employment of the IoT, for automated recognition of Regions of Interest (RoIs), combined with the employment of mathematical methods and algorithms, driven by “machine intelligence”, will be soon able to “view” and “quantify” the inner depths of the human body. We can capture “deeper” data and we can also gain much more “contextual” data, for example in Oncology, where the richness of data plays a major role, both, in R&D and in treatment. Dense networks of IoT, re-evaluating different RoIs, driven by data-science methods and executed with iterative methods, could eventually lead us to trigger the emergence, of presently latent clinical information and, thus, to the acquisition of new medical knowledge. We could soon advance our ability to recognize early signs of bodily deterioration and try to link them with macroscopic patients' conditions change.

Radiology can produce really “BIG” data; however, we need to discover heuristic methods, by “merging” the potential of Imaging, Mathematics and IoT related grids (or arrays), into a new, almost “quasi-robotic” technique.

The traditional leader companies in Radiology have already made, as we have shown previously, their own initial preparations, to combine all the necessary aspects of Medical Imaging with the emerging IoT.

Concerning Radiation Therapy, the present and emerging applications of IoT are mostly focused on the precision and the accuracy of the delivered Energy-dose, delivered to the Patient. Equipment connectivity and interoperability was a first priority in Radiotherapy and since 2013, Varian Medical Systems and Siemens Healthcare, are now using Varian software to plan and manage radiotherapy treatments, delivered on a Siemens medical linear accelerator. These two companies have developed and deployed an interface that connects Varian ARIA-Oncology information system with Siemens Oncor and Primus Accelerators and Imaging systems. This step, as part of the company's "Agenda 2013" sector initiative, demonstrates once again Siemens Healthcare's role as a strong partner for imaging systems in Radiation Oncology. However, appropriate IoT-devices, allow for the real-time follow-up of critical parameters, as for instance values of Temperature, of Vacuum, of RF-power, Current etc. and the recordings of Therapeutic and scattered Energy-doses.

Radio Frequency IDentification (RFID), the “ancestor” of IoT-devices, already support Radiotherapy for decades, as for instance, for implantable in-vivo Dosimetry, they are combining a dosimeter and a wireless RFID communication system [29]. Breast locating devices including an RFID transponder as a diagnostic instrument, for examining a female breast, Methods for Radiotherapy patient-identification, using surface imaging etc. [30]. There is no doubt that during the next few years, IoT-devices will replace RFID, in their supporting functions, resulting in further accuracy and precision in RT.

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Finally, as far as Self-organization, Interoperability and Security are concerned, the tasks to be performed constitute still the main obstacle, to achieve a really disrupting influence of IoT, in these two fields.

### 3.3. Surgery Intensive Care Units and the Wards

The importance of data, in delivering efficient and effective health-care, is obvious. Sensor technologies are making the creation of new data easier, however, tracking Nursing activities, pills, hospital-beds etc. need to be communicated, aggregated, and analyzed. The Internet of Things promises to turn any object into a source of information about that object. This creates a new way, to differentiate products and services and a new source of value. Admitting a patient for acute-care treatment, unleashes an avalanche of new data, as current vital signs, patient’s medical history, reviewing treatment options etc. All these data may reach to a diagnosis and to a recommended course of treatment.

The two major common-aspects of ICU, Surgery and Nursing Wards are to employ the emerging IoT Technology, in order to optimize the care provided in Emergency situations, in the Operating Room and in the Wards and the safety of the patients during their hospitalization, since the hospital environment “kills” by accident or mistake, over 50,000 people every year, only in the US. The main reason is that still today, a huge number of medical equipment, operate independently and there is no way yet to acquire and process the provided data and information.

Nevertheless, several providers are developing and offer systems that wirelessly link the sensors measuring electrical and non-electrical Biosignals, in the ED, in the ICU and in the Operating Rooms. These systems aim to optimize the care provided in Emergency situations, in the Operating Room and in the Wards and the safety of the patients during their hospitalization, since the hospital environment “kills” by accident or mistake, over 50,000 people every year, only in the US. The main reason is that still today, a huge number of medical equipment, operate independently and there is no way yet to acquire and process the provided data and information.

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Therefore, beyond sensors creating data, Artificial Intelligence tools are needed, that can analyze the vast amount of acquired data and are able to identify meaningful interrelations, so that better clinical decisions are made and, thus, the right treatment is provided.

An advanced example [31], is the “da Vinci OnSite”, a service that allows for, the da Vinci Surgery Technical Assistance Team (dVSTAT®), to remotely monitor the system-status for real-time diagnostic feedback. OnSite utilizes any already existing 10/100/1000 Mb Ethernet connection/port or 802.11b or g-wireless network in the OR that has access to the Internet and can be configured to the specifications provided by an organization’s IT department. The IoT is indispensable in Surgery, in the ICUs and in the Wards, offering monitoring services. The Heterogeneity and the Scalability of the Devices is extremely multifaceted and thus, connectivity becomes a difficult and costly task, however, necessary for a lean and less risky operation. Self-organization, Interoperability and Security, constitute as well a major challenge, due to the necessity to incorporate proper Clinical Decision Making modules, increasing the reliability of the monitoring outcomes. Finally, Low Energy Data-exchange and Tracking is still implementable, however, the multifarious systems and devices accumulated in these Departments, increases the necessary effort, to avoid induced electronic noise and mutual interactions, between them.

3.4. In vitro Diagnostics Hematology and Cell Therapy

The traditional in vitro Diagnostics (IVD) Laboratories have more or less pioneered in the introduction of Computers and later of Networks in Laboratory practice. Therefore, a description of the established systems will be omitted and we shall proceed directly to the emerging IoT-applications of IVD Point of Care Testing (PoCT) and the emerging possibility of networking of hundreds of millions acts in Hospital, Medical Practice and at Home [32]-[34].

PoCT is defined, as any analytical test performed for a patient by himself, by a professional, or a third one, outside the conventional laboratory/clinical setting. Recent years have seen a rapid growth in the use of PoCT, largely as a result of technological advances, such as the development in solid-phase Chemistry, Nano-sciences and µ-processors integration, resulting in equipment and cost minimization.

The implementation of PoCT should be the effective response to a valid clinical need, and the outcome of the clinical need for PoCT depends on, which groups of patients need testing, what test(s) need to be performed and how the service currently provided meet the needs.

3.5. The various Supporting Facilities of the Hospital

This part addresses the usually disregarded non-Clinical Hospital Services, such as Cleaning-Disinfection, Sterilization, Incineration, Electromechanical Networks, Hospital Clothing & Gear, Pharmacy etc. and the proposed IoT-related solutions are realistic and well-documented. The designed IoT-based Information-system, for the “non-directly Clinical” Hospital Services include presently: Cleaning Disinfection and Asepsis: The “CDC-2008: Guideline for Disinfection and Sterilization in Healthcare Facilities” [35] was adopted and an IoT-based monitoring system is designed for the chemical disinfectants (ethylene-oxide, formaldehyde, hydrogen peroxide etc.), the sterilization methods (steam sterilization, ethylene oxide, hydrogen-peroxide, gas plasma etc.) and other related in-Hospital procedures. Hospital Incineration of Bioactive wastes: Incineration of hospital wastes has been banned in many European countries, and there is generally a move towards larger, centralized facilities; our designed system is supporting the logistics of “incineration outsourcing procedures”. Electro-mechanical Networks as Water and Power Supply, Heating, Air Conditioning etc.: These networks can be managed easier and less expensive, by employing BAC-net (Building Automation & Control NETworks) approach, an ASHRAE 135-2012 Data Communication Protocol that enables interoperability between different building systems and devices, in building automation and control applications. Hospital Food Services: The designed system gives priority in risk minimization, along with the other technical-managerial aspects of running a Hospital food-service, as RFID-tagging and “smarter” IoT-devices, may control better Temperature, Moisture etc. Hospital protective clothing and gear Management: Clean linen should be delivered in such a way, as to minimize microbial contamination from surface contact and air borne deposition. Linen transport carts should be sanitized in the cart washer, after being emptied of soiled linen and prior to being filled with clean linen and be properly covered for storage. A designed network of interconnected RFID and IoT-devices, enable easy and continuous monitoring of the procedure. Pharmacy Medicaments Reagents and Disposables: The designed Hospital Pharmacy management system is supervising and documenting, the Medicaments, Reagents and other Disposable purchasing and allocation procedures, by employing a smart custom-developed combination, of RFID and IoT-based tagging, tracing and monitoring procedures. The non-Clinical Hospital Services have an important influence on the safe and smooth Hospital operation. The optimization of the function of these Facilities and the associated Services, require modern ICT- and gradually also IoT-technology installed in the Hospital.

However, the functional-managerial aspects of the Hospital operation are not always up-to-date and sometimes are not present at all. Presently seven important functional-managerial services and aspects of a Hospital are included in our system and Figs. 2 & 3 display the innovation-trail reflected on IP-Documents.
4. PROCURING AND EMPLOYING “GREEN” ICT AND BMT IN THE MODERN HOSPITAL

One of the key tasks of the Health-systems is to translate needs into Health-services, by procuring and employing ICT, BMT and other Technologies and Services, in order to translate them into appropriate facilities, i.e. Hospitals and other Healthcare Institutions. The context, within which health-capital investment takes place, is complex and constantly changing and it is often disrupted, by novel emerging Technologies. Health-care facilities should be able to adapt to altering expectations and increasing needs and they have to respond to the opportunities, offered by new Technology and the contemporary Healthcare evolution trail. Services and development plans and initiatives may be parallel; however, capital support will inevitably lag behind.

On the other hand, only some aspects of capital investment are disposed to rapid change, while others are constrained by historical, social and economical inequalities, undergoing only slow evolutionary changes.

For example, in Europe there are at least 28 different National Health-systems frameworks, within which public and private Hospitals operate. It is important to recognize the different contexts that differ greatly, in terms of funding,
organization and administration, a multiplicity that reflects different history, culture and political trail. Although pre-Commercial Procurement and Public Procurement of Innovative solutions facilitate a wide dissemination of innovation in the market, as already mentioned in the introduction, Hospital-systems have different levels of human and material resources and a variety of institutional and social inheritance. Finally, the levels of investment in developing medical and managerial professional competences also fluctuate essentially and at the same time, as some general trends are common, each country faces specific prospects and restrictions. This multifarious and multifaceted “picture” of Health-care, combined with the explosion of the ICTs, creates a “boom” of interdisciplinary Technologies that are already altering radically the social reality and consequently the already dramatically disproportionate and imbalanced health-status of the Earth’s population, even of the “privileged” portion, living in the most socially and economically advanced countries, as the counter-reform against the ACA has revealed in the USA. It is true that the present technological explosion, creates opportunities for a radical improvement of the health-status of billions of people worldwide, by adopting remotely and virtually monitoring, nearly the entire earth’s population. Following for decades the development and the correlation of Biomedical, ICTs and “Green” Technologies, as they are reflected on the “innovation trail”, shaped by retrieved and evaluated published Industrial Property (IP) documents (cf. Figures 2 and 3), it becomes obvious that preventive Medicine, self-evaluation and tele-care, could improve public-health, even in the most deprived regions. However, the increased automation, related to the mentioned Technology “boom”, will diminish the availability of jobs and will lead to a rather long and massive “interim unemployment gap”, due to the lack in proper education and professional qualification of a major portion of the citizens.

5. CONCLUDING REMARKS

We are all already moving toward the big-data driven [36], [37] “smart” and “green” Hospital and Health-care in general, with different starting-points and speeds and all of us carrying the burden of our historical, cultural and political tradition. A number of indicators in the health-care systems, such as the number of hospital beds, the average Length of Stay in a hospital etc. suggest that a fundamental transformation of the sector is ongoing. Healthcare is being shifted from the 20th Century centralized model toward the 21st Century “networked-Society”, wired or wireless, spread and multifaceted model. The social and cultural versatility of our global society is a new, much promising, however, also a rather terrifying environment and the Hospital, its ancient “progress flagship”, is more than ever, in the human History, the most complex and concurrently the most representative system, this society has given birth to…

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SOCIO-ECONOMICS AND EDUCATIONAL CASE STUDY WITH COST-EFFECTIVE IOT CAMPUS BY THE USE OF WEARABLE, TABLET, CLOUD AND OPEN E-LEARNING SERVICES

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ABSTRACT

In this paper the authors show a case study reporting educational experiences in a Japanese university's digital campus supported by the cost-performance improvement in Information and Communication Technologies (ICT) including electronic devices and networks. The authors also report the use of wristband wearable devices to monitor walking and sleeping habits of a student and the influence on health consciousness. Considering education effectively on campus has become important in every country and area worldwide. In this regard, we have conducted a socio-economics case study with cost-effective ICT and Internet of Things (IoT) devices including tablet PC, wearable and e-learning services. In order to promote educational innovation regardless of economic and political status of each country, the standardization is urgent and important concerning education methods with advanced technologies. We propose ITU to study best practices in education in terms of network, devices, applications, contents and teaching methods. ITU should seek the quality of education methods including managing operational aspects like ISO 9001 Quality management and ISO/IEC 27001 Information security management. In this paper our case study consists of two parts, a deployment of large-scale tablet PCs and a successful improvement in student’s Body Mass Index (BMI) implemented by wearable devices as a basic condition for study attitude.

Keywords — Education; Innovation; Digital Campus; Tablet PC; Wearable Device; IoT; Cloud Service; Learning Management System; Best Practices; Methodology Standard

1. INTRODUCTION

After more than a 50-year advancement in development of electronic products due to “Moore’s law” [1], high performance mobile information devices are currently available in the global market in a cost-effective manner. Wireless technology and services are also becoming less costly and widespread not only in developed countries but also in developing countries. For personal communications, the “smartphone” is becoming quite popular. The smart tablet PC with wireless communication capability and various applications is considered to be an innovative device to greatly improve educational activities from elementary and middle school levels to higher education. Advancement of ICT should be very beneficial to students as well as faculty and administrators [2].

The price per performance of a tablet PC has decreased each year since 2010, because of strong product competition among vendors that install iOS from Apple and Android from Google for the devices. As the result, smartphone and tablet PC have become prevalent in most Asian countries and the US especially for users in the 20s as shown in Fig. 1 [3]. Japan figures are slightly different as conventional mobile phones or feature phones show a higher usage in comparison with the US and China, probably from the fact that the prices of smartphone are still higher in Japan. The growth and prevalence of those ICT devices among the younger generation have provided various educational opportunities.

In addition, Wi-Fi systems have become available at higher speed and lower price, and Internet connectivity cost performance is much improved, which suggests that ICT has become more cost-effective for the university educational environment in combination with student tablet PC, or even smartphone, in support of Wi-Fi, intra-network, Internet and Learning Management Systems (LMS).

In recent decades the Massive Open Online Courses (MOOCs) such as Coursera, edX or Khan Academy, have developed and many free educational content services are also provided for professional or qualification certificates and examinations. In 2011, the authors delivered about 500 sets of Apple's iPad to all students, faculty and staff members of the Department of Humane Informatics of Otani University, Kyoto, Japan. Every year since 2011, about 100 sets are delivered to new students as a basic tool at the university free of charge. This relatively large-scale field trial was initiated to improve undergraduate
education in humanities, culture and informatics programs. Since then the faculty and staff undertook various preparations for educational contents and lecture notes. This paper reports on important educational items in the field of the Digital Campus, such as the improved test results on students’ information and technology knowledge by comparing before and after implementation of the proposed system. LMS is a very useful tool for distributing lecture slides and documents without printed handouts so that students can pay more attention to the lecture rather than note taking with the help of a tablet PC. Groupware and Social Networking Services (SNS) are also proven to be effective tools to communication means among professors and students. There are several open databases and e-learning services available free of charge. We use one powerful open online education service for the “IT Passport Examination” (a Japanese government approved test) for a preparation of study and successful results. Writing an e-Pub format document is another meaningful subject for the Digital Contents class, as e-format books with multimedia are very interesting for students to read with a tablet PC.

In recent years students have started to use wristband-type wearable devices on campus. Using those devices we have implemented a system to monitor students’ daily behavior in walking and sleeping for the purpose of improvement of their health consciousness.

This structure of educational platforms is depicted in Fig. 2 as layers of the campus network [4].

2. CHANGE OF HIGHER EDUCATIONAL NEEDS AND CURRICULUM REFORM

After the rapid economical growth in the years between 1955 and 1980 in Japan, the population of children began decreasing. The number of universities, however, doubled from the year 1980, according to the deregulation of Japanese higher education policy. In general, Japanese household economy became relatively better compared to the previous generation, and the ratio of students who attend university was 50.2% in 2009, which may have changed the needs for students with less academic ability and diverted interests to vocational skills. The Department of Humane Informatics of Otani University was established in 2000 within the Faculty of Letters for the purpose of coping with the requirements for interdisciplinary higher education opportunity. Students are able to study humanities and social sciences while simultaneously developing Information Technology skill. Ten years from the department’s establishment, educational needs have changed even further. For example, simple programming skills are less valuable in advanced countries. On the other hand, ICT consumer markets are growing. Digital content production has become target skills for students such as animation, electronic games, e-book, e-editor and IPTV.

The iPad as a typical tablet PC was considered a very useful device for our educational purposes when it first appeared on the market in April 2010 in the U.S. and later in Japan. In July 2010, Otani University decided that all the students of the Department of Humane Informatics for coming academic year 2011 were given this device in order to improve lectures, practice and seminars in a drastic manner.

After Apple released the product, there have been many tablet PC vendors using Android OS provided by Google. In general Apple’s products are more expensive however we continue to adopt iPad because of strong linkage with Apple PC and application software useful to content developers as our student business model.

In order to maximize curriculum reform and educational improvement, the “digital campus” concept was created as shown in Fig. 3. Places for mobile tablet usage are not just classrooms but many other locations within the campus, as well as off-campus, on the train or at home. Collaboration is important among students, faculty and service-providers/vendors on the same platform.

Regarding curriculum reform, Fig. 4 depicts an overview. Students are motivated to gain skills as digital content creators or ICT professionals, as they use iPad almost every day during class, out of class and at home. Four years of undergraduate
schooling, step-by-step lectures, practices and seminars are provided. Automated class attendance record keeping is effective for students to cope with the daily habit of class attendance, and for teachers no more tiresome record keeping is required.

Another interesting project is an Audio Visual Guide for the Otani University museum, developed and operated for regular visitors to the museum.

### 3. COMPARATIVE DATA OF STUDENT IT SKILLS BEFORE AND AFTER TABLET PC DEPLOYMENT

In order to evaluate educational results within the digital campus platform, we tested students for IT knowledge and computing skills using “RASTI examination” [5] provided by an IT testing-service company. Fig. 5 shows the results for the last four years and three years before the deployment of the tablet PC [6]. Sophomores are tested each year, so that the same student group was not tested but results may show a general tendency. Upper level student groups have clearly improved the test points, however lower level students did not improve.

![Fig. 5. IT Test Results – Before and After](image)

We surmise that upper level students are stimulated by high technology devices, such as the iPad, and motivated by those tools and educational materials.

Otani University introduced Moodle, a Learning Management System on campus in 2014 for the purpose of developing infrastructure of efficient classroom operation and as an e-learning tool. This application provides many useful services such as lecture scheduling, lecture slide contents, attendance records, receiving reports and making quizzes and questionnaire.

### 4. UTILIZATION OF LEARNING MANAGEMENT SYSTEM

It is confirmed that students try to improve test results by taking the same quiz several times. This content helps student comprehend lectures. Fig. 6 shows the improvement of quiz results from the first trial to one when several weeks have passed from the first trial. In the duration students took the quiz several times and evidence that a normal distribution on the first test has changed to one with higher frequency of 100 points at the final test.

![Fig. 6. An example of improved quiz results](image)

In cooperation with Moodle, iPad has become more useful in that students check lecture contents in advance from home to work prior to the beginning of class, which is the basis for active learning. The iPad also plays important role when no PCs are equipped in classrooms. Since Wi-Fi services are available in most classrooms, the iPad complements environments where PCs are not installed.

### 5. UTILIZATION OF SOCIAL NETWORKING SERVICES

In recent years social networking services (SNS) have become popular among students for sending messages to each other. The penetration rate of smartphone usage to access the Internet in Fig.7 indicates that 91.3% of young people in their twenties mainly use smartphones in Japan in 2015 [7]. A higher percentage is possible if the survey only questioned university students.

On the basis of the popularity of smartphones SNS messaging has become de-facto standard on campus even for messaging between students and faculty members. To stimulate students’ motivation in face-to-face communication on campus is important but SNS messaging by the use of smartphone does not depend on time and place which has promoted smoother and more frequent communication opportunities by forming a necessary groups like classroom with professors.

![Fig. 7. Penetration Rate of Smartphones to access Internet](image)
6. UTILIZATION OF OPEN ONLINE COURSES ON WEB

When considering Japanese language web sites, there are many useful materials from open online courses. In Japan gacco, eboard, schoo [8] listed as Japanese Massive Open Online Courses (JMOOC) have been providing free online education with a variety of courses such as arithmetic, science, programming, management, marketing, statistics, accounting, as well as business planning for elementary school children through grown-ups.

Otani University has been using a site of the past questions of the IT Passport Examination founded by the Japanese Government. When one passes the examination, one is qualified as having basic skills and knowledge on ICT technologies, management and business strategies, certified by the Ministry of Economy, Trades and Industry (MITI). The authors organized one-week intensive course on IT Passport Exam during the summer and spring breaks of the academic years 2015 and 2016. Those courses using iPad and the past examination site assisted students to complete the examination with the successful result of seven to eight students each from 2015, in comparison with just a few students, each year in the past. Based upon this improvement, our faculty has decided to have all juniors take the examination from April 2017.

7. WRITING PRACTICE OF DIGITAL MULTIMEDIA CONTENTS USING E-PUB FORMAT

The Class for Digital Contents Research involves training for producing digital multimedia books in standard e-Pub format. Students use desktop or laptop PC with hardware keyboard and mouse since tablet PC isn’t conducive to easy input of letters and figures and content information layout. However, when an e-book is completed the product may be attractive compared to a PDF format.

There are several free use web sites for making e-Pub books for beginners. Most of those websites are capable of publishing commercial products as well. Each year more than 70 students participate in submit in their work with stimulating content.

8. VITAL DATA SHARING SYSTEM WITH IoT WEARABLE DEVICES

Recent observation at campus shows that some students use wristband type wearable devices. Expecting that more and more students will wear those devices, we have implemented a system to share students’ vital data such as heart rate and sleeping hours as well as activity logs such as distance travelled and the means to obtain information by wearable devices and smartphones. Our system allows vital data to be shared securely within a limited number of private group members so that individual vital data can be properly managed.

In general as depicted in Fig. 8, the market of wearable devices is forecast to grow steadily with 62.6 billion US dollars in 2020 [9]. When usage is divided into two categories, private usage and business usage, private usage includes the monitoring vital data and life log with GPS for healthcare as well as positioning one’s location while business usage includes medical, security services, defense and monitoring the workplace.

The authors propose a method to improve students’ health consciousness by taking advantage of IoT technologies such as wearable devices and smart phones along with a cloud service. Fig. 9 shows an implemented web application system consisting of RStudio’s Shiny server [10] in a cloud, a Fitbit [11] as a wristband type wearable device and its associated applications on smartphones and Moves [12] as an application on smartphones to log active data such as walking, running, cycling and transportation. A mash-up of two applications, Fitbit and Moves generates a more precise description on one’s daily behavior. The RStudio’s Shiny server interacts with both Fitbit and Moves data through cloud with API in accordance with OAuth2.0. The application is implemented with a password to show the contents of vital data even though the site may be accessed to anyone who knows the URL.

Another issue for further study is the use wearable devices such as eyeglasses JINS MEME [13]. This device has an accelerometer, gyroscope and electrooculography sensors to
monitor eye focus or drowsiness. In analyzing each student’s total data from wristband wearable device Fitbit and eyeglasses JINS MEME, a student’s behaviors can be more clearly modeled for the purpose of a more productive educational system on campus.

1. Data from Fitbit and Moves
The system allows selection one member of a formed group with any date of the past records concerning heart rate, walking steps, sleeping hours and life log.

Fitbit allows the monitoring of such vital data as heart rate, walking steps, walking distance and consumed calories. Once synchronized between Fitbit on a wrist and smartphone, data are reflected via application on smartphone and data are forwarded to a cloud storage that can interface with the RStudio’s Shiny server.

Moves, an application on smartphone allows the monitoring of life log such as what activities are deployed such as walking, running, cycling and transportation. Locations and travelling routes can also be monitored on a map but such data are excluded from this system because of privacy issues.

(1) Records on heart rate and activity record
Heart rate is recorded every five minutes. An example of heart rate in a day is shown in Fig. 10. A vertical red line shows the increase in beats by five or more and a vertical blue line shows the decrease in heart rate by five or more by default. Walking or other activities are accompanied by higher rates while sleeping or other passive activities lower beats. Data from Moves on walking, running, cycling or transportation explains why Fitbit can sense heart rate change. The combination of two data, one from Fitbit and one from Moves, to one screen allows labeling action for changes of heart rate.

(2) Walking steps
An average walking steps, the standard deviation and the variation factor of standard deviation divided by average are shown in Fig. 11. Total walking steps in a given day show how a person spends a day in terms of a range of activities. About 2,000 steps may indicate that activity is quite limited for a person. By accumulating data of relating walking steps the number of steps may indicate a typical daily activity such as commuting to school, staying at home or joining a sport activity. One week to 4 weeks may be selected to show the monitoring period. Activity patterns can be recognized depending upon a day of the week.
(3) Sleeping hours

Fig. 12. Sleeping hours for four weeks

Fig. 12 includes the average, standard deviation and its variation factor for sleeping hours. Sleeping data may show the most important factor of daily activity to indicate a person’s condition during daytime. The start of sleep at night may be recognized as the start of the day in order to determine the whole activity level following the time of waking. A constant length of sleeping hours can assure a healthy condition along with a constant level of activity. One to four weeks may be selected to show the monitoring period in this case as well.

(4) Life log from Moves

Fig. 13. Activity of a day in duration and distance

Moves application collects data using GPS on a smartphone. The four activities of walking, running, cycling and transportation in duration and distance are shown in Fig. 13 and this data will indicate the activity level during a day. For instance on May 21, 2017 the author walked 3344m, cycled 2793m, moved 3806m by transportation and ran 5739m.

2. The agreement with student collaborators

An agreement with student collaborators in this study who provided vital data and life log information has been prepared in accordance with the ethics rules stipulated by Otani University. The collaborators shall understand that data provided for this study, and more specifically how those data are provided to the system and how those data feeding, may be terminated at the sole discretion of student collaborators.

9. SUCCESS IN STUDENT’S HEALTH CONCIOUSNESS

The implemented system applied to several students as collaborators in this study. One collaborator has been wearing Fitbit since summer 2016 and has started to monitor weights and Body Mass Index (BMI) by himself. BMI is defined by weight in kilograms divided by square of height in meters to show the degree of obesity. Below 25 is normal while the obesity degree 1 if below 30 and the degree 2 below 35. Collaborator efforts along with the author’s advice based upon shared data within the system has proven to be a success in twelve weeks. Collaborator BMI became 28.15 in the obesity degree 1 from 30.6 in degree 2 with an improvement of 2.48. Fig. 14 indicates variation factors of both walking steps and sleeping hours have decreased from October 9 through December 31, 2016, which suggests that as the student walks and sleeps constantly the variation factor has become smaller. Fig. 15 indicates that both data are strongly related to each other with a correlation factor of 0.708. Those data are displayed on the system by selecting who and when.

Fig. 14. Variation factors of walking steps and sleeping hours

Fig. 15. Correlation between walking steps and sleeping hours

Collaborator comments after the successful achievement in BMI improvements are as follows:
(1) Subject motivation to continue by constant walking and sleeping maintained by checking the record on the system, especially visualization of data is more effective than just checking data;

(2) Sleeping hours are sometime out of control but targeted walking steps are easier to achieve every day. When walked 8,000 steps, subject indicated a desire to walk 9,000 steps the following day. Constant walking every day has become his habit;

(3) The author’s advice on subject’s activity was quite effective for maintaining motivation. The program worked well in promoting peer support [14] especially as motivation weakened after several weeks had passed;

(4) Successful results are depicted in Fig.16. Apart from data taken from Fitbit and the system, subject recorded independently weight and BMI every day. BMI changes are shown based upon subject records for the twelve weeks. Subject reported feeling quite active in twelve weeks after starting the practice.

The author's challenges in supporting collaborator’s efforts are as follows:

(1) Subject’s BMI improvement was not checked by the author until shown by subject. Therefore, to check the variation factors of walking steps and sleeping hours on the system instead of BMI became quite important. With the existence of variation factors, sleeping hours and walking steps, the author ability to anticipate the subject’s daily routine;

(2) The author sent some comments to collaborators by social networking service (SNS) in support after checking the status of heart rate, walking steps and sleeping hours. Subjects had often irregular sleeping pattern which indicated that a means of communication must be maintained between subjects and the author.

(3) Confidence: After having practiced walking and sleeping, subject started to improve BMI. Subject understood the likelihood for success and motivation to increase practice;

(4) Satisfaction: The subject was rewarded with improved fitness and that concluded the use of Fitbit was beneficial along with feedback from the author and peer support.

10. CONCLUSIONS

In this paper the authors have presented two means of education system, educational platforms with tablet PC as the core device and health support systems with IoT wearable devices.

The educational platform consists of tablet PC for each student, access to Wi-Fi networks, LMS, groupware and SNS as well as recent useful open data and various free open online courses available globally. We are confident that a high performance mobile information device will open a new era in the field of education. Except initial investment of tablet PC that becomes cheaper every year because of almost paperless educational operation feasible at campus and off-campus, low cost study is possible. As this type of ICT functionality has impacted the elementary and secondary educational systems as well, a global standard setting should be considered to ensure the development of future educational contents and environment.

A health support system for students has proven to be an appropriate visualization of vital data. Moreover, that advice should work effectively for student’s health consciousness that should be a realistic goal for students in order to spend a fruitful life on campus.

By sharing data among group members, educators need a careful approach. This study has shown that if members are reliable, one’s motivation continues. We conclude that student engagement in health consciousness may be enhanced with proper and constant advice from peers. The authors trust that student engagement in health consciousness is crucial in achieving productive study habits.

Those ISO standards, for example, have accelerated the proliferation of the quality management skills by the 9000 series and the security management skill by the 27000 series. Standards should lower costs and increase quality by means of openness to technology. Likewise, when a standard is established in the use of systems and devices of ICT and related content for educational purposes, a great benefit should be expected irrespective of areas and countries worldwide.

The authors conclude that more and more new electronic devices and cloud services are emerging on university campuses that should be utilized for education enhancement apart from private use in a students’ daily life. If educational usage is standardized in ITU in order to increase quality, the outcome from university education should advance with more benefits for more students regardless of employment and job market changes in future [16].

REFERENCES


DRONE READINESS INDEX

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ABSTRACT

This paper proposes a new model for evaluating the robustness of the ecosystem for drone projects in a given country, considering nine factors ranging from the regulatory framework to economic and social impact. The objective of this study is to provide a tool in the form of an index that can be used to gauge countries readiness for drone projects. Governments, NGOs as well as commercial drone companies can use the index to gain insights into the possibilities of drones for non-military use. Notable successful projects using drones were used as a benchmark to chart out the various components of the Drone Readiness Index (DRI). We first reviewed selected projects that have attempted to use drone aircrafts for non-military activities, using secondary data. We then quantify the elements of the drone ecosystem and present derivations of the proposed drone readiness index. To show applications and examples of the proposed drone readiness index, we compute the values of the drone readiness index for selected African countries. These values are further presented in a website \[1\].

Keywords – Communications and control technologies, drones, drone ecosystem, readiness index

1. INTRODUCTION

Aside from their use for military purposes, drone aircrafts are increasingly being used for a range of civilian purposes including land mapping, wildlife monitoring and protection, delivery of medical supplies among others. Recreational drones are also used for private aerial photography.

African countries are taking advantage of this technology in an effort to improve the lives of their people through innovation. Drones provide an opportunity to use aerial platforms for development, which include the possibility of community based projects based on the low cost of drones, as well as opportunities to access areas with limited transportation infrastructure in rural areas of Africa.

For example, Zipline launched its drone delivery project in Rwanda in October 2016 with the support of the government \[2\]. Zipline drones deliver blood to 21 hospitals around the country (as of August 2017) and use GSM technology for communication during flight with the base station, as well as GPS for navigation. A number of factors were identified as being critical to the implementation of Zipline blood delivery project such as the regulatory framework, government investment in the form of utilities like power, fiber optic connectivity, and availability of skilled local capacity that could provide support to their operations. Another example is WeRobotics which established Tanzania Flying labs to spearhead innovative projects for social good in Tanzania. Also, Drone Adventures carried out a mapping project in Zanzibar using SenseFly drones, where the World Bank, the Zanzibar commission of lands and the state of Zanzibar joined forces. The project is being completed in conjunction with the State University of Zanzibar and involves training local geospatial technicians in the use of drones and aerial image processing. Images from the project are expected to be shared in an open source geo-spatial platform.

Common characteristics among these established projects were identified and used to chart out the elements of a drone readiness index. This is a tool which can be used by governments, NGOs and private companies to assess the preparedness of a country to adopt drones for commercial projects.

In the study of drone governance \[3\], the authors discuss the present regulatory framework in different parts of the world focusing on existing rules, policy dialogue, regulatory void, and enforcement. The present work goes a step further to consider other factors that make up a drone ecosystem. These include the overall environment for the technology adoption; the infrastructure and skills; the usage of the technology as can be seen from the projects in place; and finally the impact that the use of the technology has both on an economic and social standpoint.

Our work also freely borrowed ideas from the Networked Readiness Index (NRI) devised by the World Economic Forum \[4\]. The Networked Readiness Index (NRI) is used as tool to assess the preparedness of a country to benefit from emerging technologies and capitalize on the opportunities represented by digital transformation. The Drone Readiness Index similarly asks whether a country has the necessary drivers to initiate drone projects and whether these projects impact society both economically and socially. As with the Network Readiness Index, the components of the Drone Readiness Index were grouped into four sub-categories. While the Network Readiness Index has a broader focus and coverage in terms of number of countries reviewed and technologies considered our work has a narrower focus on drone technology. Moreover, due to non-availability of data, we first applied the proposed Drone Readiness Index to a limited number of countries.

2. METHODOLOGY

Our approach to the development of the drone readiness index involved:

1. Collecting data from drone projects to understand, assess and identify the various factors that contribute to the success of drone projects that are currently operating.
2. After reviewing various projects employing drones, the key factors used for the design and development of the Drone Readiness Index were identified.
3. The selected factors were grouped into four categories that represent the components central to the success of drone projects. These categories are explained in details in latter
sections. The Drone Readiness Index comprises of four categories (components) and nine subcategories (sub-indices) over which the countries are assessed.

The main source of data for the sub-index scores is secondary data from the World Bank [5], World Economic Forum [4],[6], International Telecommunication Union [7] and The Swiss Foundation for Mine Action (FSD) through the Global Drone Regulation Database [8]. When data gaps were encountered for some countries, alternative online data sources were carefully selected, these included online material such as websites, blogs, news articles and national sources such as national civil aviation authorities and ministries websites.

3. STRUCTURE OF THE DRONE READINESS INDEX

The Drone Readiness Index (DRI) comprises of four components as illustrated in Figure 1. Each component is further divided into nine sub-indices. The computation for the overall score of a country on these specific components is done by successive aggregation of the values assigned to the sub-indices.

3.1. Environment

The success of a country in having drone projects setup depends in part on the quality of the operating environment. The Environment component assesses the country’s drone regulatory framework, research and development aimed at drone technology and investments made by the private or public sector that directly or indirectly contributes to drone projects and activities.

3.1.1. Regulations

The regulation sub-index assesses the presence or absence of regulations on drones, considering the exceptions made to allow certain drone projects to be carried out in the country. To quantify the regulation sub-index, a score was assigned to each country to represent the presence and quality of drone regulations in the country. The Global Drone regulations database [8] was used as the main source of data however, other online sources like ministry and civil aviation websites and news articles were used for updated information.

3.1.2. Investment

This sub-index measures the level of investment made by the public or private sector that directly or indirectly contributes to drone projects. Investment made by government and/or private companies in the form of infrastructure or in monetary terms is considered here.

3.1.3. Research and development

This is a measure of the conducted research and development in the drone sector. We look at research being conducted that may contribute to the next generation of drones. In the African context, this is mostly accomplished through trans-national partnerships that countries enter into with overseas drone manufacturing companies.

3.2. Readiness

The Readiness component measures the extent to which a country has in place the infrastructure and other factors to support drone projects.

3.2.1. Local capacity

The local capacity sub-index measures the capacity of the population to work with drone technology. To compute local capacity we used data about the number of drone technical training schools and the gross enrolment rate in tertiary education. A country with a high percentage level of university graduates offers a large pool of individuals to pick from to specialize in drones operation, maintenance and repair. We also consider the availability of drone technical training schools which equip students with specific skills on operating, maintaining and repairing drones.

3.2.2. Communication and energy

The communication and energy sub-index captures the country’s main infrastructures that matter to the setup, maintenance and overall operation of drone projects. This includes GSM towers for communication between drones and base stations as well as availability of power supply for the operation of the drone base stations. The indicators mobile network coverage rate and Quality of electricity supply from the Global Competitiveness Report were used in the computation of the score for this sub-index.

3.2.3. Technology

This sub-index assesses availability of the latest technologies in the country. To measure this sub-index, we used availability of latest technologies and government procurement of advanced technology products indicators from the Global Competitiveness Report.

3.3. Usage

The Usage component strives to capture the number of drone projects currently operating in the country and their maturity. This component has only one Sub-index: Drone Project explained below.

3.3.1. Drone projects

This sub-index maps the number of drone projects operating in a country, as an indicator of how easily other projects can enter the country. The projects assessed had a greater impact to the readiness index if they had entered into a maturity phase. This maturity phase depends on the time the project has been operational. Recreational use of drones was not considered owing to data availability constraints.
3.4. Impact

The Impact sub-index gauges the broad economic and social impacts accruing from drone projects. The observed impact is assessed for countries that currently have or have had a drone project in the past. We decided to assess impact of drones in countries that currently have or have had drone projects before. An alternative approach would be to assess the potential benefit of drone projects in a country, which would result in a different index.

3.4.1. Economic impact

The economic impact sub-index measures potential cost-saving benefits, the effects drone projects have on job creation in the country, investment and transfer of capacity.

3.4.2 Social impact

The Social impact sub-index measures the effect the drone projects have had on the lives of the people in the country; this could be in the form of improved access to healthcare and service delivery.

4. DESIGN OF THE PROPOSED DRONE READINESS INDEX

In this section, we provide a detailed description of the computation of the Drone Readiness Index.

4.1 Analysis and Evaluation of the Sub-indices

Figure 1 summarizes the overall components and sub-indices used to calculate the drone readiness index. Except for the indicator scores retrieved from elsewhere and the score assigned for the number of projects, each indicator was assigned a value of 0, 0.5 or 1 depending on whether this specific aspect is not observable, partially perceptible or extensively noticeable. A larger scale was used for number of projects. Table 1 gives the details of the different sub-indices indicators, the rationale behind the scores assigned for each indicator and the data source. The Regulation and Impact sub-indices are evaluated using qualitative data while the rest of the scores were obtained using quantitative data.

4.1.1. The Drone Readiness Index (DRI)

The drone readiness index was computed using the additive utility function model. Equation (1) gives the expression of the readiness index using a utility function:

\[ DRI = k_1 \times U_{Reg} + k_2 \times U_{Inv} + k_3 \times U_{R&D} + k_4 \times U_{Cap} + k_5 \times U_{Com&En} + k_6 \times U_{Tech} + k_7 \times U_{Proj} + k_8 \times U_{Eco} + k_9 \times U_{Soc} \]  

(1)

where the utility functions are defined below:

- \( U_{Reg} \): score assigned for drone regulations
- \( U_{Inv} \): score given for investment in the drone sector
- \( U_{R&D} \): score assigned for the research and development being conducted in the sector
- \( U_{Cap} \): score allocated for the local capacity building done on drones as well as for the presence of repair and maintenance facilities
- \( U_{Com&En} \): score given for the communication and energy infrastructure in place
- \( U_{Tech} \): score for the type of drone technology in place
- \( U_{Proj} \): score assigned on the drone projects in place
- \( U_{Eco} \): score assigned for the economic impact
- \( U_{Soc} \): score assigned for the social impact

Each country was assigned scores on the above attributes following the score description in Table 1. Swing weighting [9] was used for setting the value of the various k constants in (1) representing the attribute weights. The weight assessment process can be summarized in the following steps documented with the results in Table 2:

1. Taking the various sub-indices as attributes, the best and worst values of each attribute were determined to the lowest and highest score in Table 1, zero and one respectively.
2. Eleven fictional alternatives were devised following the ten attributes in (1). Ten alternative cases where each one of the 10 attributes were in turn set to the best score keeping all the other attributes low, as well as a worst-case alternative where all attributes were considered to be at their lowest score.
3. Ranks were then assigned to each case. The worst-case received the highest rank to indicate that this was the least desirable case and the lowest rank was assigned to the most desirable case. The best alternative was chosen to be that of the case where a country would have ready infrastructures in terms of communication and electricity followed by the case of a country with only favorable regulations in place.
4. Rates were assigned to each alternative case following the rank that was assigned. The rating of the worst-case alternative was zero while the best alternative received a value of 100. All the alternatives were rated following how likely or unlikely they would contribute to the overall readiness of a country.
5. The rating of each alternative case was then normalized by the division of each rating with the sum of all the ratings to obtain the weight associated with each attribute.
Table 1. Utility scores for each of the sub-indices of the Drone Readiness Index

<table>
<thead>
<tr>
<th>Sub-index</th>
<th>Indicator</th>
<th>Indicator scores</th>
<th>Sub-index (Utility) score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulations</td>
<td>Regulatory framework, regulations draft and policies on drones ([8])*</td>
<td>0 – No regulations published and no draft pending for approval 0.5 – No approved regulations, but there are some preliminary steps taken towards having regulations (e.g.: a draft of regulations which is pending for approval) 1 – Comprehensive drone regulations in place</td>
<td>Same score as the indicator score</td>
</tr>
<tr>
<td>Investment</td>
<td>The number of investment instances in the drone sector</td>
<td>0 – No instance of investment in the drone sector 0.5 – One instance of investment in the drone sector by a private company or by the government (monetary or infrastructure) targeted directly to drones 1 – At least two instances of investment in the drone sector</td>
<td>Same score as the indicator score</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Number of research and development work instances in sector by drone companies and other institutions*</td>
<td>0 – No instance of research work done in regards to drones 0.5 – One instance of research work conducted on drones either by a private company conducting research in the country or outside the country 1 – At least two instances of research work done on drones</td>
<td>Same score as the indicator score</td>
</tr>
<tr>
<td>Local capacity</td>
<td>Gross enrolment ratio, tertiary, both sexes (%) ([5])</td>
<td>Percentage value out of 1</td>
<td>Average of the indicator scores</td>
</tr>
<tr>
<td></td>
<td>Number of drone training schools and certifying institutions*</td>
<td>0 – No drone training schools in the country 0.5 – One drone training school 1 – Two or more drone training schools in the country</td>
<td></td>
</tr>
<tr>
<td>Communication and energy</td>
<td>Mobile-cellular telephone subscriptions /100 pop. ([7])</td>
<td>Percentage value out of 1 (converted to 1 for a percentage greater than 100)</td>
<td>Average of the indicator scores</td>
</tr>
<tr>
<td></td>
<td>Quality of electricity supply ([6])</td>
<td>Normalized value of the score</td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>Availability of latest technologies ([6])</td>
<td>Normalized value of the score</td>
<td>Average of the indicator scores</td>
</tr>
<tr>
<td></td>
<td>Government procurement of advanced technology products ([6])</td>
<td>Normalized value of the score</td>
<td></td>
</tr>
<tr>
<td>Drone projects</td>
<td>Number of commercial drone projects*</td>
<td>0 – No commercial drone projects in the country 0.5 – one commercial drone project operational in the country 1 – at least two drone projects operational in the country</td>
<td>Average of the indicator scores</td>
</tr>
<tr>
<td></td>
<td>Maturity of the commercial projects*</td>
<td>0 – No commercial drone projects in the country 0.2 – At least one commercial project operational for less than 3 months 0.4 – At least one commercial project with operations between 3 to 6 months 0.6 – At least one commercial project with operations between 6 to 12 months 0.8 – At least one commercial project with operations between 12 to 24 months 1 – At least one commercial project with operations running for more than 2 years</td>
<td>Average of the indicator scores</td>
</tr>
<tr>
<td>Economic impact</td>
<td>Observed economic impact of drones through job creation, investment*</td>
<td>0 – No observed economic impact, most likely because there has never been any drone commercial projects before 0.5 – Short-term impact 1 – Observed economic impact through direct and indirect job creation, process optimization, etc.</td>
<td>Same score as the indicator score</td>
</tr>
</tbody>
</table>
If the utility (sub-indices) were assumed to have equal weight, the DRI becomes:

$$DRI = \left( U_{Reg} + U_{Inv} + U_{R&D} + U_{cap} + U_{Com&En} + U_{Tech} + U_{Proj} + U_{Eco} + U_{Soc} \right)/9$$

(2)

Table 2. Summary of the swing weighting approach for weight assignment

<table>
<thead>
<tr>
<th>Attribute swing from worst to best</th>
<th>Consequence to compare</th>
<th>Rank</th>
<th>Rate</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark (Worst Alternative)</td>
<td>all scores low</td>
<td>10</td>
<td>0</td>
<td>0/510 = 0</td>
</tr>
<tr>
<td>Regulations</td>
<td>all scores low except regulations</td>
<td>2</td>
<td>90</td>
<td>90/510 = 0.16</td>
</tr>
<tr>
<td>Investment</td>
<td>all scores low except Investments</td>
<td>3</td>
<td>80</td>
<td>80/510 = 0.14</td>
</tr>
<tr>
<td>Research and development</td>
<td>all scores low except R&amp;D</td>
<td>8</td>
<td>40</td>
<td>40/510 = 0.07</td>
</tr>
<tr>
<td>Local capacity and facilities</td>
<td>all scores low except local capacity building and drone facilities</td>
<td>7</td>
<td>40</td>
<td>40/510 = 0.07</td>
</tr>
<tr>
<td>Communication and energy</td>
<td>all scores low except communication and energy</td>
<td>1</td>
<td>100</td>
<td>100/510 = 0.18</td>
</tr>
<tr>
<td>Technology</td>
<td>all scores low except technology in use</td>
<td>9</td>
<td>20</td>
<td>20/510 = 0.04</td>
</tr>
<tr>
<td>Drones projects</td>
<td>all scores low except drones projects</td>
<td>4</td>
<td>80</td>
<td>80/510 = 0.14</td>
</tr>
<tr>
<td>Economic impact</td>
<td>all scores low except economic impact</td>
<td>5</td>
<td>60</td>
<td>60/510 = 0.11</td>
</tr>
<tr>
<td>Social impact</td>
<td>all scores low except social impact</td>
<td>6</td>
<td>60</td>
<td>60/510 = 0.11</td>
</tr>
</tbody>
</table>
5. APPLICATION OF THE DRONE READINESS INDEX TO SELECTED COUNTRIES

In this section, we apply the proposed Drone Readiness Index given by equation (1) to selected countries and analyze the performance of these selected countries. Although, the proposed index is intended to be applied to all countries, due to limitations in data, we apply the proposed model to a selected number of African countries. This choice was also motivated by the greater proliferation of drone projects on the African continent mainly because African countries have emerged these past years as a test bed for new technologies that take too long to start elsewhere [10]. The computed indices for these various countries are also available on the drone readiness webpage [1].

As observed in Figure 3, using the proposed Drone Readiness Index given by equation (1), Mauritius tops the chart among the countries for which the Drone Readiness Index is computed. This is attributed to the fact that Mauritius has provided an environment that seems conducive for drone projects and companies to develop. This includes comprehensive drone regulations, infrastructure and development of skilled capacity resulting in a number of drone companies setting up and operating in the country offering services from aerial photography to mapping to agriculture solutions.

Like Mauritius, South Africa and Tanzania, Rwanda have comprehensive drone regulations in place coupled with a growing number of drone projects most notably Agrilift focusing on crop monitoring with drones, the Zipline project and CHARIS that assembles drones for rental for commercial or private purposes. Similarity, South Africa has regulations in place as well as public and private investments in drone technologies. In addition, there are several training schools to provide certification for drone pilots. South Africa has also a number of projects using drones in wildlife to combat poaching and in entertainment for video and photography.

Tanzania and Rwanda are next in the ranking. In the case of Tanzania, the mapping project and the flying lab for training drone operators contributed to the high score. Tanzania has also received considered investment from private companies and NGOs in the drone sector, for example from the World Bank and the Red Cross [11].

South Africa emerged second among the considered countries. Similarly, South Africa has regulations in place as well as public and private investments in drone technologies. In addition, there are several training schools to provide certification for drone pilots. South Africa has also a number of projects using drones in wildlife to combat poaching and in entertainment for video and photography.

Figure 4 compares computation of the proposed Drone Readiness Index using unequal weights as described in Table 2 and the same index when the weights are assumed equal. As observed in Figure 4, the Drone Readiness Index slightly varies under these different assumptions. Moreover, most countries seem to have a higher index with the non-equal weight. This is particularly observed for

<table>
<thead>
<tr>
<th>Country</th>
<th>REGULATION</th>
<th>INVESTMENT</th>
<th>R&amp;D</th>
<th>LOCAL CAPACITY &amp; INFRA</th>
<th>COMMUNICATION</th>
<th>TECHNOLOGY &amp; ENERGY</th>
<th>DRONE PROJECTS</th>
<th>IMPACT</th>
<th>ECONOMIC</th>
<th>SOCIAL</th>
<th>READINESS INDEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algeria</td>
<td>0</td>
<td>0</td>
<td>0.6</td>
<td>0.7</td>
<td>0.3</td>
<td>0.8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.1</td>
<td>0.9</td>
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<td>Benin</td>
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<td>0.5</td>
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<td>0.3</td>
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<td>0</td>
<td>0</td>
<td>0.1</td>
<td>0.7</td>
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<td>0.1</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0.5</td>
<td>0.7</td>
</tr>
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<td>0</td>
<td>0</td>
<td>0.1</td>
<td>0.6</td>
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<td>0.1</td>
<td>0.5</td>
<td>0</td>
<td>0.3</td>
<td>0.1</td>
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<td>1</td>
<td>0.1</td>
<td>0.3</td>
<td>0.5</td>
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<td>0.6</td>
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<td>0.6</td>
<td>1</td>
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<td>Ivory Coast</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>0.9</td>
<td>0.4</td>
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<td>0</td>
<td>0.1</td>
<td>0.5</td>
<td>0.1</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
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<td>0.6</td>
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<td>0.9</td>
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<td>1</td>
<td>0.2</td>
<td>0.5</td>
<td>0.4</td>
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<td>1</td>
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<td>6</td>
<td>0</td>
<td>0</td>
<td>0.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 3. Sub-indices scores per country
countries where there are active drone projects. This observation can be explained by the fact that the attributes with higher weights such as communications, regulations, investments and projects are usually achieved by countries where there are active drone projects.

6. DISCUSSION

Notwithstanding the novelty of the paper, the computation of the Drone Readiness Index has the following limitations which could affect the values of the computed Drone Readiness Index.

- We selected some sub-indices and indicators based on qualitative data. In addition, quantifying these sub-indices was sometime dependent on qualitative data. This can increase the sensitivity of the Drone Readiness Index. If different and/or additional sub-indices and/or indicators were selected, different values of the Drone Readiness Index could be expected.

- The results of the computation are as good as the data collected. If comprehensive data was available, the accuracy of the Drone readiness index would be higher. In this study, we have experienced difficulty collecting some data and therefore there are some data gaps, that we expect to bridge in our future work. For example, in the absence of the desired Mobile geographic coverage indicator data for the communication and energy sub-index, Mobile-cellular telephone subscriptions /100 pop was used. This emphasizes the need to optimize the selection of the indicators used in the study to ensure accuracy of the results.

- The number of countries, for which the drone readiness index was computed, was limited. This was partly due to difficulties in data collection. In the next phase, more data is expected to be collected from countries on different continents, e.g., using crowdsourcing. Hence we expect to extend the application of the Drone Readiness Index, and rank almost all countries.

- In our work, we used scores of 0, 0.5 and 1 for many of the sub-indices. However, the level of granularity can also be increased by using a wider scale to provide greater accuracy for the Drone Readiness Index. For example, if the same indicators were quantified using a gradation of 0.1 instead of 0.5 used in this paper, more differentiation would be expected for different countries.

7. CONCLUSION

We proposed a novel drone readiness index that can be used to evaluate the robustness of the ecosystem for drone projects in a given country. The proposed readiness index is built using factors such as the regulatory structure, the economic and social impact, the investment in the sector, research and development. Using the derived formula, we computed the drone readiness index for selected countries. These values are further presented in a website [1].

Our future work will focus on refining the proposed drone readiness index for greater accuracy. This will be done through a sensitivity analysis for the different sub-indices, collecting more data using crowdsourcing, using a finer granularity when evaluating the sub-indices and applying the drone readiness index to more countries in different continents.

REFERENCES


APPENDIX

Table A.1. Scores environment sub-indices per country

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SESSION 5

ADVANCING NETWORK INFRASTRUCTURE AND ARCHITECTURE FOR DATA

S5.1 Machine learning approach for quality adaptation of streaming video through 4G wireless network over HTTP

S5.2 Modeling and analysis of spatial inter-symbol interference for MIMO image sensors based visible light communication

S5.3 Secrecy energy efficiency optimization for artificial noise aided physical-layer security in cognitive radio networks

S5.4 Data centric trust evaluation and prediction framework for IoT
MACHINE LEARNING APPROACH FOR QUALITY ADAPTATION OF STREAMING VIDEO THROUGH 4G WIRELESS NETWORK OVER HTTP

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ABSTRACT

Video streaming over HTTP through 4G wireless network used for multimedia applications faces many challenges due to fluctuations in network conditions. The existing HTTP Adaptive Streaming (HAS) techniques based on prediction of buffer state or link bandwidth offer solution to some extent, but if the link condition deteriorates, the adaptation process may reduce the streaming bit rate below an acceptable quality level. In this paper, we propose a machine learning based method, State Action Reward State Action (SARSA) Based Quality Adaptation algorithm using Softmax Policy (SBQA-SP), which identifies the current state (Throughput), action (Streaming quality) and reward (current video quality) at client to determine the future state and action of the system. The ITU-T G.1070 recommendation (parametric) models embedded in the SBQA-SP to implement adaptation process. The proposed system was implemented on the top of HTTP in a typical internet environment using 4G wireless network and the streaming quality is analyzed using several full reference video metrics. The test results outperformed the existing Q-Learning based video quality adaptation (QBQA) algorithm. For instance, an improvement of 5% in average PSNR and 2% increase in average SSIM index over the QBQA approach was observed for the live stream.

Keywords— HTTP Adaptive Streaming, SARSA, Q-Learning, Video Quality Adaptation.

1. INTRODUCTION

The explosive growth of multimedia application and services over wired and wireless networks demands a paradigm shift in system design. In North America, 71% percent of data traffic in evening consists of streaming audio and video over fixed networks [1]. Further, as per the Cisco Visual Networking Index (VNI), the video in IP network will account for 82% of total consumer internet traffic globally in 2021 [2]. It is also reported that in the year 2016, the Fourth Generation (4G) mobile system supported 69% of the total mobile traffic [3]. This extremely fast increase in video data traffic poses a challenge to network operators and system designers to enhance the ability of the network considering end-to-end connectivity while supporting high-quality video streaming.

The widely used Hypertext Transfer Protocol (HTTP) employing Transmission Control Protocol (TCP) has become a primary approach for supporting adaptive video streaming over internet [4]. The Dynamic Adaptive Streaming over HTTP (DASH) [5] has turned into the accepted video transport mechanism these days, which exploits the functions of widely used HTTP platforms in the internet world. HTTP Adaptive Streaming (HAS) is widely used model in DASH which encodes video content with numerous video qualities (chunks) that have diverse bitrate and adapts the video qualities based on client’s feedback [6].

In HAS based implementation, the selection of chunk duration directly effects the bit rate adaptation process. For example, a small chunk leads to a sub-optimal implementation, while a larger chunk will cause lack of adaptation in the fast changing internet traffic. The adoption of TCP/HTTP leads to an inefficient network bandwidth utilization, and a mismatch between the specified quality of a chunk and the actual encoding rate further aggravate the problem [7].

The bit rate adaptation algorithm needs to deal with multidimensional aspects of video streaming over HTTP through wireless networks. Most video codec, e.g., High Efficiency Video Coding (HEVC), H.264/AVC etc., generates variable bit rate of encoded video. However, the meta-data of MPEG-DASH does not carry this which can be used by the client for adaptation process [8]. The existing HAS approach do not provide control of transfer rate of video data. In fact, the TCP controls the transmission rate of video chunk, which respond to the congestion in network connecting client and server [9]. The fluctuation in received signal strength in wireless network further inflicts the system capacity. In a typical multiple access cellular system, the data rate at user equipment depends on prevailing channel conditions [10]. Most of the earlier work tries to estimate the future bandwidth and hence the efficiency of this approach depends on accuracy of prediction. However, it is inherently difficult to predict the receiving bit rate based on past history [11].

A machine learning technique can be employed in adaptation process provided it is incorporated into feedback quality loop. Reinforcement Learning (RL) [12] is an efficient solution for environmental learning problem. In RL, rather than relying on a fixed algorithm, learning agents can try different actions and gradually learn the best
strategy for each situation. By continuous learning the RL algorithms like Q-learning can adapt to the changing conditions of the streaming system. However, the complexity of the model based on Q-learning [13] could seriously downgrade the system performance especially in dealing with the live streaming of video.

The Full Reference (FR) metrics [14] of video quality evaluation produces best result as it compares the received signal with original at frame level. However using FR metrics in dynamic adaptation of quality is not practical as the receiver does not have the original video. If the learning technique can be incorporated into No Reference (NR) metrics of video quality estimation, a dynamic streaming system can be designed and developed to deal with the client’s terminal requirement. Although, the ITU-T G.1070 [15] recommendation is targeted towards quality of experience / service (QoE/QoS) planners in video telephony, its parametric model is adapted here in supporting video streaming system to meet the end to end service quality.

In this work, we propose a new algorithm based on RL approach called, State Action Reward State Action (SARSA) Based Quality Adaptation using Softmax Policy (SBQA-SP) algorithm to manage the adaptive streaming using NR metrics. SARSA is an online policy approach of RL [16], which doesn’t require a separate learning and deployment phase. In SBQA-SP, the system is characterised by a set of states and the algorithm decides the suitable action to be taken based on the current state. The SBQA-SP identifies the current state of the system and based on the state chooses an action to perform. It calculates the reward as a result of the action performed and determines the resulting state of the system after the action. Next, the SBQA-SP determines the future action to be performed based on the Softmax exploration policy and update the Q-matrix. The chosen action is sent as feedback to the server.

To analyse the performance of the proposed approach, it is compared with other two approaches, namely (i) Q-Learning Based Quality Adaptation (QBQA) [13], and (ii) SBQA using ε-Greedy Policy (SBQA-GP). In QBQA, Q-learning method is used for controlling video quality adaptation. The Q-Learning approach similar to SARSA, expect for the fact that it is an off-line policy algorithm which requires a learning and deployment phase. Also, the formula to update Q-matrix varies for SARSA and Q-learning. SBQA-GP is a variant of SBQA-SP approach in which ε-Greedy policy is used in selecting the best possible future action.

The proposed algorithms were implemented in accordance with the ITU-T J.247 recommendation (Table 1) which describes about “objective perceptual video quality measurement” [17].

2. PROPOSED SYSTEM

2.1. System Architecture

The architecture diagram of the proposed system is illustrated in Figure 1. It works on the top of HTTP in a typical internet environment where the last mile connectivity between client and server is supported on a 4G wireless network. Initially, the client requests the Media Descriptor file from the server, and the server replies with the Media Descriptor Sidewcar file containing default settings and video parameters. Once the server streams the video to the client, the client continuously monitors the streaming quality using proposed SARSA based quality adaptation algorithm to determine the corrective action to be taken by the server in the near future and send this decision as feedback to the server. The server adapts the streaming video quality accordingly to match the client’s requirement.

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2.2. Server Side Functions

The server initially set media locator URL either with location of the stored video or with the application program interface (DirectShow [18]) for accessing camera to capture live video. The media player / encoder objects initialized to perform video transcoding during streaming process. The variation of the frame rate is set between lower (e.g., 20 fps) and upper limit (e.g., 30 fps) and the resolution is set with standards like QCIF, CIF etc. The destination address is linked with server’s IP address and application’s port number. Once the transcoding parameters are set, the server starts streaming at the specified URL through the HTTP port. It waits for client’s reply in the application’s port and connect with the client which request for connection.

The server continuously listens for client feedback about the video quality, and then based on client’s feedback adapt the video parameters. Now, the server’s work can be outlined as: a) Video capture, b) Video transcoding, c) Video streaming, and d) Adapting video based on client’s feedback.

2.3. Client Side Functions

The client initializes the media player component to decode and play the video. It specifies the streaming URL as a parameter to support media function, and connects with the server using sockets by specifying the IP address and port of server application. The client captures the packet using a packet capture framework. It calculates the throughput for certain period and assesses the frame rate (fps) and the bit
rate at which the video need to be encoded at the server. The client also estimates the percentage of packet loss. Based on these three parameters, the video quality is estimated using ITU-T G.1070 parametric model. This is used for reward calculation in the proposed algorithm, and estimated throughput is assigned as the current state, and the video parameter is set to guide the current action. With the help of state, action, and reward, the SBQA algorithm determines the future action. This action is sent as the feedback to the server periodically.

**Q-Table, Q(S, A):** The rows of this matrix represent the states of the system and each column contains one of the possible actions (the segment qualities). For a given pair (s, a), Q(·) indicates the learned benefit that the system will get in taking action a in states. In order to formulate the client’s learning and corresponding actions procedure, the SARSA approach updates Q-matrix after each quality decision as follows.

\[
Q[s_{cur}, a_{cur}] = Q[s_{cur}, a_{cur}] + \alpha [V_q + \gamma Q(s_{new}, a_{new}) - Q(s_{cur}, a_{cur})]
\]  
(1)

Where \(s_{cur}\) is the current state, \(a_{cur}\) is the selected action, \(v_{q}\) is the associated immediate reward, \(s_{new}\) is the next state after action \(a_{cur}\), and \(a_{new}\) is the action from state \(s_{new}\). The learning rate (\(\alpha\)) indicates how much the acquired information will affect to the old value of \(Q(·)\) in its updating, and the discount factor (\(\gamma\)) weights the contribution of the immediate and future rewards (0 ≤ \(\gamma\) ≤ 1).

c) **Exploration Policy:** Two exploration policies are taken into consideration here namely, Softmax and \(\varepsilon\)-Greedy. Softmax policy chooses action by converting the action’s expected reward to a probability. The action is chosen according to the resulting distribution, which is the Boltzmann distribution given by

\[
P(a_i) = \frac{e^{\frac{Q(s, a_i)}{T}}}{\sum_{a_j} e^{\frac{Q(s, a_j)}{T}}}
\]  
(2)

Where \(r\) is a positive parameter called temperature, and \(a_i\) is number of state of the system. High temperatures cause all actions to be nearly equiprobable, whereas low temperatures cause greedy action selection.

With \(\varepsilon\)-greedy, the agent selects at each time step a random action with a fixed probability, 0 < \(\varepsilon\) < 1, instead of selecting greedily one of the learned optimal actions with respect to the Q-function:

\[
Action = \begin{cases} 
\text{random action from } A(s), & \text{if } r < \varepsilon \\
\arg\max_{a \in A(s)} Q(s, a), & \text{otherwise}
\end{cases}
\]  
(3)

Where 0 < \(r\) < 1 is a uniform random number drawn at each time step.

The SBQA approach is differentiated as two methods based on two exploration policies: SBQA using Softmax Policy (SBQA-SP), and SBQA using \(\varepsilon\)-Greedy Policy (SBQA-GP).

---

**Fig. 1. Architecture of the proposed work**

3. **ELEMENTS OF PROPOSED WORK**

The SARSA based algorithm implemented at client forms the major part of the proposed algorithm. The different elements of SARSA approach used in quality and reward calculation represent the learning and adaptation process. No reference (NR) video quality metric is used as a reward function to guide the corrective actions.

3.1. **Elements of SARSA Approach**

a) **State:** It contains pertinent data about the environment conditions in a given time instance. In particular, the proposed model characterizes the state vector as \(s_{cur} = \{T_k\}\) where \(T_k\) is the estimated throughput. The throughput values are mapped to different discrete finite states.

b) **Action:** Qualities are defined on the basis of analyzed data segment, and the quality segments are mapped to actions.

c) **Reward Function:** This function evaluates the fitness of the choice. The quality measurements through NR video metrics provides the main input in reward calculation.

---

**Challenges for a data-driven society**
3.2. Video Quality Estimation using No-reference Metric

The ITU-T G.1070 defines a model [15] for estimating the video quality based on measurable parameters of IP network. The video quality ($V_q$) is represented as

$$V_q = 1 + I_c J_c$$

(4)

Where $I_c$ represents the basic video quality resulting from the encoding distortion due to the combined effect of bit rate and frame rate, $J_c$ is the factor governed by degree of robustness due to packet loss.

$I_c$ is expressed in terms of bit rate ($b$) and frame rate ($f$) according to equations (5-8) as follows.

$$I_c = I_0 e^{-\frac{(ln(f) - ln(f_0))^2}{2Dp_{plv}^2}}$$

(5)

$$f_0 = v_1 + v_2 b$$

(6)

$$Dp_{plv} = v_6 + v_7 b$$

(7)

$$I_0 = v_8 \left(1 - \frac{1}{1 + \frac{b}{v_9}}\right)$$

(8)

Where $I_0$ represents the maximum video quality ($0 < I_0 < 4$) at each video bit rate, $f_0$ is optimal frame rate ($1 < f_0 < 30$) maximizing the video quality at bit rate $b$, $Dp_{plv}$ is the degree of video quality robustness due to frame rate.

$I_c$ depends on packet loss robustness factor ($Dp_{plv}$) and rate of packet loss ($p$) given by

$$I_c = e^{-\frac{p}{Dp_{plv}}}$$

(9)

$$Dp_{plv} = v_{10} + v_{11} e^{-\frac{f}{v_{12}}} + v_{12} e^{-\frac{b}{v_{13}}}$$

(10)

Here $Dp_{plv}$ represents the degree of video quality robustness against packet loss. The value of coefficients $v_1$, $v_2$, $v_3$, ..., $v_{12}$ depends on type of codec, video format, interval between key frame, and size of video displayas mentioned in ITU-T G.1070.

4. PROPOSED ALGORITHM

4.1. SBQA USING SOFTMAX POLICY (SBQA-SP)

This approach uses Softmax exploration policy for action selection. The SBQA-SP algorithm is defined as follows.

**SBQA-SP Algorithm**

1. Initialize the number of packets $N$, learning rate $\alpha$ and discount factor $\gamma$, last state $s_{last}$ and Q-matrix $Q$.
2. Compute throughput ($Th$) resulting from the capture of $N$ packets.
3. Identify current state $s_{cur}$ based on $Th$ value.
4. Read the resolution $res$, and frame per second $fps$ from the header in streamed video.
5. Determine current action $a_{cur}$ based on the current quality segment.
6. While $s_{cur} < s_{last}$ till last state reached
7. Read the encoded bitrate $b$, and compute frame loss percentage $p$.
8. Calculate the reward (video quality) $V_q$ using (4)
9. Estimate the current throughput $Th_{cur}$ and based on $Th_{cur}$ identify new state $s_{new}$.
10. Compute new action $a_{new} \leftarrow$ SoftMax($Q(s)$).

**Softmax ($Q(s)$)**

1. Initialize $r = 1$, $offset = 0$, $sum = 0$, $flag = 0$ and $prob[] = [0]$, $prob_{length} = length$ of $prob[]$.
2. For $i = 1$ to $prob_{length}$
3. $prob[i] = e^{Q[s,i]}$ // Access $Q[s,i]$ in the $Q$ matrix
4. $sum = sum + prob[i]$
5. End
6. For $i = 1$ to $prob_{length}$
7. $prob[i] = prob[i] / sum$
8. End
9. Generate a random value $ran$, $0 < ran < 1$ // pointer for random action selection.
10. For $i = 1$ to $prob_{length}$
11. If $ran \geq offset$ and $ran < offset + prob[i]$
12. $selectedAction = i$
13. $flag = 1$
14. $offset = offset + prob[i]$
15. End
16. If $flag = 0$
17. Repeat from step 9
18. Else
19. Return $selectedAction$

4.2. SBQA USING $\varepsilon$ GREEDY POLICY (SBQA-GP)

SBQA-GP is a variant of SBQA-SP algorithm uses $\varepsilon$-greedy exploration policy for action selection. The method for selecting action using this policy is defined below.

**$\varepsilon$-greedy ($Q(s)$)**

1. Initialize fixed probability $\varepsilon$ and $max$ // Store maximum value $max$ in s' row of $Q$-matrix.
2. Generate a random value $ran$ in the range 0 to 1.
3. If $ran < \varepsilon$
4. $selectedAction = -1$
5. Else
6. For $i = 1$ to $Q_{length}$ // get $Q_{length}$ from $Q$-matrix
7. If $Q[s,i] > max$
8. $selectedAction = i$ // action with max reward
9. $max = Q[s,i]$
10. End
11. If \( selectedAction = -1 \)
12. Generate a random number \( r \), in range of action.
13. \( selectedAction = r \)
14. Return \( selectedAction \)

### 4.3. Q-LEARNING BASED QUALITY ADAPTATION (QBQA)

Q-Learning is a model free reinforcement learning algorithm. The QBQA is based on [13], where the authors have designed and optimized a Q-Learning approach for video quality adaptation. The system state \( (s_t) \) was modeled with Bandwidth \( (bw_t) \), Buffer occupancy level \( (buf_t) \), and quality level \( (q_t) \) of the segment. The action \( (a_t) \) of the system is based on different qualities of video segment which is expressed using nominal bit rate. The reward is formulated for the action taken by considering three factors which are quality affected by bandwidth and buffer, video freeze, and quality switching. The exploration policy used for action selection is value based differential Softmax. The adaptation algorithm based on Q-Learning [13]is as follows.

**QBQA Algorithm**

1. Initialize the learning rate \( \alpha \), discount factor, \( Q \)-matrix, and optimal bandwidth value \( B_{opt} \).
2. Read the current buffer occupancy level \( buf_k \) for \( k^{th} \) segment and quality level \( q_{k-1} \) for segment \( k-1 \) while streaming
3. For \( i = 1 \) to \( t \), Training Phase
4. Estimate the bandwidth \( bw_k \)
5. Assign \( s = \{ bw_k, buf_k, q_{k-1} \} \) // Current State
6. \( a = \text{Softmax}(Q, s) \) // Exploration policy function to get best possible action.
7. Calculate the quality factor related to bandwidth and buffer occupancy level using the equation
   \[
   R_{quality} = -1.5 \times \left[ \frac{bw_k^{12}(buf_k/B_{opt}) - a_k}{3-bw_k/a_k} \right]
   \]
   (11)
8. Calculate the quality factor related to switch in quality using the equation
   \[
   R_{switches} = -|q_{k-1} - a_k|
   \]
   (12)
9. Read the duration of video freeze \( \tau_{stall} \), time elapsed from the last freeze \( \tau_{play} \) and number of freezes \( n \)
10. Calculate the quality factor related to video freezing using the equation
    \[
    R_{freezes} = \begin{cases} 
    -100 \times \frac{a_k}{bw_k} & \text{if } \tau_{stall} = \text{min}(\tau_{play} + 1) \text{ and } \tau_{play} = \tau_{play} + 1 \\ 
    -100 \times \frac{a_k}{bw_k} & \text{if } \tau_{stall} = \text{min}(\tau_{play} + 1) \text{ and } \tau_{play} = \tau_{play} + 1 \\
    \end{cases}
    \]
    (13)
11. Calculate
    \[
    R_{total} = R_{quality} + R_{switches} + R_{freezes}
    \]
    (14)
12. End
13. Determine the resultant state, \( s_{k+1} \) using \( \{ bw_{k+1}, buf_{k+1}, q_k \} \)
14. Update the Q-matrix using

\[
Q[s_k, a_k] \leftarrow (1 - \alpha) Q[s_k, a_k] + \alpha \left[ R_{total} + \gamma \max_a Q(s_{k+1}, b) \right]
\]
(15)
15. Estimate the bandwidth \( bw_k \), Testing Phase begins
16. Assign \( a = \{ bw_k, buf_k, q_{k-1} \} \)
17. \( a = \max_a Q(s_k, a) \)
18. Send \( a_k \) as feedback to the server.
19. Repeat from Step 15 until streaming occurs.

### 5. IMPLEMENTATION ENVIRONMENT

The Java programming environment based on 64bit JDK Version 7 was chosen for implementation purpose and the code was developed using Eclipse IDE. The 64 bit VLC media player was used for playing the media, as VLC can be easily manipulated using java with the help of VLCJ framework. Dshow API [18] was used for capturing live video for streaming, but for packet capturing Jnetpcap [19] framework was used. The client and server were connected through 4G Mobile Hotspot devices in a typical cellular wireless network. Frame rates were varied with values 20, 24, 27, 30 while default rate was chosen to be 24. Standard video resolutions like QCIF(176*144), CIF (352*288), VGA (640*480), SQCIF (128*96) and QVGA (320*240) were used dynamically at encoding / decoding process during the experiment. The server and client were implemented in Windows 10 (64 bit operating system) Core i3 processor with 8GB RAM and Windows 10, 64bit OS, Core i5 processor with 4GB RAM respectively. The streaming was implemented on top of the HTTP in a typical internet environment.

The network bit rate carrying capacity of the Airtel Mobile Hotspot (4G-LTE TD) [20] dongle was analyzed using online tool Speedof.me [21] and one instance result is shown in Figure 2. Internet speed of wireless connection was measured without using FLASH or java which is currently used by many other speed test websites. The online tool provided a broadband speed test service which uses pure browser capabilities suchs HTML5 and JavaScript. For the reliability of measured data, it utilizes multiple test servers around the world and the server is chosen automatically. Both download and upload speed of the network device is observed independently.
6. RESULTS AND DISCUSSION

The proposed approach SBQA-SP and its variant SBQA-GP along with existing QBQA algorithms were implemented and tested in typical internet environment. The system performance was evaluated using full reference video quality metrics: PSNR, SSIM, MS-SSIM and VQM. The numerical data representing different quality index arising out of live streaming of video were analyzed offline.

6.1. Peak Signal to Noise Ratio (PSNR)

The commonly used video / image quality metric PSNR is used here because it is fast and simple to implement. Figure 3 depicts the PSNR values corresponding to the SBQA-SP, SBQA-GP and QBQA algorithms. The SBQA-SP algorithm exhibits a higher average PSNR, which is 8% and 5% higher than the SBQA-GP and QBQA algorithm respectively. The SBQA-SP performs better compared to other two approaches as it learns the environment conditions without any pre learning phase and adapts the video quality as data arrives. Also, the exploration policy used helps to convergence at a faster rate.

6.2. Structural Similarity Measurement (SSIM)

The SSIM index was computed for the three algorithms (SBQA-SP, SBQA-GP and QBQA), and the proposed SBQA-SP algorithm exhibited a higher value with an average index of 0.9940 which is 2% higher than the QBQA algorithm 3% better than SBQA-GP. The SSIM index on few decoded consecutive frames at receiver corresponding to three algorithms is plotted in Figure 4. The higher SSIM index for the proposed algorithm is a reward for the perceived video quality as there is need for the perseverance of luminance and contrast factors that are influenced by the distortions.

6.3. Multi Scale Structural Similarity (MS-SSIM) Measurement

A multi scale SSIM being more flexible than single scale metric provides better result with respect to correlations to human perceptions. On an average SBQA-SP algorithm produces 1.2% higher quality on MS-SSIM scale than QBQA algorithm and 2.2% SBQA-GP algorithm. Figure 5 shows the variation of MS-SSIM values on different consecutive frames. Although the improvement in quality by SBQA-SP algorithm over other two is marginal, it still leads the pack.

6.4. Video Quality Metric (VQM)

The VQM is an important metric for the evaluation of video quality because it considers the spatial-temporal aspects of visual perception. Since the VQM score is the sum of many weighted parameters and its higher value represents the maximum loss of quality in the video, the lower values observed by the SBQA-SP, SBQA-GP and QBQA algorithms are desirable. The SBQA-SP based method shows 15% lower than the SBVQA-GP and 23% lesser than the QBQA algorithm. The VQM values for 20 Frames are depicted in Figure 6.
6.5. Three-component Structural Similarity (3-SSIM) Measurement

3-SSIM is a form of SSIM that is calculated as a weighted average of SSIM for three categories of regions: edges, textures, and smooth regions. From Figure 7, it is evident that the proposed SBQA-SP approach shows a higher 3-SSIM value compared to other approaches. The average values show that SBQA-SP approach provides quality which is 0.4% higher than QBQA approach and 1.04% higher than SBQA-GP approach with respect to 3-SSIM scale.

6.6. Inter Arrival Packet Delay

Figure 8 shows the observed inter arrival packet delay on the Airtel4G LTE-TD network during live video streaming. An average delay of 7.6 milliseconds was observed during the experimentation process.

7. CONCLUSION AND FUTURE WORK

An HTTP adaptive streaming through 4G wireless network was implemented using Q-learning with NR metrics for live video considering the challenges due to varying wireless link condition and internet traffic. To achieve maximum obtainable quality, the decisions that are made to adapt video quality in a real time video streaming were based on the current state of the system and the action to be taken in that state that maximizes the reward. The proposed SBQA-SP algorithm using Softmax policy was formulated and implemented using ITU-T G.1070 model for no-reference metrics quality evaluation. Since ITU-T G.1070 is targeted at QoE/QoS in video telephony, it constrains in achieving higher quality of streaming video in an IP network.

The framework was implemented in one way communication but it can easily be extended to support two-way video communication. On the other aspect, the...
The system can be structured in such a way that it enables the server to engage multiple clients at a time.

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MODELING AND ANALYSIS OF SPATIAL INTER-SYMBOL INTERFERENCE FOR MIMO IMAGE SENSORS BASED VISIBLE LIGHT COMMUNICATION

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ABSTRACT

In this paper, a MIMO image sensors based visible light communication system is designed and researched. In our study, the spatial inter-symbol interference was considered and the formation mechanism of the stray light and the influence of the spatial inter-symbol interference is analyzed. The mathematics expression of the system SNR and BER is given. The simulation result indicates that there is a critical communication distance in the system. Once the communication distance exceeds the critical value, the system BER increases sharply. In addition, an adaptive threshold detection method is introduced and the performance is simulated. By means of estimating the spatial inter-symbol interference noise power, the optimal detection threshold can be obtained and the system BER performance enhances significantly.

Keywords— Optical wireless communication, Image sensor communication, MIMO, spatial inter-symbol interference, optimum detection threshold method

1. INTRODUCTION

With several advantages such as saving the radio frequency resource and being harmless to human being, the visible light communication (VLC) technology develops rapidly in the last decade. Depended on the detection method, the VLC system can be divided into photodiode (PD) based VLC system and image sensors based VLC (IS-VLC) system [1]. Due to the widespread use of image sensors, the IS-VLC technology has a promising future in low-speed optical wireless communication, indoor positioning application and intelligent transportation system [2, 3, 4].

In order to improve the performance, multi-input multi-output (MIMO) scheme is utilized in IS-VLC system. Compared with the single-input single-output scheme, MIMO-IS-VLC system can not only achieve a higher symbol transmission rate but also a lower bit error rate [5]. In a MIMO-IS-VLC system, a frame of digital data stream drivers the LED array where the on status of LEDs represents the data ‘1’ and off status corresponds to the data ‘0’. An image sensor used as receiver captures a picture and send it to be processed. By

![Fig. 1: Demonstration of the SISI. (a) The designed experiment board with 6 × 6 LED array and the LED spacing distance d. (b) Imaging result of the LED array. (c) Light intensity contour plot of (b).](image-url)
means of digital signal processing, every LED channel on the array will be recognized and analyzed individually. After the demodulation, a frame of original digital data stream is obtained from the image [6].

However, there exists spatial inter-symbol interference (SISI) in MIMO-IS-VLC system which will degrade the system performance. In ideal imaging system, the light reaching the imaging plane is the target light of imaging objects. Nevertheless there will be non-target stray light in a practical imaging system leading to the interference between different LED channels.

The stray light is defined as the irregular incident light of the imaging object. It is the major factor contributed to the SISI. As is shown in Fig.1(c), the LED of on status has similar light intensity contour distribution which can be equivalent to concentric circles. However, in the region that LEDs of on status are relatively concentricating, the outermost of each concentric circles is going to connect together and generates a larger area. It reveals the fact that in MIMO-IS-VLC system, different LED channels will influence each other and produces the SISI.

A, B and C in Fig.1(c) is the position of LEDs of off status. According to the light intensity distribution, the SISI value of LED on position A is higher than that of the other two position and the light intensity value of LED on C is the lower. B is on the boundary of light intensity contour among A and C. The interference light intensity from other LED channels makes it easier for A LED to be recognized as a on status LED when applying a constant judgment threshold to demodulate the signal. From point of view of optical wireless communication system, the spread distribution of LEDs’ light intensity on the image plane gives rise to the SISI and degrades the system performance. The paper [7] studies the impacts of SISI on the visual MIMO system’s capacity from the prospective of the imaging process. However, the generation mechanism of SISI is not discussed and the further analysis such as the estimation of the SISI noise intensity is not provided.

For the purpose of modeling and analyzing the SISI in MIMO-IS-VLC system, a more specific system description will be given in Section 2. Then the generation mechanism of the stray light and the mathematical description is discussed. In Section 3, the mathematical expression of the signal-to-noise (SNR) and the bit error rate (BER) of MIMO-IS-VLC system with SISI is deduced and the corresponding simulation result is demonstrated and analyzed. The conclusion is obtained in Section 4.

2. THE SYSTEM MODEL

2.1. System Description

The block diagram of MIMO-IS-VLC system is shown in Fig.2. Firstly, a frame of serial input data is converted to the parallel data and drives a \( n \times n \) LED array by OOK modulation scheme. According to the given protocol, each digital signal channel controls a specific LED on the array and maintains independence with each other.

Assuming that \( P_{LED} \) is the rated optical power of LEDs and \( s_i(t) \) is the input digital signal of the \( i \) channel, there is:

\[
P_i(t) = \begin{cases} 
P_{LED}, & s_i(t) = 1 \\
0, & s_i(t) = 0 \end{cases}
\]

(1)

Where \( 1 \leq i \leq n \times n \), \( P_i(t) \) is the \( i \) channel’s LED transmitting optical power.

Secondly a high speed CCD or CMOS device with lens captures the picture of the LED array and transfers it to be processed. The image processing algorithm segments the picture and every single LED channel will be analyzed individually. Then the LED optical signal is demodulated to digital signal and a \( n \times n \) data matrix is generated.

At last, after the parallel-to-serial conversion, a frame of the transmitted serial data is obtained.

2.2. Distribution model of the stray light

The spatial inter-symbol interference of the MIMO-IS-VLC system is mainly caused by the stray light. The stray light can be considered as a additively background noise component to the system. There are two main sources for the stray light: One is the external light such as the sunlight, the indoor illumination light and the atmospheric diffusion light. It is considered as a constant background light and the light intensity value can be expressed as \( K \). The other one is the irregular incident light of the imaging object. In the ideal condition, the incident light of the imaging object follows a certain angle. However, a part of imaging light reach the image sensor at an uncertain angle and lead to the disorder of imaging process. In particular, there are three reasons account for the irregular incidence:

- The diffraction caused by the grating edge and the grating slit takes place.
- The refraction takes place because the camera lens is contaminated and the surface of the optical components such as gratings, prisms, lenses, filters and other is not flat.
- The reflection takes place on the inner wall of the tube.

For the image sensor, the incident angle of the stray light is stochastic but its spatial distribution has characteristic. According to [8], the spatial distribution of stray light can be
The Imaging Plane

Fig. 3: The optical path of the imaging light in MIMO-IS-VLC system. ① Diffraction light at the edge of the grating. ② Refraction light from the lens. ③ Reflection light on the inner wall of the lens’ tube.

described as the Kirk model. Establish the rectangular coordinate system based on one of four corners’ LED and set \((x_0, y_0)\) as the original point as is shown in Fig.3. Then the point spread function (PSF) of the stray light is written as

\[
s(r_i) = \frac{1}{\sigma \sqrt{2\pi}} \exp \left(-\frac{r_i^2}{2\sigma^2}\right) \tag{2}
\]

Where \(r_i = \sqrt{x_i^2 + y_i^2}\) is the distance from the point \((x_i, y_i)\) to the original point. \(\sigma\) is the intensity coefficient of the stray light distribution. Assuming \(P(x_0, y_0)\) is the light intensity of the original point. Thus, to a certain area based on the center coordinate of \((x_i, y_i)\), the stray light intensity is written as

\[
S(x_i, y_i) = K + \iint P(x_0, y_0) \cdot s(x-x_i, y-y_i) \, dx \, dy \tag{3}
\]

When calculating the influence of stray light in the imaging system, the exposure time \(t_e\) ought to be considered. The total exposure value \(P_v\) is the time integral of the instantaneous light intensity \(P\) and is expressed as \(P_v = \int P \, dt\).

Because the stray light distribution function is not a time correlation function, the total exposure energy can be simply written as \(P_v = P \cdot t_e\).

Fig.4 shows imaging results of three different lens and the fitting curve of the stray light intensity distribution. In the experiment, the LED and the lens of image sensor is kept parallel as possible to eliminate the aberrations. Analyze the pixels on image’s transversal line. For the purpose of increasing accuracy, select the transversal line from different angles and averaging. As is shown in Fig.4, he horizontal coordinate is the pixels position from 0 to 450 and the vertical coordinate is the normalized gray value. A industrial CMOS camera is utilized in the experiment. The 3W white LED is at rated illumination status. The three lenses are from different manufacturers with the same parameter. The diameter of the three lenses is 40mm. In the experiment, the focal length of lenses is set as 20mm and the aperture is F1.6. The exposure time \(t_e\) is 10ms and the distance from the LED to the image sensor is 1m. The pixel size of the original image is 450 × 450.

It can be seen that under the same photograph condition, three lenses show difference on the imaging performance.

To evaluate the degree of concentration of the light intensity distribution, set 0.2 as a threshold of the normalized gray value and define the range that the gray value of the pixels exceed 0.2. The narrower range the pixels distribution is, the more concentrated the light intensity distribution will be. In Fig.4(a), the range of horizontal coordinate is (126, 328) that the normalized gray-value is higher than 0.2. It means that 80% of the pixels formed by the incident light is concentrated on around 45% pixels of the whole image. However, the range is (101, 353) and the proportion is around 56% in Fig.4(b) while in Fig.4c the range is (107, 359) and the proportion is 56% as well. It demonstrates that imaging light of the LED is more concentrative in Fig.4(a) than the other two.

With the purpose of obtaining the parameter \(\sigma\) in equation (2), the least square method is used to get the fitting curve of the light intensity distribution. As a result, the obtained \(\sigma\) of the curve from Fig.4(a) is 86.2 while it is 95.1 of the Fig.4(b) and 90.2 of the Fig.4(c) (The adjusted R-square value of the fitting curve in three images is 0.984, 0.980 and 0.985 correspondingly). A smaller \(\sigma\) value of the equation (2) leads to a narrower distribution range of the stray light, thus it is proved that the imaging pixel of the LED is more concentrative in Fig.4(a). It also come to the conclusion that under
the same condition, the lens with a smaller $\sigma$ value of the stray light PSF has a higher imaging performance because the imaging light is more concentrative and the imaging result suffers less from the stray light.

### 2.3. Channel model

Assuming $S(t) = (s_1(t), ..., s_i(t), ..., s_{n \times n}(t))$, $(1 \leq i \leq n \times n)$ is a frame of the original serial digital data and according to the equation (1), the output optical signal of the LED array is $P = (P_1(t), ..., P_i(t), ..., P_{n \times n}(t))^T$. Therefore, the received current signal of the image sensor $I = (I_1(t), ..., I_i(t), ..., I_{n \times n}(t))^T$ can be written as

$$I = \xi H \times P + N$$

where $\xi$ is the photoelectric conversion coefficient of the image sensor, $H$ is the channel gain matrix of $n \times n$ order, $N = (\delta_1, ..., \delta_{n \times n})^T$ is the system noise matrix of $n \times n$ order.

Considering the channel as a line of sight (LOS) link, the MIMO channel gain matrix is composed of the link gain $G$ and the SISI gain $S$ as well as $H = G + S$. Both of them is $n \times n$ order. In addition, the link gain matrix $G$ is a diagonal matrix and the SISI gain matrix is a matrix that the diagonal elements is zero.

Fig.3 shows a geometric graph of the MIMO-IS-VLC system. The focal length of lens is $f$, $u$ is the object distance and $v$ is the image distance. $d$ is the spacing distance of two adjacent LEDs in the array. On the basic of the imaging system, there is $u > 2f$ and $f < v < 2f$ so that a real and miniature image of the object is acquired on the imaging plane. The LED light radiation follows the Lambertian model. Thus the diagonal elements of $G$ is written as [9]

$$g_{ii} = \left\{\begin{array}{ll} \frac{A}{\pi^2} R(\phi) \cdot \cos(\psi_i), & 0 \leq \psi_i \leq \frac{\psi_c}{2} \\ 0, & \psi_i > \frac{\psi_c}{2} \end{array}\right.$$  (5)

where $R(\phi) = [(m + 1)/2\pi] \cos^m \phi$, $\phi$ is the LED irradiance angle. $\psi_i$ is the incident angle of $i$th LED, $m = -ln2/ln(cos^2\psi_c)$, $m$ is the order of the Lambertian radiation. $\psi_c/2$ is the emission angle at half power of the LED. $\psi_c$ is the angle of view of the lens.

Establishing the rectangular coordinate system based on one of the LED in the array, the distance of $i$th and $j$th LED can be expressed as $r_{ij} = d \cdot \sqrt{|x_i - x_j|^2 + |y_i - y_j|^2}$. Under the condition that the object distance $u$ is far more larger than the image distance $v$, there is $v \approx f$. Hence, the spacing distance of two adjacent LEDs in the imaging plane can be expressed as

$$r_{ij}' = \frac{f \cdot r_{ij}}{u}$$  (6)

From equation (1), the off-diagonal elements of $S$ is written as

$$s_{ij} = \iint P(x_j, y_j) \cdot s(r_{ij}') \, dx \, dy$$  (7)

Where $P(x_j, y_j) = g_{jj} \cdot P_j(t)$. The additive noise in the MIMO-IS VLC system includes the constant stray light noise, the thermal noise, the shot noise and the readout noise. Since the noise of the latter three is far less than the constant stray light noise, the additive noise in system of the $i$th channel is expressed as $\delta_i = K$. As a consequence, the received current signal of $i$th channel is obtained as

$$I_i(t) = \xi e \left\{ g_{ii} \cdot P_i(t) + \sum_{j=1, j \neq i}^{n \times n} s_{ij} \cdot P_j(t) + K \right\}$$  (8)

### 3. THE SIMULATION AND ANALYSIS

#### 3.1. The SNR and BER

Supposed that the optical active area of the LED is circular and the radius is $Ra$, the projective radius of the LED optical active area on the imaging plane can be given from the equation (6) as $Ra' = \frac{f \cdot Ra}{u}$. Combined with the equation (2)(7)(8), the received SISI noise of the system $(0 \leq \psi_i \leq \psi_c)$ is obtained as

$$I_{SISI} = \xi e \left\{ \sum_{i,j=1}^{n \times n} \int_{0}^{Ra'} \frac{g_{jj} \cdot P_j(t)}{\sigma \sqrt{2\pi}} \exp \left( -\frac{r_{ij}'^2}{2\sigma^2} \right) \, dr \right\}$$  (9)

The SISI noise component is an additive noise to the system. The equation (9) indicates that SISI noise component mainly depends on the spacing distance of two adjacent LEDs in the imaging plane $r_{ij}'$. In other words, three major factors, the communication distance $u$, the lens' focal length $f$ and the spacing distance of two adjacent LEDs $r_{ij}$ in the LED array influence the system BER performance jointly according to the equation(6). As a result, with given communication distance and lens, the probability of received SISI noise intensity is the function of $r_{ij}'$. The average expectation value of $r_{ij}'$ can be calculated by permutation and combination theory. Under the circumstance that $P[s(t) = 0] = P[s(t) = 1] = \frac{1}{2}$, the average expectation intensity of SISI noise is able to be estimated. For a $n \times n$ channels MIMO-IS-VLC system, $r_{ij}'$ is integer times of the LED spacing distance $d$ or not the integer times. Based on the permutation and combination theory, the average expectation value of $r_{ij}'$ is calculated as

$$r'(n, q) = \left\{\begin{array}{ll} C_2^q C_{n-q}^1 \frac{q!d}{C_n^2} \frac{u}{u}, & r' = qd \\ C_2^q C_{n-q}^1 \sum_{p=1}^{t} \frac{C_1^{n-p}}{C_n^2} \sqrt{q^2 + p^2d^2} \frac{u}{u}, & r' \neq qd \end{array}\right.$$  (10)

Where $q, p \in N$, and $0 < q \leq n$. Combined with equation(9), the total expectation received SISI optical in-
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In the simulation, the LED array size is

\[ I_{SISIN} = G \sum_{q=1}^{n-1} \sum_{p=1}^{q} \left[ 2n(n-q) \exp \left( -\frac{(qd)^2}{2\sigma_n^2} \right) ight] + 4(n-q)(n-p) \exp \left( -\frac{(q^2 + p^2)d^2f^2}{2\sigma_t^2u^2} \right) \]  \hspace{1cm} (11)

Where \( G = \frac{\xi g_{11} \cdot P_{LED} \cdot t_e \cdot \pi Ra^2}{\sigma \sqrt{2\pi}} \). The equation (11) is a summation of the total expectation \( I_{SISIN}[^r(n,q)] \). Therefore, the signal noise ratio (SNR) of the receiving terminal can be calculated as

\[ R_{SN} = \sum_{i=1}^{\infty} \frac{[GP_i(t)]^2}{I_{SISIN}^2 + (\xi K)^2}. \]

The MIMO-IS-VLC system can be considered as a Unipolar On-Off key modulation system. From the paper [10] it is known that the ISC system’s noise distribution complies with Gaussian distribution and signal dependence. Assuming that the constant stray light component \( K \) is equal to the background noise light and the one-dimensional probability density of the signal sampling value is a Gaussian random variable, the one-dimensional probability density when transmitting signal ‘1’ is expressed as

\[ f_1(x) = \frac{1}{\sigma_n \sqrt{2\pi}} \exp\left\{ -\frac{(x - P_{LED})^2}{2\sigma_n^2} \right\} \]  \hspace{1cm} (12)

When transmitting signal ‘0’, the one-dimensional probability density is expressed as

\[ f_0(x) = \frac{1}{\sigma_b \sqrt{2\pi}} \exp\left\{ -\frac{(x - \sigma_b - \sigma_{SISI})^2}{2\sigma_b^2} \right\} \]  \hspace{1cm} (13)

Where \( \sigma_{SISI} \) and \( \sigma_b \) is the variance of SISI noise and background noise’s sampling value correspondingly. There is \( \sigma_{SISI}^2 = I_{SISI}^2, \sigma_b^2 = (\xi K)^2 \) and \( \sigma_n = \sqrt{\sigma_{SISI}^2 + \sigma_b^2} \). Thus, with given detection threshold \( Th \) \((0 < Th < P_{LED})\), the bit error rate (BER) of the system can be obtained as

\[ P_e = \frac{1}{2} \left[ \sigma f_e \left( T - \frac{1}{\sqrt{2}} \right) + \sigma f \left( T - \sqrt{R_{SN}} \right) \right] \]  \hspace{1cm} (14)

Where \( T \) is normalized detection threshold and \( T = \frac{Th}{\sigma_n \sqrt{2}} \).

The optimal detection threshold is able to be defined by finding the extreme value of \( \frac{\partial P_e}{\partial T} = 0 \). As a result, the optimal detection threshold is obtained as

\[ Th = \frac{GP_{LED} + I_{SISI} + \xi K}{2} \]  \hspace{1cm} (15)

3.2. The Simulation Result

In the simulation, the LED array size is \( 6 \times 6 \). Fig. 5 shows the simulation results of the system BER with different communication distances. The curve shows the same trend that the BER increases sharply when the system communication distance is increased to a critical distance. The other trend is that the critical distance shifted to right when the LED spacing distance \( d \) or the focal length \( f \) increases. The larger \( d \) the LED array has or the the larger \( f \) the lens have, the longer communication distance the system can be achieved. From the equation (6) and the equation (10), the increases of the communication distance leads to the decreases of \( r_1 \), which will significantly increase the system’s SISI noise. It means that the critical communication distance of the MIMO-IS-VLC system is mainly affected by the SISI noise intensity.

![Fig. 5: BER performance of different communication distances.](image)

It is known from section 2 that the system stray light produces the SISI noise and the background noise component in the form of additive noise. The additive noise results in the degrade of the system BER performance. Generally, the background noise component can be calculated so that the fixed detection threshold is \( Th = \frac{GP_{LED} + \xi K}{2} \).

![Fig. 6: The impact of SISI and detection threshold on BER performance.](image)

The ideal system BER performance with fixed detection threshold is demonstrated in the Fig. 6. It is shown that in
the certain communication distance, the SISI noise reduces the BER performance remarkably. In order to define the optimal detection threshold, the distribution coefficient $\sigma$ of the stray light PSF can be estimated by fitting analysis tool so that the average SISI noise intensity is able to be obtained as well. Hence, the optimal detection threshold can be calculated. In Fig.6, the simulation result indicate that compared with the fixed detection threshold condition, the BER curve with optimal detection threshold moves closer to the ideal BER performance curve. In other words, by means of estimating the SISI noise intensity and adaptively adjusting the detection threshold, the system BER performance improve significantly.

The Fig.7 shows that there exists a optimal normalized detection threshold that make the system achieve the best BER performance. In the MIMO-IS-VLC system, the background noise mainly comes from the ambient light while the SISI noise is related to the received LED light power $P_{LED}^{d}$, the spacing distance $d$ on the LED array and the lens’ focal length. As a result, the background noise component and the SISI noise component are independent. The simulation result shows that the $\sigma_b$ influence the detection threshold value. If the $\sigma_b$ increases from 9.5dB to 12dB, the normalized detection threshold value increases approximately 0.05 when the system SNR is 20dB. In addition, it is indicated that along with the decreasing of the system SNR, the optimal normalized detection threshold increases.

4. CONCLUSIONS

In this paper, a MIMO image sensors based visible light communication is designed and researched from the perspective of optical communication system. The formation mechanism of the stray light in the imaging system and the influence of the spatial inter-symbol interference is analyzed. The stray light, caused by the incident light’s diffraction, refraction and reflection, produces the spatial inter-symbol interference. The SISI noise intensity is related to the received LED light power $P_{LED}^{d}$, the spacing distance $d$ on the LED array and the lens’ focal length $f$. According to the imaging laws, the SISI noise intensity is directly correlated to the average expectation value of the spacing distance $r_{ij}$, which is the distance of two adjacent LEDs in the imaging plane. Consequently, the SISI noise intensity is able to be estimated with the given $d$, $f$ and the certain communication distance $u$. The simulation result and analysis is given.

Furthermore, an adaptive threshold detection method is introduced and the performance is analyzed. The SISI noise impacts the system BER performance in the form of additive noise. By means of estimating the SISI noise power, the optimal detection threshold can be obtain and the system BER performance enhances significantly. The simulation result and analysis indicates that $\frac{\sigma_b}{\sigma_{SISI}}$, the ratio of the background noise intensity and the SISI noise intensity, determines the normalized optimal detection threshold value. In summary, the modeling and analysis of SISI is significant to improve the MIMO-IS-VLC system performance. In the future work, the optical power to pixels intensity conversion will be taken into consideration so that the optimal image-binary threshold can be applied in the practical application to improve the system performance.

5. REFERENCES


SECRECY ENERGY EFFICIENCY OPTIMIZATION FOR ARTIFICIAL NOISE AIDED PHYSICAL-LAYER SECURITY IN COGNITIVE RADIO NETWORKS

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ABSTRACT

In this paper, the artificial noise (AN) is used to improve the secrecy energy efficiency (SEE) for underlay cognitive radio networks (CRNs). A joint zero-forcing (ZF) beamforming and power allocation problem is formulated to maximize the SEE under the constraints of the total transmit power, the secrecy rate (SR) of cognitive user (CU) and the quality-of-service (QoS) requirement of primary user (PU). As a consequence, we firstly transform the formulated non-convex optimization problem in fractional form into an equivalent one in subtractive form, and use the difference of two-convex functions (D.C.) approximation method to obtain an equivalent convex problem. Then, a power allocation algorithm is presented to obtain the optimal solution. Simulation results show the advantage of the proposed scheme.

Keywords— Power allocation, artificial noise, energy efficiency, secure communication, cognitive radio networks

1. INTRODUCTION

Recently, physical-layer security (PLS) [1] has attracted increasing attention, especially in cellular cognitive radio networks [2]. Under this situation, extensive research efforts have been devoted to improving the PLS of wireless communication by employing beamforming [3], artificial noise (AN) [4], cooperative jammers [5], and so on. For example, a scheme by jointly utilizing multiple antennas and cooperative jammers was investigated in [6] to maximize the secrecy rate. In [7], the authors injected the AN at the transmitter to degrade eavesdropping channel and exploited spatial degrees of freedom in massive multiple-input multiple-output (MIMO) systems to enhance the PLS.

Also, there is an increasing interest in energy efficiency (EE), which is regarded as an effective metric to balance the spectral efficiency (SE) and power consumption especially in the condition of the tremendous demand of high SE and low power consumption [8]. In [9], a resource allocation algorithm for EE communication was studied in an orthogonal frequency division multiple access (OFDMA) system. An uplink energy minimization problem was investigated with non-orthogonal multiple access for machine-to-machine communications in [10]. Besides, the authors of [11] studied a power allocation problem to maximize the EE under the constraints of total power and sum rate in amplify-and-forward-based energy harvesting two-way relaying systems.

Generally, the aforementioned work is either the case only concerned about secrecy rate (SR) or the case focused on EE. In order to achieve a better trade-off between the SR and EE, the secrecy energy efficiency (SEE), which is defined as the ratio of the SR to the total power consumption, was introduced in [12]. Motivated by this, this paper presents an SEE maximization (SEEM) scheme with the constraints of a total transmit power, the SR of cognitive user (CU) and the quality-of-service (QoS) requirement of primary user (PU). A two-tier iterative power allocation algorithm is adopted to solve our formulated SEEM problem, where the outer iterative mainly focuses on converting the formulated fractional problem into a subtractive one which is then transformed into a convex problem with the help of difference of two-convex functions (D.C.) approximation method in the inner iterative. Finally, the advantage of the proposed SEEM scheme is illustrated by numerical results.

The reminder of this paper is organized as follows. In Section II, we present the system model of secure communications in CRNs and formulate an SEEM problem to maximize the SEE of cognitive transmissions. Next, Section III presents an optimal solution to the formulated SEEM problem as well as the corresponding iterative algorithm, followed by Section IV, where simulation results are given to show the advantage of proposed SEEM scheme. Finally, some concluding remarks are provided in Section V.

2. SYSTEM MODEL AND PROBLEM FORMULATION

As shown in Fig. 1, we consider an underlay cognitive radio network (CRN) where a cognitive base station (CBS) with \( N \) antennas transmits confidential message to a single-antenna CU in the presence of a eavesdropper (ED) with a single antenna. The CBS uses the licensed spectrum that is unoccupied by a PU to transmit confidential message. To improve the PLS of cognitive transmissions, AN signals are used to confuse the ED.

Thus, the transmit signal of CBS can be expressed as \( \mathbf{x} = \mathbf{v}_c x_c + \mathbf{v}_z z \), where \( x_c \) is the confidential signal, satisfying \( E(|x_c|^2) = P_c \), \( z \) is the AN signal with \( E(|z|^2) = P_z \), \( \mathbf{v}_c \) and \( \mathbf{v}_z \) are the beamforming (BF) weight vectors of the con-
Figure 1. System model for secure communication in CRN.

Confidential and AN signal, respectively. Denote by $h_c \in \mathbb{C}^{N \times 1}$, $h_p \in \mathbb{C}^{N \times 1}$ and $h_e \in \mathbb{C}^{N \times 1}$ the fading coefficients of the channel between CBS to CU, PU and ED, respectively. The received signals at the PU, CU and ED can be expressed as

$$y_p = h_p^H v_c x_c + h_p^H v_z z + n_p,$$

$$y_c = h_c^H v_c x_c + h_c^H v_z z + n_c,$$

$$y_e = h_e^H v_c x_c + h_e^H v_z z + n_e,$$

where $n_p \sim \mathcal{CN}(0, \sigma_p^2)$, $n_c \sim \mathcal{CN}(0, \sigma_c^2)$ and $n_e \sim \mathcal{CN}(0, \sigma_e^2)$ denote additive white Gaussian noises (AWGN) at PU, CU and ED, respectively, with the same variance $\sigma_p^2 = \sigma_c^2 = \sigma_e^2 = \Delta f N_0$, where $\Delta f$ and $N_0$ are the system bandwidth and single-sided noise spectral density, respectively.

Based on (1)-(3), the output signal-to-interference-plus-noise ratios (SINRs) at PU, CU and ED can be, respectively, written as

$$\gamma_p = \frac{|h_p^H v_c|^2 P_c}{|h_p^H v_z|^2 P_p + \sigma_p^2},$$

$$\gamma_c = \frac{|h_c^H v_c|^2 P_c}{|h_c^H v_z|^2 P_c + \sigma_c^2},$$

$$\gamma_e = \frac{|h_e^H v_c|^2 P_c}{|h_e^H v_z|^2 P_c + \sigma_e^2}.$$

According to (5) and (6), the available SR of the considered CRN can be obtained as [13]

$$R_{sec}(P_c, P_z) = \left[ \log_2 \left( \frac{1 + \gamma_c}{1 + \gamma_e} \right) \right]^+ = \log_2 \left[ \frac{1 + \frac{|h_p^H v_c|^2 P_c}{|h_p^H v_z|^2 P_p + \sigma_p^2}}{1 + \frac{|h_c^H v_c|^2 P_c}{|h_c^H v_z|^2 P_c + \sigma_c^2}} \right]^+, \tag{7}$$

where $[ ]^+$ is a function such that $[x]^+ = x$ if $x > 0$ and $[x]^+ = 0$ if $x \leq 0$.

Besides, the total power consumption at the CBS is given by [14]

$$P_{tot}(P_c, P_z) = P_c + P_z + P_b, \tag{8}$$

where $P_b$ is a constant basic power consumed by CBS. The SEE of interest in this paper can be represented as [15]

$$\eta_{SEE} = \frac{R_{sec}(P_c, P_z)}{P_log(P_c, P_z)}, \tag{9}$$

which evaluates the number of available secret bits transferred from the transmitter to receiver per unit energy and bandwidth.

We formulate an optimization problem to maximize SEE of the cognitive transmission under the constraints of the total transmit power, the SR of CU and the QoS requirement of PU, namely,

$$\max_{P_c, P_z} \eta_{SEE} = \log_2(1 + \gamma_c) - \log_2(1 + \gamma_e) \tag{10a}$$

$$\text{s.t.} \quad \gamma_p \geq \gamma_p^g, \quad \log_2(1 + \gamma_c) - \log_2(1 + \gamma_e) \geq 0 \tag{10b}$$

$$0 \leq P_c + P_z \leq P_{max} \text{CBS}, \tag{10c}$$

where $\gamma_p^g$ in (10b) denotes the minimal acceptable SINR for the PU, (10c) specifies the minimum SR requirement, and $P_{max} \text{CBS}$ in (10d) means a limit on the amount of the transmit power for the CBS.

3. OPTIMAL SOLUTION TO SEE MAXIMIZATION

In this section, we first design the normalized BF vector $v_c$ in the null space of $h_p$, namely $h_p^H v_c = 0$, which ensures that all confidential signals would not interfere with PU, so $v_c$ is given by [16],

$$v_c = \frac{(I_N - h_p^H h_p)^{-1} h_p}{\| (I_N - h_p^H h_p)^{-1} h_p \|_F}, \tag{11}$$

where $h_p = h_p (h_p^H h_p)^{-1} h_p^H$ is the orthogonal projection matrix of $h_p$, $I_N$ the $N \times N$ identity matrix, and $\| \cdot \|$ the Frobenius norm of a matrix or Euclidean norm of a vector.

Meanwhile, $v_z$ is designed at the null space of $h_c$ and $h_e$ to guarantee that the artificial noise only degrades the channel condition of eavesdropper. Then, a power allocation algorithm is proposed to find the optimal solution of $P_c$ and $P_z$. By substituting (11) into (10), we can obtain

$$\max_{P_c, P_z} \eta_{SEE} = \log_2(1 + \frac{eP_c}{dP_c + \sigma_c^2}) - \log_2(1 + \frac{eP_z}{fP_z + \sigma_e^2}), \tag{12a}$$

$$\text{s.t.} \quad \log_2(1 + \frac{eP_c}{dP_c + \sigma_c^2}) - \log_2(1 + \frac{eP_z}{fP_z + \sigma_e^2}) \geq 0 \tag{12b}$$

$$0 \leq P_c + P_z \leq P_{max} \text{CBS}, \tag{12c}$$

where $a = |h_p^H v_c|^2$, $b = |h_p^H v_z|^2$, $c = |h_c^H v_c|^2$, $d = |h_c^H v_z|^2$, $e = |h_e^H v_c|^2$ and $f = |h_e^H v_z|^2$.

Combining with the objective function (12a) and constraint conditions (12b)-(12c), we can readily show the non-convexity of (12) due to its fractional form and logarithmic function. It is thus challenging to solve a non-convex
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problem of (12). To this end, we design a two-tier power allocation iterative algorithm based on the following Theorem 1.

**Theorem 1** The optimization problem (12) and (13) are equivalent if and only if \( f(\eta_{\text{SEE}}) = 0 \).

\[
f(\eta_{\text{SEE}}) = \max_{P_c, P_z} \log_2(1 + \frac{eP_c}{dP_c + \sigma_z^2}) - \log_2(1 + \frac{eP_z}{fP_z + \sigma_z^2}) - \eta_{\text{SEE}}(P_c + P_z + P_b) \]

\[
s.t. \quad \log_2(1 + \frac{eP_c}{dP_c + \sigma_z^2}) - \log_2(1 + \frac{eP_z}{fP_z + \sigma_z^2}) \geq 0 \quad (13b) \]

\[
0 \leq P_c + P_z \leq P_{\text{max}}^{\text{CBS}}. \quad (13c)
\]

**Proof 1** By comparing the problems (12) and (13), we can note that they have the same constraints, which means the set of feasible solutions to (12) is also applied to (13). Firstly, we denote \((\bar{P}_c, \bar{P}_z)\) as the optimal solution of problem (12). The maximum SEE \(\eta_{\text{SEE}}\) can be obtained by using the following formula.

\[
\eta_{\text{SEE}} = \max_{P_c, P_z} \log_2(1 + \gamma_c) - \log_2(1 + \gamma_c) = \log_2(1 + \gamma_c) - \log_2(1 + \gamma_c) = \frac{\log_2(1 + \gamma_c)}{P_c + P_z + P_b} \]

\[
\geq \log_2(1 + \gamma_c) - \log_2(1 + \gamma_c) - \eta_{\text{SEE}}(P_c + P_z + P_b), \quad (14)
\]

where \(\gamma_c = \frac{eP_c}{dP_z + \sigma_z^2}\) and \(\gamma_c = \frac{eP_z}{fP_z + \sigma_z^2}\). Since \(P_c + P_z + P_b > 0\), we can further transform (14) into the following form, i.e.,

\[
\log_2(1 + \gamma_c) - \log_2(1 + \gamma_c) - \eta_{\text{SEE}}(P_c + P_z + P_b)
\]

\[
= 0
\]

\[
\geq \log_2(1 + \gamma_c) - \log_2(1 + \gamma_c) - \eta_{\text{SEE}}(P_c + P_z + P_b), \quad (15)
\]

After some simple manipulations, we can obtain the following inequality:

\[
\log_2(1 + \gamma_c) - \log_2(1 + \gamma_c) = \frac{\eta_{\text{SEE}}}{P_c + P_z + P_b} \quad (17)
\]

from which one can observe that \((\bar{P}_c, \bar{P}_z)\) is equal to \((\bar{P}_c, \bar{P}_z)\) if and only if \(f(\eta_{\text{SEE}}) = 0\).

Letting

\[
f_1(P_c, P_z, \eta_{\text{SEE}}) = \log_2(1 + \frac{eP_c}{\sigma_z^2}) + \log_2(fP_c + \sigma_z^2)
\]

\[
- \eta_{\text{SEE}}(P_c + P_z + P_b), \quad (18)
\]

and

\[
f_2(P_c, P_z) = \log_2(eP_c + fP_z + \sigma_z^2), \quad (19)
\]

we can further rewrite (13) as

\[
\max_{P_c, P_z} f_1(P_c, P_z, \eta_{\text{SEE}}) - f_2(P_c, P_z) \quad (20a)
\]

\[
s.t. \quad P_z \geq \frac{eP_z^2 - \eta_{\text{SEE}} c_f^2}{c_f} \quad (20b)
\]

\[
0 \leq P_c + P_z \leq P_{\text{max}}^{\text{CBS}}. \quad (20c)
\]

However, the problem (20) is still non-convex, due to the fact that the logarithmic function (19) is concave.

Next, we apply the D.C. approximation method [17] to approximate \(f_2(P_c, P_z)\) into a linear one. Assuming \((\bar{P}_c, \bar{P}_z)\) is a feasible solution of \(f_2(P_c, P_z)\), the first-order Taylor series expansion of \(f_2(P_c, P_z)\) is given by

\[
f_2(P_c, P_z) \approx f_2(\bar{P}_c, \bar{P}_z) + \frac{e(P_c - \bar{P}_c) + f(P_z - \bar{P}_z)}{(eP_c + fP_z + \sigma_z^2) \ln 2} \quad (21)
\]

By substituting (21) into the objective function (20a) , we can obtain the optimal solution to problem (20) through the following iterative procedure, i.e.

\[
(T_{c, z}^{i+1}, \bar{T}_{c, z}^{i+1}) = \max_{P_c, P_z} \left\{ f_1(P_c, P_z, \eta_{\text{SEE}}) - f_2(T_{c, z}^{i+1}, \bar{T}_{c, z}^{i+1}) \right\}
\]

\[
- \frac{e(P_c - \bar{T}_{c}^{i}) + f(P_z - \bar{T}_{z}^{i})}{(eT_{c}^{i} + fT_{z}^{i} + \sigma_z^2) \ln 2} \quad (22a)
\]

\[
s.t. \quad P_z \geq \frac{eP_z^2 - \eta_{\text{SEE}} c_f^2}{c_f} \quad (22b)
\]

\[
0 \leq P_c + P_z \leq P_{\text{max}}^{\text{CBS}}, \quad (22c)
\]

where \((T_{c, z}^{i+1}, \bar{T}_{c, z}^{i+1})\) and \((T_{c, z}^{i}, \bar{T}_{c, z}^{i})\) are the optimal solutions in (22) at iterations \(i\) and \(i + 1\), respectively. Then, we can
obtain
\[
\begin{align*}
& f_1(T^{i+1}_c, T^{i+1}_z, \eta_{\text{SEE}}) - f_2(T^{i+1}_c, T^{i+1}_z) \\
& \approx f_1(T^{i+1}_c, T^{i+1}_z, \eta_{\text{SEE}}) - f_2(T^{i}_c, T^{i}_z) \\
& = \max_{P_c, P_z} \left\{ f_1(P_c, P_z, \eta_{\text{SEE}}) - f_2(T^{i}_c, T^{i}_z) \right\} \\
& \geq f_1(T^{i}_c, T^{i}_z, \eta_{\text{SEE}}) - f_2(T^{i}_c, T^{i}_z).
\end{align*}
\] (23)

From (23), the proposed iterative procedure is monotonically non-decreasing, which ensures the achievement of the optimal solution. Now, it is clear that the problem (22) is convex due to the fact that the objective function (22a) is concave and all constraints (22b)-(22c) are linear. Therefore, it is simple and straightforward to obtain the optimal solution to (22) by using existing convex software tool, e.g., CVX [18].

Algorithm 1: The proposed iterative algorithm to solve problem (12).

**Function Outer Iteration**

Step 1: Initialize the maximum number of iterations \(i_{\text{max}}\) and the maximum tolerance \(\varepsilon\).
Step 2: Set maximum SEE \(\eta_{\text{SEE}} = 0\) and iteration index \(i = 0\).
Step 3: Call **Function Inner Iteration** with \(\eta_{\text{SEE}}\) to obtain the optimal solution \((P^i_c, P^i_z)\).
Step 4: Update \(\eta_{\text{SEE}} = \frac{\log_e\left(1 + \frac{\sum_{i=1}^{i_{\text{max}}} \sigma_z P^i_c}{P^i_c + P^i_z + P_b}\right)}{P^i_c + P^i_z + P_b}\).
Step 5: Set \(i = i + 1\).
Step 6: if \(\left|\eta_{\text{SEE}} - \eta_{\text{SEE}}^i\right| \geq \varepsilon \) or \(i \leq i_{\text{max}}\)
Step 7: goto Step 3.
Step 8: end if
Step 9: return \(P^i_c\) and \(P^i_z\).
Step 10: Obtain the optimal solution \(P^*_c = P^i_c\) and \(P^*_z = P^i_z\) for problem (12).

**Function Inner Iteration (\(\eta_{\text{SEE}}\))**

Step 11: Initialize \((\bar{T}^0_c, \bar{T}^0_z) = (0, 0)\) and \(f^0 = 0\).
Step 12: Set \(i = 0\).
Step 13: Find the optimal solution \((P^*_c, P^*_z)\) of (22) for given \((\bar{T}^i_c, \bar{T}^i_z)\) and \(\eta_{\text{SEE}}\) by using CVX.
Step 14: Compute \(f^{i+1} = f_1(P^{i+1}_c, P^{i+1}_z, \eta_{\text{SEE}}) - f_2(P^{i+1}_c, P^{i+1}_z)\).
Step 15: Set \(i = i + 1\).
Step 16: if \(\left|f^i - f^{i-1}\right| \geq \varepsilon \) or \(i \leq i_{\text{max}}\)
Step 18: end if
Step 19: return \(P_c\) and \(P_z\).

As shown in Algorithm 1, a two-tier iterative power allocation algorithm is provided to obtain the optimal power allocation for the considered SEE problem. First of all, we initialize the maximum SEE \(\eta_{\text{SEE}} = 0\). Based on the given \(\eta_{\text{SEE}}\) at the outer tier, D.C. approximation method is applied to solve (22) for achieving the optimal solution \((P_c, P_z)\) at the inner tier, where the value of \(f(\eta_{\text{SEE}})\) is updated for the next outer iteration. Meanwhile, \(\eta_{\text{SEE}}\) is found to satisfy \(f(\eta_{\text{SEE}}) = 0\) by using the Dinkelbach’s method [19] at each iteration. When all the updated data nearly keeps unchanged or the number of iterations approaches to the maximization, the iteration stops; otherwise, another round of iteration starts.

4. SIMULATION RESULTS

In this section, we evaluate the performance of our proposed SEE scheme through simulations. Simulation parameters can be found in Table I. All simulation results were averaged over 1000 random channel realizations.

<table>
<thead>
<tr>
<th>Table I. System Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>Values</td>
</tr>
<tr>
<td>Path loss model, (\log_{10}(d'))</td>
<td>(-34.5 \sim -38\log_{10}(d[\text{m}]))</td>
</tr>
<tr>
<td>Corresponding distance, (d)</td>
<td>500m</td>
</tr>
<tr>
<td>Numbers of antennas, (N)</td>
<td>4</td>
</tr>
<tr>
<td>Bandwidth, (\Delta f)</td>
<td>10MHz</td>
</tr>
<tr>
<td>Noise spectral density, (N_0)</td>
<td>-174dBm/Hz</td>
</tr>
<tr>
<td>Basic power consumption of CBS, (P_b)</td>
<td>40dBm</td>
</tr>
<tr>
<td>Maximum iteration, (i_{\text{max}})</td>
<td>100</td>
</tr>
<tr>
<td>Convergence threshold, (\varepsilon)</td>
<td>(10^{-4})</td>
</tr>
</tbody>
</table>

Fig. 2 illustrates the SEE results of proposed SEE, SR maximization (SRM), and EE maximization (EEM) schemes versus the transmit power constraint \(P_{CBS}^{\text{max}}\). As \(P_{CBS}^{\text{max}}\) increases, the average SEE performance of proposed SEEEM and SRM schemes all improve. This means that both SEEEM and SRM schemes can achieve the maximum SEE with the full transmit power. Then, as \(P_{CBS}^{\text{max}}\) continues to increase after 40dBm, the average SEE performance of proposed SEEEM scheme approaches to a constant, while the SRM scheme begin to degrade in terms of its SEE performance since the power allocator would not consume more transmit power when the maximum SEE has received. By contrast, in order to achieve a higher SR, the SRM scheme will continue to allocate more transmit power, which will result in reducing the average SEE. In addition, as observed, the proposed SEEEM scheme significantly outperforms the EEM scheme in terms of the average secrecy energy efficiency.

Fig. 3 shows the SEE results of proposed SEEEM scheme with the optimal power allocation and simple equal power allocation strategies versus the transmit power constraint \(P_{CBS}^{\text{max}}\). As we seen, the proposed optimal power allocation significantly outperforms the equal power allocation in terms of average secrecy energy efficiency, due to the optimization of the power allocation factor.
5. CONCLUSION

In this paper, we studied the use of artificial noise to improve the physical-layer security of underlay CRNs. We first applied the ZF method to construct the downlink BF, and then formulated a power allocation algorithm to maximize the secrecy energy efficiency. To be specific, we transformed the formulated non-convex problem into a convex one by jointly applying the Dinkelbach’s method and D.C. approaches. Finally, numerical results showed that the proposed optimal power allocation scheme achieves higher SEE than the equal power allocation scheme. In addition, the proposed SEE maximization scheme can improve the SEE of CRN significantly compared with conventional SRM and EEM schemes.

6. ACKNOWLEDGMENT

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DATA CENTRIC TRUST EVALUATION AND PREDICTION FRAMEWORK FOR IOT

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ABSTRACT

Application of trust principals in internet of things (IoT) has allowed to provide more trustworthy services among the corresponding stakeholders. The most common method of assessing trust in IoT applications is to estimate trust level of the end entities (entity-centric) relative to the trustor. In these systems, trust level of the data is assumed to be the same as the trust level of the data source. However, most of the IoT based systems are data centric and operate in dynamic environments, which need immediate actions without waiting for a trust report from end entities. We address this challenge by extending our previous proposals on trust establishment for entities based on their reputation, experience and knowledge, to trust estimation of data items [1-3]. First, we present a hybrid trust framework for evaluating both data trust and entity trust, which will be enhanced as a standardization for future data driven society. The modules including data trust metric extraction, data trust aggregation, evaluation and prediction are elaborated inside the proposed framework. Finally, a possible design model is described to implement the proposed ideas.

Keywords— Data Trust, Knowledge, Reputation, Experience, Collaborative Filtering, Ensemble Learning.

1. INTRODUCTION

With the exponential growth of applications of internet of things (IoT) including social networks and e-commerce systems, users always surf in the universe of data, in which users often do not know about who they are interacting with and receiving data from. In such situations, the concept of trust plays an important role in managing these interactions and developing a trustworthy environment for all providers, users and the communities. However, generating trust relationships among users is extremely hard due to diversified nature of the users and how each entity understands trust. In traditional forms of trust management systems, trust is computed based on the relationship among end entities and behaviors in certain transactions as explained in [1], [2], [4-6]. Moreover, these systems use certain set of metrics like honesty, cooperativeness, community interest, reputation, certificate validity, length/frequency of the transaction and etc., to evaluate the trustworthiness of end entities and then to find trust relationship among the trustees and the trustors.

However, trust on end entities is not always prominent but the data receiving in form of various types. As an example, reliable, up to date and location sensitive information about weather, traffic, safety warnings and transport information from a smart city application are more important than the facts about entities who are actually generating them. The other common misinterpretation is that the assumption of having entity trust would guarantee data trust which is in fact indubitably different in various aspects like validity of data, timeliness and other properties unique to data which are often ignored in calculating trust for end entities. Further, information is the governing factor for any IoT systems and is generated from the data by combining it (data) with the context. Hence, if there is a data quality (DQ) problem, it would eventually lead to information quality (IQ) problem [22]. In other words, once the right data item is delivered to a desired entity at the precise time in a clear, useable and meaningful manner, IQ is guaranteed.

Therefore, it is important to address the challenge of establishing a data centric trust while preserving the traditional form of trust computation. To this end, firstly we define a set of dynamic factors, which essentially describe the DQ attributes and also metrics which define the knowledge, experience and reputation as in our previous work [2] and [1] to get the best of traditional means of trust computation. Then, we combine these attributes built on REK (Reputation, Experience and Knowledge) model described in [4] and [7]. After that, a technique which assesses the data centric trust for every user who is new to the system and who needs to access the data streams, is investigated based on the concepts of recommendation systems (RS). Here, we apply the RS due to its ability to generate approximate trust value for unknown records based on the available trustor–trustee relationships. Finally, we discuss a realistic design model of the proposed items.

From global standardization perspective, ITU-T Study Group (SG) 13 established the correspondence group on trust (CG-Trust) for preliminary work on trust standardization [8]. The CG-Trust developed a technical report containing definition, use cases, functional classification as well as challenges, technical issues related to trust including overall strategies of standardization for trust provisioning. As the lead group of trusted networking infrastructure, ITU-T SG13 successfully completed to publish the recommendation Y.3052 on trust in March 2017 [9]. Recently Question 16/13 “Knowledge-centric trustworthy networking and services” has focused on basic issues and key features on trust. Q16/13 is now mainly focusing on the development of core technical solutions for trust provisioning from ICT infrastructures and services. Q16/13 also plans to consider technology
deployment as well as new services and business aspects on trust-based networks and eco-platforms. Our proposals provide a strong suggestion to improve the current standardization activities on trust in ITU-T SG13 towards a hybrid model based on the concepts of entity trust and data trust. Among them, a trust relationship model described in this work elaborates some important factors when it comes to trust-based decision making that is a vital part of standardization process. On the other hand, trust evaluation via ensemble methods, which is by combining numerical, machine learning and recommendation algorithms, provides robust perception about trust compared to traditional ones. Let us discuss such a model based on the social trust metrics and trust-based data prediction. A possible implementation scenario is explained in Section 5 and Section 6 concludes the paper and outlines our future work.

2. RELATED WORK

Marsh proposed "Formalizing trust as a computational concept" [10] and argued that trust is the degree of uncertainty and optimism regarding an outcome. He further explains a trust model based on three trust metrics, direct trust, trust based on experience and the situational trust. Even though the direct trust measurements are the most reliable way of assessing trust, when it comes to applications like social networking, indirect measurements are more prominent due to collaborative behavior of the users. In this sense, [11], [12] and [2] discuss trust assessment models based on indirect trust metrics like reputation and recommendation. Further, there are situations when both direct and indirect trust information are not available. In such situation, "stereo-trust" [13] will be appropriate to generate first guess of trustworthiness even before the direct interactions occur.

Moreover, social interactions among entities disclose the valuable information of trust in analogy to the sociology concept of human interactions based on trust relationships. [14-17] discuss such models based on the social trust metrics like community of interest, friendship, followers, and frequency/duration of an interaction. After trust metrics are calculated individually, it is a must to combine them to have an overall idea about the final trust value. [18] and [19] investigate such a model based on the adaptive weightages. However, assessment of a proper weightage is a complex task due to the fact that trust is a varying quantity which depends on many factors like expectations of a trustor, time, context, etc. Thus, more intelligent schemes are required, preferably with well-known machine learning techniques like regression, supervised and unsupervised learning as discussed in [5], [20] and [21]. Presently, data is the key governing factor with respect to service provisioning and decision making process in IoT. Hence, the assurance of DQ and IQ are utmost important for trustworthy interactions. In this regard, authors in [22], [23] and [24] discuss various techniques and metrics that can be considered for DQ and IQ measurement. The framework proposed by Askham et al. [25] is one of the most prominent and widely accepted model for DQ assessment due to its generic nature. Hence, we adopt most of the concepts from this work in order to develop our framework. Moreover, authors in [26] and [27] argue a data centric trust model for vehicular networks based on several techniques like Bayesian inference and Dempster-Shafer theory.

In contrast to traditional means, there are several works on trust prediction based on collective methods where numerically assessed trust metrics are analyzed through an intelligent algorithms like supervised and unsupervised learning. In this regard, a model to improve trust prediction accuracy by combining user similarity rating and the traditional trust is proposed in [28] and [29]. Furthermore, Xiang et al. proposes a model based on unsupervised learning algorithm to estimate relationship strength from interaction activities like tagging, communication and interference [30].

3. TRUST IN IOT

Among the various definitions of trust, we identify trust as a qualitative or quantitative property of a trustee measured by a trustor for a given task in a specific context and in a specific time period [1]. Furthermore, we distinguish properties of trustworthiness into three categories: Reputation, Experience, and Knowledge as we proposed in [3], [1] and [4] and formulate a trust assessment model as shown in Fig. 1. The Knowledge trust metric (TM) incorporates the first party or direct information, provided by a trustee to evaluate its trustworthiness and estimated by some trust attributes (TAs) depending on the services and entities. As examples, relationship attributes (Co-location, Co-work and parental), cooperativeness, spatial attributes (social centrality, community of interest) and temporal attributes (frequency
and duration of interactions) can be recognized as some of prospective TAs for knowledge TM.

Moreover, the main purposes of trust assessment are to facilitate more intelligent decision making and task delegation. In this regard, we further elaborate two more metrics, which comes under knowledge TM as non-social TMs and social TMs. In non-social trust, the idea is to find whether the trustor can rely on a physical or cyber entities and social trust determines whether a trustor can depend on other social entities [14]. We define four parameters; Competence, Disposition, Dependence and Fulfilment, which define the non-social trust as well as three parameters; Willingness, Persistence and Confidence which define the social trust when it comes to delegation and decision making as opposed to beliefs discussed in [28]. With respect to the REK model, these additional metrics define the knowledge TM particularly in the decision making process. Let us consider a specific trustor $A$ and a trustee $B$ with respect to a particular goal $g$ in the decision making process. Based on this setup the definitions of the aforementioned attributes are;

- Competence Trust: B is beneficial and capable of realizing $g$
- Disposition Trust: B actually performs the task
- Dependence Trust: Achievement of goal $g$ relies upon B
- Fulfilment Trust: B’s contribution is necessary to achieve the task
- Willingness Trust: B shows no resistance over accomplishing the goal $g$
- Persistence Trust: Consistency over time, conquering the task

In the meantime, reputation and experience TMs falls under indirect observations as information to calculate these metrics comes only after a particular interaction or from third party sources. The process of indirect trust measurement is essentially an interactive process as shown in Fig. 2. For instance, attributes such as credibility and feedback which represent experience metric can be calculated only with the accumulated knowledge metrics. Similarly ratings and recommendations can only be generated after the accumulation of experience over a community.

4. DATA TRUST FRAMEWORK

To the present day, evaluation of trust in data is assumed to be identical to trust estimation of end entities. However, this is not entirely true and in fact most IoT systems rely highly on several data streams and these systems often care about the integrity and quality of who is generating them. As an example, obtaining accurate information about certain accident situation from less trustworthy entities like taxi drivers and passengers are more important than waiting for a report from a police officer, who is more trustworthy to a taxi driver, in order to get quick attention from medical authorities and other relevant parties. Another example is where the interactions happened for short duration without any prior relationship with the trustee. In such situations, it can be a disadvantage to calculate trust between entities due to time criticalness of the application.

To address these challenges, we propose a Data Centric Trust Evaluation and Prediction Framework as shown in the Fig. 2, which is capable of analyzing both data centric as well as
entity centric trust separately or in a collective manner. The platform consists of several important modules such as Trust Computation, Prediction and Decision Making (TCPD), Trust Agent (TAg), Trust Data Access Object (TrustDAO), Data Repository, Trust Computation and Decision making module, Trust Service Enabler and API. Once the TCPD identify a requirement of data, it ask the TAg via Trust DAO to collect necessary information and preprocessed them for trust evaluation. Then, these preprocessed data is stored in the data repository to be used by other modules including external platforms through TCPD API.

Afterwards, trust metric extraction module estimates the necessary trust attributes based on the requirement. These attributes can either be categorized as data centric attributes as explained in Section 4.1 or traditional entity centric attributes as described in Section 3. Next, all the attributes are combined based on the REK model with the assistance of trust computation module, which is capable of performing the calculation based on either numerical methods or artificial intelligence approach as described in sections 4.2 and 4.3 respectively. Finally, decision making and delegation module uses the predicted trust values in order to complete the decision process perhaps with the support of service enabler who is actually perform the judgement made by the decision module. In the following sections, we explain the data centric trust attribute estimation, data trust computation and data trust prediction in detail.

4.1. Data Trust Attributes

Alongside with the REK model, we first consider a separate set of trust attributes which essentially define the properties of data. Many research work on DQ shows that the six parameters (e.g., completeness, uniqueness, timeliness, validity, accuracy and consistency) provide prominent insight for assessing the DQ matters as in [22], [25], [32]. With respect to trust notion, we can consider these properties as trustworthiness attributes. Further, we consider two additional attributes, “success” and “cost”, which characterize experience and reputation data trust metric (DTM) calculation, in addition to aforementioned attributes stated in Section 3. We consider these eight data trust attributes (DTA) as the core dimensions in finding the trust between a data item and the trustor. Thus, we model these properties as below:

- **Success** ($T_B^{su}$): the probability that B will successfully execute the task
- **Cost** ($T_B^{ct}$): the probability that the cost of executing the task by B is not more than expected
- **Completeness** ($T_B^{cm}$): the probability of complete data records over total data records
- **Uniqueness** ($T_B^{uq}$): the probability of expected records over total records noted
- **Timeliness** ($T_B^{tm}$): the difference between last update to the current one
- **Validity** ($T_B^{va}$): the validity of data type, syntax and range
- **Accuracy** ($T_B^{ac}$): the probability of accurate data records over total data records

4.2. Data Trust Computational Model

In this section, we extend our entity centric model in Fig. 1 to comply with the data centric trust as shown in Fig. 3 and explain how each DTA is combined to generate data centric trust. For that we identify completeness, uniqueness, timeliness, validity, accuracy and consistency as DTAs which represent knowledge TM as it conveys trustworthiness information about the trustee. On the other hand “success” DTA and “cost” DTA represent the experience DTM of the trustor after each task. Finally reputation DTM can be considered by aggregating opinions of other trustees if there are any. Based on this, basic data trust assessment towards B by A ($T_{AB}^{dk}$) over x DTM can be numerically modeled as below:

$$T_{AB}^{dk} = \alpha T_B^{cm} + \beta T_B^{uq} + \gamma T_B^{tm} + \delta T_B^{va} + \epsilon T_B^{ac} + \phi T_B^{ac}$$

(1)

where $\alpha, \beta, \gamma, \delta, \epsilon, \phi$, and $\epsilon$ are weighting factors such that $\alpha + \beta + \gamma + \delta + \epsilon = 1$. However, calculating these weighting factors are computationally costly and not practical due to infinite number of possibilities. Hence, we suggest to apply machine learning (ML) techniques to combine all TAs, which we have discussed in our previous work [7].

$$T_{AB}^{ks} = \sigma T_B^{ks} + \phi \frac{1}{T_B^{ks}}$$

(2)

where $\sigma$ and $\phi$ are weighting factors such that $\sigma + \phi = 1$ and $T_B^{ks} > 0$. The ML method discussed in [7] is preferable for TA combination in this case as well.
For now let's assume this parameter is denoted by $\theta$ which describes the profile of users involved in a certain situation.

The next step of our algorithm is to find a parameter that predicts the data trust value of each data source based on DTAs as follows:

$$T_{dA} = \rho T_{dA}^k + \tau T_{dA}^E + \omega T_{dA}^R$$

(4)

where $\rho$, $\tau$, and $\omega$ are weighting factors based on the trustors preference on each TM. In here, we suggest two mechanisms to combine each TM either based on the ML approach we followed in [7] or applying the rule based reasoning mechanism explained in [4].

### 4.3. Data Trust Prediction

Once the trust values based on DTA are collected, next step is to find the trust relationship among data sources and the trustors who do not have prior encounters. For that, we use the concepts of well-known collaborative filtering (CF) technique to predict the unknown trust values between the user and specific data source with respect to six different data centric features (e.g., completeness, uniqueness, timeliness, validity, accuracy and consistency). As now the prediction is solely based on properties of data, it is unnecessary to rely on trustworthiness of the data source as in traditional methods anymore. Among various methods of recommendation techniques, we particularly choose a variant of a multifaceted CF model for our application due to its unique properties that match with our data trust model like stressing the concept of social contribution where everyone’s contribution matters, capacity to capture weak signals in the overall data, ability to detect strong relationships between close items and competence to avoid overfitting [33].

First, we define the inputs to our algorithm as number of trustors or users ($n_u$), number of Trustees or DSs ($n_m$) and six features as shown in Table 1. Users who already have trust relationship with DSs are noted with “●” symbol which actually represents some trust value between [0,1], calculated using equation (4) and the blank spaces denote the missing information, which is to be predicted. Formally, if user $j$ and item $i$ already have trust relationship, then $r(i,j)=1$ and $r(i,j)=0$, otherwise. Moreover, the data trust value given by user $j$ to DS $i$ is denoted by $y_{i,j}$. The symbol “*” represents the values of each six features in between 0 and 1.

The next step of our algorithm is to find a parameter that describes the profile of users involved in a certain situation. For now let’s assume this parameter is denoted by $\theta$ for a particular user $j$ and feature vector for DS $i$ is denoted by $T(i)$. Then the predicted trust data value $T_{ji}^{dp}$ between the trustor and the data can be calculated as in equation (5). The symbol $(.)^T$ represent the transpose of the vector.

$$T_{ji}^{dp} = (\theta)^T(i)$$

(5)

### Table 1. The users × items × features input matrix of the CF algorithm

<table>
<thead>
<tr>
<th>Trustees (DS)</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>$u_1$</td>
<td>$d_1$</td>
</tr>
<tr>
<td>$i_1$</td>
<td>$\Delta$</td>
</tr>
<tr>
<td>$i_2$</td>
<td>$\Delta$</td>
</tr>
<tr>
<td>$i_n$</td>
<td>$\Delta$</td>
</tr>
</tbody>
</table>

The basic but essential requirement of the predicted trust value is that it must provide closest possible prediction for each trust value that is already calculated by each user. With this assumption, we can use mean square error (MSE) method to find the distance between actual trust values and predicted one. The parameter $\theta^0$ which gives minimum error would be our best predicted trust value. This idea is formulated as below for trustor $j$:

$$\min_{\theta^0} \frac{1}{2} \sum_{(i,j) \in S} (\theta^0(i,j))^2$$

(6)

In the first part of the equation, the mean error is calculated over all the records where the trust value is already available through preliminary calculation. The second part of the equation is used to regularize the minimization process and there-by avoiding the overfitting issues. The $k$ denotes the number of features. Similar manner, we can find the best parameter for each trustor as below:

$$\min_{\theta^{(i)}} \frac{1}{2} \sum_{(i,j) \in S} (\theta^{(i)}(i,j))^2$$

(7)

where $J(.)$ denotes the cost function as described in equation (6). In order to minimize the cost function, we simply adapt the gradient decent method and solve for best parameter $\theta_k^{(i)}$ as below [34]:

$$\theta_k^{(i)} = \begin{cases} \theta^{(i)}(i) - \sigma \sum_{(i,j) \in S} (\theta^{(i)}(i,j))^2 T_{ji}(i,j), k = 0 \\ \theta^{(i)}(i) - \sigma \sum_{(i,j) \in S} (\theta^{(i)}(i,j))^2 T_{ji}(i,j) + \lambda \theta_k^{(i)}, k \neq 0 \end{cases}$$

(8)

Once the parameter $\theta^{(i)}$ is estimated through equation (7) and (8), predicted trust value between user $j$ and item $i$ will be given by the equation (5). Please note that this process is an iterative process and that more users who have experience with similar DSs would make the system more accurate and trustworthy.

### 5. IMPLEMENTATION MODEL

In this section, we propose a possible implementation scenario of our findings based on air pollution crowd sensing use case, aimed at collecting and monitoring pollution data. The air pollution sensing requires active citizen participation by carrying wearable sensors as they traverse the city based on opportunistic crowd sensing application [35]. However, monitoring such air pollution via crowd sensing requires that the data being provided are trustworthy and can be relied upon by city authority or government to make an immediate decision. The air pollution crowd sensing application will take advantage of citizen’s smartphones and smart city’s air...
pollution/environment sensors. The data collected from the air pollution sensors are delivered to the IoT Cloud, hosting the TCPD proposed in this paper. Thus, a mobile app for trusted air quality data monitoring can be developed on top of this framework integrating data collected from low-cost environment sensors for temperature, humidity, CO, CO2 NO2, SO2, as well as compounds including benzene and lead (VOCs), etc. The sensors’ readings will be transmitted via either an Android or IOS app to the proposed system for assessing and predicting the trust of the data before it is sent to the IoT Cloud. Such data can then be visualized along with its trust level by interested individuals, government, city administrators etc. via a web application.

For the above use case to profit from the proposed solution, we have proposed a distributed publish-subscribe architecture such as CoreDX distributed publish subscribe middleware [36] whereby an interested parties can subscribe via a broker to environmental data of interest in specific location of their choice as illustrated in Fig. 4, the implementation architecture. TCPD section of the figure implements appropriate components of the framework as shown in Fig. 2, for providing trusted data to the interested parties. This is a typical publish subscribe system whereby publishers publish the sensor data to the broker and subscribers receive notifications matching their subscriptions from the broker. As illustrated in the Fig. 2, the TCPD can communicate with the IoT platform via an edge server that implements the IGetTrustData and IProvideTrustData interfaces. Also, the TCPD can receive data from the IoT platform for predicting the trust of such received data.

Finally, Fig. 5 illustrates an example of a scaled down sequences of interactions between some important stakeholders of an implementation instance of the system. Anytime a new environment sensor is available, it registers its presence with the sensing broker, which in turn informs the framework of the new available sensor. The new sensor can then publish its data to the broker. The broker notifies the TCPD to predict the trust of the received data. Similarly, whenever a new subscriber joins the system, its subscription is submitted to the broker via the TCPD system. If a subscription matching at least one of the subscriptions of the new subscriber is available, the broker notifies the TCPD system to deliver the data to the subscriber along with the trust level of the data.

### 6. CONCLUSION

In this work, we argue that the traditional means of trust computation for entities does not necessary guarantee the trustworthiness of data that they generate. Hence, we propose a hybrid trust computational platform which is capable of assessing both data centric trust as well as traditional entity based trust. Further, we provide a model to compute individual DTA and the main DTM by combining numerical models with learning algorithms. Afterward, a data trust prediction scheme based on collaborative filtering is proposed to find the data trust between trustors and data sources who do not have prior encounters that avoids using data from malicious actors. Finally, a possible implementation scenario is discussed based on a crowd sensing use case. Similarly, our algorithm would be beneficial to filter out malicious data and data sources to maintain integrity and quality of the outcomes that any crowd sensing application produces.

For future work, we would like to incorporate content and contextual information for data trust prediction and propose a more accurate prediction model based on artificial intelligence concepts. Although ITU-T has started a new work on trust index which is a comprehensive accumulation of trust indicators to evaluate and quantify trust of entities, until now, standards on trusted data are still very limited and current standards on entity or network based trust must be expanded for taking into consideration the data trust matters as explained in this work.

### ACKNOWLEDGMENT

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P.2 The IEEE 1906.1 standard: Nanocommunications as a new source of data
P.3 TASIS: Trend Analysis System for International Standards
P.4 Exploiting multi-radio cooperation in heterogeneous wireless networks for absolute security against eavesdropping
P.5 The immutability concept of blockchains and benefits of early standardization
P.6 Standardization in emerging technologies: The case of additive manufacturing
CONTRACT THEORY BASED CACHING AND PRICING STRATEGY FOR CONTENT CENTRIC NETWORKS

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ABSTRACT

Content centric networks (CCNs) have emerged to deliver a large amount of contents in the networks. However, it has become a new challenge to efficiently cache the contents in the CCNs. Therefore, in this paper, we design a contract theory based content caching scheme to improve the performance of CCNs. Firstly, a two-layer heterogeneous network model is introduced to study the interaction between users and content providers. Secondly, based on the contract theory, the optimal caching and pricing strategy can be obtained under two constraints in CCNs. Finally, simulation experiments are carried out to prove that our proposal can efficiently improve the cache performance of CCNs.

Keywords — Content centric networks, edge cache, contract theory

1. INTRODUCTION

An ever-increasing number of contents are delivered and shared in content centric networks (CCNs) with the rapid development of communication technologies. These large-sized contents put a high pressure on the network operator to provide users with a satisfied quality of experience (QoE). Different from the conventional IP-based scheme, the content-based scheme in CCNs [1–3] can reduce the content transmission delay and consumption. Due to the limited cache capacity in CCNs and network congestion, caching the contents in the edge node becomes a novel method to improve the network performance. With caching content at the edge of networks, the cached content can be provided to the users from a nearby node where the delay for users to obtain the content can be reduced. Besides, as the content need not to be fetched from the remote server, the network traffic can be reduced at the same time.

Although many efforts have been made to study the content cache performance [4–6], most of them focus on the cache resource allocation [7–9], where the cache performance of the CCN can not be fully optimized. Besides, the current optimal strategy and pricing strategy seldom take heterogeneous network into account. Therefore, it is a new and open problem to design an efficient caching scheme for large amounts of contents in CCNs.

To address these issues, we design a contract theory based caching and pricing strategy to provide users with the optimal contract to improve the performance of content caching in CCNs. Firstly, a novel two-layer heterogeneous network model is proposed in CCNs. In this heterogeneous network model, users can access the contents from both Small-Cell Base Stations (SBSs) and CCNs. Then, we present the optimal contract to users and content provider to obtain the maximum utility. In addition, we compare the proposal with other previous schemes in simulation. Experiment results show that our proposal can be efficient to deliver contents in the CCNs.

The rest of the paper is organized as follows. Related work is reviewed in Section 2. The system model is introduced in Section 3. The proposed solution is proposed in Section 4. Simulation results are shown in Section 5. The conclusion of this paper and the future work are given in Section 6.

2. RELATED WORK

Le et al. [10] compare several previous caching policies to evaluate the performance of the network, whereby the caching policies with content replacement strategies are also evaluated. Hajimirsadeghi et al. [11] develop an analytical framework for popular content distribution, in which the caching and pricing strategies can be determined through a game to reach the Nash equilibrium. Su et al. [12] propose a novel caching scheme to reduce the delivery latency in CCNs, whereby the content store and pending interest table can be utilized efficiently. Guo et al. [13] propose a novel architecture to cache and transmit contents for cooperative nodes in CCNs, whereby the content popularity degree is considered. Zhang et al. [14] propose an implicit cooperative cache scheme to cache the contents in CCNs, whereby the content cache delay can be reduced and the cache resource utilization can be improved.

Ramawamy et al. [15] propose an utility-based data placement scheme in edge cache networks, whereby the virus costs and caching benefits of the individual edge cache node are included. Wang et al. [16] propose a novel analytic model based on the Markov-chain to estimate the caching performance among different edge nodes, in which the bandwidth consumption among user equipments can be minimized. Wang et al. [17] review the latest research works on mobile edge networks including the application and use cases, which can accommodate the user demands due to its distributed network architecture. Wang et al. [18] propose a novel Markov-
chain based edge caching scheme to minimize the transmission cost of base stations, whereby the traffic offloading is taken into consideration.

### 3. SYSTEM MODEL

As shown in Fig. 1, there is a content provider in the two-layer heterogeneous network. There are $I$ types of users and $N$ contents in CCNs. Users have two ways to access contents: SBSs and CCNs. We classify bandwidth between the user and the SBSs. $\theta_i$ denotes the size of content, and $b_1$ is the wireless bandwidth between the user and the SBSs.

We classify $N$ contents into different types according to the popularity. The probability that a requested content is the $k$th popular content can be obtained by

$$p(k) = \frac{1/k^\alpha}{\sum_{\gamma=1}^{N} 1/\gamma^\alpha}$$

where $\alpha$ is the Zipf parameter, $k$ denotes the popularity ranking of the requested content [19].

According to the Least Recently Used (LRU) strategy, for the $k$th popular content, its cache hit ratio can be described as follows

$$h(k) = 1 - e^{-q(k)T_C}$$

where $T_C$ is the maximum inter-arrival time between two adjacent requests for the same content in the relay node with cache capacity $C$ and $q(k)$ is the average access rate for the $k$th popular content. Then, the average hit rate for $N$ contents can be obtained by

$$hit(C) = \sum_{k=1}^{N} p(k)h(k)$$

The transmission path of contents in CCNs can be simply shown by the sequence $n_1, n_2, \ldots, n_M$. When the requested contents are not in the relay routing nodes, the user needs to access contents from the Macro-Base Station (MBS) in the CCNs. Thus, the transmission delay can be derived from

$$d = d_{MC}^{int} + d_{MC,1}^{int} + \sum_{m=1}^{M-1} d_{m,m+1}^{int} + d_{MC}^{int} + d_{CP,M}^{dat} + d_{MC}^{dat} + d_{dat}^{MC} + d_{MC}^{dat}$$

$$d = \rho_m \frac{L_s}{\mu_m(1-\pi_0)}$$

where $T_C$ is the maximum inter-arrival time between two adjacent requests for the same content in the relay node with cache capacity $C$ and $q(k)$ is the average access rate for the $k$th popular content. Then, the average hit rate for $N$ contents can be obtained by

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We assume that the length of pending interest table is $L_m$ and the transmission process of data packets in the relay node follows $M/M/1/L_m$ Markov decision process. The arrival process of contents follows Poisson distribution with parameter $\lambda$. The service time of relay node $n_m$ follows exponential distribution with parameter $\mu_m$. The delivery delay of data packets in node $n_m$ can be described as follows [20]:

$$d_m^{wait} = \frac{L_s}{\mu_m(1-\pi_0)}$$

in which,

$$L_s = \frac{\rho_m}{1-\rho_m} \cdot \frac{(L_m + 1)\rho_m L_m + 1}{1 - \rho_m L_m + 1}$$
\[
\pi_0 = \frac{1 - \rho_m}{1 - \rho_m L_{m+1}}
\]

where \(\rho_m = \lambda/\mu_m\).

According to LRU cache strategy, the cache hit rate in node \(n_m\) with cache capacity \(C_m\) is \(hit(C_m)\). When the requested contents are in the relay routing node \(n_m\), the transmission delay can be defined by

\[
d(m) = d_{\text{hit}} + \sum_{j=1}^{m} d_{\text{hit},j+1} + \sum_{j=1}^{m-1} (d_{\text{hit}} + d_{\text{hit},j,j+1}) + d_{\text{hit},1} + d_{\text{hit}}
\]

Thus, the cache hit rate in the relay routing node \(n_m\) can be described as follows:

\[
pr(m) = hit(C_m) \prod_{j=1}^{m-1} (1 - hit(C_j))
\]

Therefore, the delivery delay of the user achieving contents from CCNs can be obtained by

\[
d_2 = \sum_{m=1}^{M} d(m) \times pr(m) + \prod_{m=1}^{M} (1 - hit(C_m)) \times d
\]

The utility function of user \(\theta_i\) can be defined by:

\[
U_{\theta_i} = v(q(\theta_i)) - T(\theta_i)
\]

where \(v(q(\theta_i))\) is the satisfaction degree of user \(\theta_i\) by obtaining contents with the capacity of \(q(\theta_i)\). User’s satisfaction degree \(v(q(\theta_i))\) can be derived from

\[
v(q(\theta_i)) = w \ln \left( 1 + \frac{1}{d_1} \theta_i q(\theta_i) + \frac{1}{d_2} (1 - \theta_i) q(\theta_i) \right)
\]

Here, \(w > 0\) which is an adjustment parameter. The user’s satisfaction increases with the capacity of \(q(\theta_i)\). On the contrary, the user’s satisfaction will decrease when the transmission delay increases. Given a contract \((q(\theta_i), T(\theta_i))\), the operator will charge user \(\theta_i\) with the price \(T(\theta_i)\). We define \(U\) to be the utility of the content provider, which can be defined by

\[
U = \sum_{i=1}^{l} p_i (T(\theta_i) - c_i \theta_i q(\theta_i) - c_2 (1 - \theta_i) q(\theta_i))
\]

where \(p_i\) is the proportion of type \(\theta_i\), \(c_1\) denotes the loss coefficient for SBSSs to provide users with contents and \(c_2\) denotes the loss coefficient for CCNs to provide users with contents.

4. PROPOSED SOLUTION

In this section, we propose a contract theory based caching scheme to improve the performance of CCNs.

4.1. Constraints for Feasibility of Contracts

Definition 1. Individual Rationality (IR) constraints are defined to ensure that the utility \(U_{\theta_i}\) of user \(\theta_i\) is non-negative if the user chooses the contract \((q(\theta_i), T(\theta_i))\). We have

\[
w \ln \left( 1 + \frac{1}{d_1} \theta_i q(\theta_i) + \frac{1}{d_2} (1 - \theta_i) q(\theta_i) \right) - T(\theta_i) \geq 0
\]

Definition 2. Incentive Compatible (IC) constraints are to maximize the users’ utilities when the user chooses a contract \((q(\theta_i), T(\theta_i))\).

\[
w \ln \left( 1 + \frac{1}{d_1} \theta_i q(\theta_i) + \frac{1}{d_2} (1 - \theta_i) q(\theta_i) \right) - T(\theta_i) \geq w \ln \left( 1 + \frac{1}{d_1} \theta_j q(\theta_j) + \frac{1}{d_2} (1 - \theta_j) q(\theta_j) \right) - T(\theta_j),
\]

\[\forall i,j \in \{1, \cdots, I\}, i \neq j\]

User \(\theta_i\) prefers to choose the contract designed specifically for its own type to maximize its own utility. And the contract is feasible only if the IR and IC constraints are all satisfied.

4.2. Optimal Contract

Firstly, we need to simplify the IR and IC constraints to reduce the computational complexity. Then, the optimal edge cache strategy is proposed based on Lagrangian function.

**Step 1. Reduce IR and IC Constraints**

We can see that there are \(I\) IR constraints in this scheme.

**Theorem 1.** If the users’ IC constraints are satisfied, users’ IR constraints can be simplified by

\[
w \ln \left( 1 + \frac{1}{d_1} \theta_1 q(\theta_1) + \frac{1}{d_2} (1 - \theta_1) q(\theta_1) \right) - T(\theta_1) \geq 0
\]

Definition 3. Spence-Mirrless single crossing condition can reduce the number of constraints efficiently, which can be described as follows

\[
\frac{\partial}{\partial \theta} \left( \frac{\partial U_{\theta_i}}{\partial q_{\theta_i}} \right) > 0
\]

The number of IC constraints reduces significantly when the users’ utilities satisfy Spence-Mirrless single crossing poverty.

**Theorem 2.** The monotony of the capacity \(q(\theta_i)\) and the sufficiency of local incentive constraints are established when the Spence-Mirrless single crossing condition is satisfied.

Definition 4. For the contract \((q(\theta_i), T(\theta_i))\) of user \(\theta_i\), \(\forall \theta_i > \theta_j, q(\theta_i) > q(\theta_j)\).
Finally, the optimal problem can be simplified as follows
\[
\max_{q(\theta_i), T(\theta_i)} U = \max \sum_{i=1}^{I} p_i \left( T(\theta_i) - c_1 \theta_i q(\theta_i) - c_2 (1 - \theta_i) q(\theta_i) \right)
\]
subject to
\[
\begin{align*}
\frac{\partial Y}{\partial q_i} & = 0 \iff p_i = \beta_i \\
q^* (\theta_i) & = \frac{w}{c_1 \theta_i - c_2 (1 - \theta_i) - \frac{1}{a_i}} \\
q^* (\theta_i) & = \frac{w}{c_1 \theta_i - c_2 (1 - \theta_i)} - \frac{1}{a_i}
\end{align*}
\]  
(26)  
(27)

If \( i = 1 \), the first order condition becomes
\[
\frac{\partial Y}{\partial q_1} = \omega \left( \frac{(\beta_1 + \mu)}{1 + (\theta_1 t + \frac{1-\theta_1}{\theta_1 t}) q_1} - \beta_2 a_2 \right) \frac{1}{1 + (\theta_1 t + \frac{1-\theta_1}{\theta_1 t}) q_1} = p_1 [c_1 \theta_1 + c_2 (1 - \theta_1)]
\]
(28)  
(29)

Thus, we can obtain
\[
\Delta_1 = \left\{ \begin{align*}
\left[ (a_1 + a_{i+1}) (c_1 \theta_1 + c_2 (1 - \theta_1)) - w a_1 a_2 \right] p_1 - 4 p_1 & \left( c_1 \theta_1 + c_2 (1 - \theta_1) \right) a_1 a_2 \\
0, & \text{otherwise}
\end{align*} \right.
\]
(30)

(31)

\section{5. Simulation Results}

In this section, we carry out simulations to evaluate the proposal by the comparison with two conventional schemes. In the Linear Pricing scheme, the operator only specifies a price \( P \) in the contract for a unit configuration. In Flat-contract scheme, each user is provided with the same contract, which also satisfies the IR constraint conditions. In the simulation, the modulation parameter \( w \) is equal to 2. The loss coefficient of caching contents in SBSs is 0.3, while the coefficient loss of providing contents in CCNs is 0.5. The delay to achieve a unit content from SBSs is 0.2, while the delay to obtain a unit content from CCNs is 0.4.

Fig. 2 shows the utilities for operator \( U \) compared with Linear Pricing scheme and Flat-contract scheme. From Fig. 2, the operator can obtain the maximum benefits with the proposed scheme. In the conventional schemes, without pricing incentive scheme for the high type of users, the users’ desires to access contents from SBSs are reduced. The utilities for operator with these three schemes decrease when the delay \( d_2 \) increases.

\section{6. Conclusion}

In this paper, we have proposed a contract-based caching scheme to improve the caching performance in CCNs. Firstly, a novel model with two-layer heterogeneous wireless network is proposed to study the interaction between users and content operator. Secondly, based on the contract theory, the optimal caching and pricing strategy for each user can be obtained in CCNs. Finally, simulation experiments are carried
out to prove the reliability and effectiveness of our proposal. For the future work, we will further study the content cache scheme in different communities.

7. REFERENCES


THE IEEE 1906.1 STANDARD: NANOCOMMUNICATIONS AS A NEW SOURCE OF DATA

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ABSTRACT

Nanoscale communications is a new paradigm encompassing all those concerns related to the exchange of information among devices at the nanometer scale. A network infrastructure consisting of a huge amount of nanodevices is envisaged to ensure robust, reliable and coordinated data transmission. This will enable a plethora of forthcoming applications and services in many different research fields, such as personalized medicine, synthetic biology, environmental science or industry, which will lead to outstanding and unprecedented advances. The IEEE 1906.1 standard provides a conceptual and general framework to set the starting point for future developments in nanoscale communication networks. This paper reviews the latest IEEE 1906.1 recommendations, observing their main features when applied to the electromagnetic (EM) nanocommunication area. We contribute by identifying and discussing the principal shortcomings of the standard, to which further research efforts must be devoted. We also provide interesting guidelines for focusing the object of future investigations.

Keywords — Nanoscale communication networks, nanodevices, EM nanocommunications, terahertz band, IEEE standards.

1. INTRODUCTION

In the emerging Internet of Things (IoT), objects are expected to be able to sense and capture the physical variables of their surroundings (e.g. temperature, humidity, pressure, etc.) as well as to process the acquired information and communicate it wirelessly to any other object/node in their network. These enhanced objects integrate small sensing/computing/communicating devices in a varied range of sizes, including the nanoscale. Moreover, devices in IoT constitute a network infrastructure connecting both physical and virtual worlds by means of all sorts of innovative applications and services, some of them currently unimaginable. In this context, a huge amount of data will be generated and should be properly managed to extract useful information. Nowadays, the IoT relies on the well-known Wireless Sensor Networks (WSN), in which numerous devices with limited resources are connected, in order to provide feasible solutions in multiple heterogeneous fields, such as agriculture, industry, smart cities, etc. Keeping in mind the way WSN operate and due to incessant technological advances, novel devices with progressively smaller dimensions are being developed, to ease their integration into the environment. However, as they become smaller, many concerns, such as available energy, transmission range or data processing capacity are far more restricted than in traditional WSN. Thus, when the scale of these tiny devices decreases to nanometers, a new paradigm arises, nanoscale communications between nanomachines, and between nanomachines and more conventional devices in the network.

These data-driven nanodevices have become a topic of increasing interest for the scientific community, since they would be able to gather physical parameters at the nanoscale with outstanding accuracy. This capacity would allow the monitoring of scenarios not explored to date, enabling a plethora of potential applications in fields as varied as biomedicine, synthetic biology, environmental science or industry, among many others. Indeed, one of the most promising applications of these nanodevices is aimed at improving medicine, because diverse medical tests, such as blood pressure, virus detection or oxygen levels in blood (Figure 1), could be collected in vivo and directly transmitted to medical personnel (e.g. information about the variation in number and size of cancer cells will be received by the oncologist).

Several works have dealt with how nanodevices should communicate with each other. This is becoming a critical issue, since the extremely limited resources of nanodevices require them to work cooperatively to carry out a useful application. Two main alternatives for communicating at the nanoscale have been envisaged so far, electromagnetic (EM) and molecular communication. EM communication is based on the use of electromagnetic waves to transmit a message between two nanodevices. Advancements in carbon electronics, mainly those devices made of graphene and carbon nanotubes (CNT), have played a key role in the development of a new generation of electronic nanocomponents, such as nanoantennas or...
nanotransceivers [1]–[3]. These novel radiocommunication nanocomponents possess unbeatable properties, which allow the radiation of EM waves at THz frequencies with antennas of just a few micrometers in length, i.e. two orders of magnitude lower than their metallic counterparts. Even so, this radiation frequency exhibits high propagation losses, which require a thorough nanoscale communication network design, also known as a nanonetwork. On the other hand, molecular communication is defined as the transmission and reception of information encoded in organic molecules [4], [5]. Molecular transceivers are envisioned to facilitate their integration into nanodevices due to their extremely small size and limited domain of operation. These transceivers can react when receiving certain molecules and release others (as a response to stimulation or after executing some process). The molecules transmitted are propagated in three different ways: moving through a fluidic medium by free diffusion (diffusion-based); moving through a fluidic medium with a guided flow (flow-based); or through pre-defined pathways by using carrier substances (walkway-based).

Both EM and molecular, nanocommunications are considered by the IEEE P1906.1 standard; the first approach to normalize diverse aspects related to communications at the nanoscale, released in December 2015. Under this general premise, this standard first defines the concept of a nanoscale communication network itself, to later propose a conceptual framework for developing communications. Studies using the guidelines of this standard would implement a similar protocol stack for each nanodevice; it is recommended that this stack be based on the components and procedures specified by the IEEE P1906.1 to share and compare results from a common set of performance metrics as defined by the standard.

This paper reviews the IEEE P1906.1 standard, focusing on EM communications; an area in which remarkable technological advances are leading to the first realistic approaches at the nanoscale. In particular, we analyze the standard definition, its pros and cons, describe the framework offered along with its components and, finally, introduce the main metrics which will be taken into consideration to evaluate the performance of a nanoscale communication network. Furthermore, we provide a functional EM communication scheme in which all the steps required to send/receive a message between a transmitter/receiver pair are explained in detail. Analyzing the standard completely, we have identified some lacks and weaknesses, which are further addressed and discussed in this work. These shortcomings pose important challenges. A few of them have been dealt with in previous works [6]–[9], but most of them are still unexplored, which will undoubtedly be the starting point for future investigation.

The rest of the paper is organized as follows. In section 2, we review the IEEE P1906.1 standard from the perspective of EM communications. Section 3 is devoted to pointing out some weaknesses of the standard for the design of EM nanonetworks. In section 4, we indicate how to tackle each detected weakness. Section 5 concludes the paper.

2. IEEE P1906.1 STANDARD DESCRIPTION UNDER EM COMMUNICATIONS

As interdisciplinary research groups are becoming more and more involved in the development of nanoscale communications, the lack of a clear common scope has been confirmed, leading to isolated developments and unrelated knowledge islands. In this sense, the different cases of study proposed in the open scientific literature have been thought about and evaluated under very specific conditions, which differ for each work. This negatively impacts the exchange of information at the nanoscale, since nanonetwork performance depends on the particular working conditions and capabilities of nanodevices. Thus, the IEEE P1906.1 standard [10] is aimed at providing a common framework, in order to join efforts and promote future advances in nanoscale communications. In addition, another significant contribution of this standard is allowing sufficient precision for the development of interoperable and reusable components. To achieve these goals, we examine the following four aspects of the standard structure: (i) definitions, (ii) framework, (iii) metrics, and (iv) EM communication reference model.

2.1. Definitions

The first part of the standard provides a complete and detailed definition of “nanoscale communication network”, which should pave the way for future studies in this emerging research field. This definition intends to strictly establish the scope of this concept but, keeping it general enough to cover both molecular and EM communications. The range chosen to delimit the nanoscale is quite narrow (from 1 nm to 100 nm), extracted from the definition of nanoscale provided in [11]. The lower limit is simply selected to exclude the use of single atoms as nanoscale systems. In contrast, the upper limit is the size at which material properties change substantially from the macroscale. This limit could cause controversy, since most of the scientific papers related to EM nanoscale communications consider nanodevices at larger scales. Nevertheless, the sentence “at or with the nanoscale” contained in the definition leaves the door open to different considerations, in particular, those concerning the size of...
the nanoscale object under study. Therefore, the nanodevices proposed in these papers would support the standard whenever they include a communication element at the nanoscale. These communication elements (transmitter, receiver, medium, message, and message carrier) are also named in the definition, even though they are not described in detail.

2.2. Framework

The second block defined by the standard provides a conceptual, general and small-scale framework consisting of an appropriate number of components comprising well-defined functions and with interoperability among them. The framework offers the organization and structure required to implement procedures and models. To this end, a set of interconnecting components is introduced, namely: (i) message carrier, (ii) motion, (iii) field, (iv) perturbation, and (v) specificity.

The message carrier is described as the physical entity which transports the message across the medium. In particular, in EM nanocommunications, message carrier would indicate the EM wave. The motion component represents the physical phenomenon that enables the message carrier to move (in EM, the wave propagation and phase velocity). This component may be randomly propagated through the medium, which would hamper the propagation of the wave. To avoid this concern, the field component organizes and guides the movement of the motion component. Concerning the EM nanocommunication system, this would correspond to the omni/directional antenna. The perturbation component refers to the mechanism required to accommodate the message carrier to the medium in order to transmit the signal that contains the message (equivalent to a modulation). Finally, specificity makes reference to the reception of the message carrier by a specific receiver (receptor sensitivity/antenna aperture).

This framework is compared to the Open System Interconnection (OSI) model in order to place the five aforementioned components in the traditional communication protocol stack, as specified in Table 1 (extracted from [10]). Due to their tiny size and their close relation to physical aspects, the nanoscale framework components are situated in the lower layers of the OSI stack, even breaching the separation between them. In section 3, we will discuss this issue, analyzing the functions and requirements of each component.

2.3. Metrics

The third section of the standard addresses the definition of common metrics to give information about the interoperability among system components, together with the computation and comparison of performance in a nanoscale communication network. Evaluating networks by using these metrics, researchers can measure and objectively compare the grade of improvement or deterioration that different nanoscale network designs experience.

The standard classifies the metrics in function of each component. So, metrics related to the message carrier measure how the transmitted information is influenced by the radio channel. Typical network metrics, such as message lifetime (a message carrier is discarded when exceeding a given time-to-live [TTL]) or information and communication energy (the energy required to move and steer a message carrier) are proposed for this component. On the other hand, metrics referring to the motion component differ from usual network metrics and focus on the physics behind the message carrier transmission through the medium. Note that these metrics mainly evaluate molecular communications. Something similar occurs with the metrics related to the field component, which copes with the extent to which the message carrier motion can be controlled, evaluating whether it follows an intended gradient. Specificity metrics point to the capacity of the message carrier to deliver a message to a specific destination. These metrics, in fact, are quite similar to those used in conventional EM links. Specificity (percentage of message carriers not addressed to an intended nanodevice which are not accepted by the intended nanodevice), sensitivity (percentage of message carriers addressed to an intended nanodevice which are checked and processed by the correct intended nanodevice), or angular spectrum (quantifying the distribution of the intensity of nanoscale communication signals received at each nanodevice as a function of angle-of-arrival), are some of the metrics suggested for this component.

Finally, the standard offers some other general metrics to assess the performance of the entire nanoscale network. For instance, the metric bandwidth-volume ratio, included in this segment, is employed to evaluate the total amount of information exchanged by nanodevices belonging to the nanoscale network, divided by the total system volume.

<table>
<thead>
<tr>
<th>OSI protocol layer</th>
<th>Framework nanoscale component</th>
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<tbody>
<tr>
<td>Application</td>
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<tr>
<td>Presentation</td>
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<td>Motion</td>
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<td>Perturbation</td>
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Table 1. OSI to nanoscale communication network mapping
2.4. EM communication reference model

Figure 2 illustrates the general communication reference model of the standard extended to EM communications. Also, the sequence of steps followed to carry out a communication between two nanodevices (in that order) is displayed. They are enumerated and commented on in the following paragraphs.

1) The sender nanodevice receives a message from the upper layers, in particular, a string of bits encoding the message to be dispatched. This message is delivered to the Transmitter Communication Interface.

2) The Perturbation component generates the message carrier, considering parameters characterizing the EM transmission, for instance, the central frequency in the THz band to transmit, the bandwidth (usually from 0.55 THz to 1.55 THz), the transmission power, pulse features, type of modulation, etc. Regarding modulation, the Time-Spread On-Off Keying (TS-OOK) modulation is the most widely extended because it is a straightforward scheme that sharply decreases the implementation complexity, alleviating the processing and computing tasks of nanodevices.

3) The Transmitter Communication Interface triggers the propagation in the physical medium by passing through the Message Carrier, Perturbation, and Field components. Regarding this last component, an omnidirectional antenna is employed.

4) The Motion component is created in function of the propagation model in the scenario under consideration (e.g. the human body), and takes into account requirements such as path loss or background noise [12] to modify properties of the message carrier, for instance, propagation loss or end-to-end delay.

5) The receiver Specificity component checks and verifies that all the aforementioned parameters stored within the received message carrier are the same as those contained in the receiver Perturbation component.

6) In the case that step 5) is correctly carried out, the message carrier is delivered to the receiver nanodevice.

7) Finally, the message is dispatched to the upper layers of the receiver.

In order to provide a common development environment, the standard proposes the discrete-event and open source network simulator denoted as NS-3 to integrate all the aforementioned steps and components. The objective is that future investigation in the field of nanoscale communications has a starting point for exploiting all the power of the IEEE P1906.1 standard. To this purpose, the simulator follows a hierarchical modular structure, dividing the EM communication implementation into two groups; both taking into account the guidelines of the standard. Specifically, the first group develops the five main framework components, while the second implements other secondary entities involved in the communication process but not classified as “components” (i.e., communication interface, transmitter communication interface, receiver communication interface, medium, and net nanodevice). It is worth remarking that the software developed under the NS3 simulator supports the interaction of all these modules, offering a complete communication scheme.

3. IEEE P1906.1 STANDARD WEAKNESSES IDENTIFIED FOR EM COMMUNICATIONS

Once the main features of the IEEE P1906.1 standard have been introduced, we identified several aspects which make the standard excessively open or even a not well-defined approach. In this section, we discuss some of the issues not thoroughly covered by the standard.

First of all, we should indicate the difficulty of giving a general definition of the concept “nanoscale communication network”, since it requires the inclusion of requirements from two different scientific fields, namely Molecular and EM. They are so different, that concepts such as “network” and “communication” may have different meanings in each discipline. In addition, in order to maintain the generality of the definition, a communication system is considered at the nanoscale when one or more essential system components are sized at nanometers in at least one dimension. Actually, following the guidelines of this definition, most works already published about EM nanocommunications [6], [8], [9], [13] (and therefore, prior to the IEEE P1906.1 standard-draft- was launched) would be included under the umbrella of the standard, since antennas employed in these studies are at the nanoscale. In detail, as can be seen in Table 2 (extracted from [10]), the THz waves radiated by graphene or CNT antennas are both considered “components below 100 nm” and therefore “non-standard physics”. So, although these studies built their designs from microscale electronic devices (and thus, the resulting design is at the microscale), the employment of THz waves as message carriers is enough to consider the communication at the nanoscale. As can be observed, the concept of “nanoscale communication network”, is diffuse enough to consider microdevices operating in a nanonetwork.

Concerning the physical level, the restrictions on the amount of available energy in each nanodevice (we name them nanodevices, although their dimensions may be at the microscale) has an important impact on the communication...
nancy, which are able to works EE P1906.1 extremely restricted standard establishes the IEEE P1906.1 STANDAR sions. In addition, the interconnection of the functionalities related to multi-hop end-to-end communications. In addition, the interconnection of the nanoscale communication network with the macro world is an issue not considered by the standard. Higher OSI layers could be implemented, including traditional functions (e.g., security techniques to improve the privacy of data); however, due to extremely restricted nanodevice capabilities regarding processing, energy harvesting or memory, serious doubts have been posed about their feasibility.

4. IEEE P1906.1 STANDARD OPEN ISSUES ON EM COMMUNICATIONS

Analyzing the shortcomings identified in the IEEE P1906.1 standard, we suggest some tips that should be considered in future EM nanoscale communications studies in order to offer the scientific community ways of confronting open research challenges not treated by the standard.

As previously mentioned, one of the main goals of the IEEE P1906.1 standard is to join efforts towards the development of nanoscale communications, so the lack of a strict definition leaves the door open to different considerations. The ambiguity of the definition may be a practical reason why the IEEE P1906.1 standard has not been taken into account in recent nanoscale communication works [15]–[18]. Therefore, we believe that a more detailed standard definition should be elaborated to better define the appropriate setting for developing future interoperable nanoscale communication networks, subject to common conditions. In particular, the definition should include, firstly, the concept of a nanodevice as a device at the nanoscale, and, secondly, the division of the standard into two clearly separated parts, one focused on EM communications and the other specifically for molecular nanoscale communications. The result would be a suitable definition in order to provide a more complete

### Table 2. Example of the equivalence between EM nanoscale network components and the IEEE P1906.1 framework

<table>
<thead>
<tr>
<th>IEEE P1906.1 component</th>
<th>Implemented component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter</td>
<td>CNT-based nanoantenna</td>
</tr>
<tr>
<td>Receiver</td>
<td>CNT-based nanoantenna</td>
</tr>
<tr>
<td>Message</td>
<td>Sodium concentration</td>
</tr>
<tr>
<td>Medium</td>
<td>Air</td>
</tr>
<tr>
<td>Message carrier</td>
<td>Electromagnetic (EM) wave</td>
</tr>
<tr>
<td>Component &lt; 100 nm</td>
<td>Sensor, message carrier (THz frequency wave)</td>
</tr>
<tr>
<td>Non-standard physics</td>
<td>Impact of scale on resonance</td>
</tr>
<tr>
<td>Motion</td>
<td>Radiation and waveguide</td>
</tr>
<tr>
<td>Field</td>
<td>Intensity/directional antenna</td>
</tr>
<tr>
<td>Perturbation</td>
<td>RF modulation</td>
</tr>
<tr>
<td>Specificity</td>
<td>Receptor sensitivity/antenna aperture</td>
</tr>
</tbody>
</table>

nanodevice involves the use of piezoelectric nanogenerators [6], [8], [13], which are able to convert mechanical strains (e.g., bloodstream movement) into electric energy. The energy harvested is stored in a nanocapacitor to feed the nanodevice components when the energy level exceeds a given threshold. Nevertheless, the main drawback to these nanogenerators is the scarce amount of energy harvested per unit of area, which strictly limits the communication capabilities of nanodevices. In addition, the available energy depends on the physical medium in which nanodevices are deployed (if nanodevices take advantage of environmental movement, the energy harvested will be greater than in a static medium) and the area of the nanogenerator. On the other hand, parameters related to the transmission and reception of EM waves, such as power transmission or signal to noise ratio (SNR), are not treated by the IEEE P1906.1 standard. This recommendation should attract even more attention when human bodies are involved, since the high transmission power envisaged for nanodevices [9] could affect health. The SNR at reception is also an important parameter to consider in order to ensure robust and reliable nanoscale communications. Although the standard deals with the channel capacity (computed by using the Shannon theorem), and therefore, calculating the upper limit for the physical data rate, in the case of a low SNR value, the receiver would not be able to demodulate the radio signal.

Aside from the shortcomings concerning the physical layer, we have also noticed a remarkable insufficiency of the IEEE P1906.1 standard to give some recommendations about the data link layer. As can be observed in Table 1, the standard places the framework components specificity and motion at the data link layer. In EM communications, these components are identified with signal radiation (motion) and antenna aperture in reception (specificity) -see Table 2-. However, as EM nanoscale communication networks must contain a huge number of nanodevices due to their extremely limited transmission range (derived from the high path loss suffered in the THz band [12], [14]), some techniques are required to enhance the data transmission robustness between adjacent nanodevices. Specifically, medium control access to arbitrate transmissions and avoid message collisions, flow control to encompass the bitrate of the communication link, or error detection mechanisms would be required. In addition, the number of fields and control/payload/footer length of the reference message is not defined by the standard, which could lead to the design of different and even non-interoperable data link layers. Concerning the network layer, nanodevices may have to reply to a request from an external macroscale device or may need to immediately report new events to external end personnel (e.g., a doctor). Due to the very limited transmission range of nanodevices, this information flow could require the creation of multi-hop routes. The IEEE P1906.1 standard establishes the field component as a piece/part of the network layer, but it does not cover the functionalities related to multi-hop end-to-end communications. In addition, the interconnection of the
Regarding the reference energy model, more effort should be devoted to characterizing the functions of a nanoscale energy generator and its operating conditions. Thus, we believe that the standard should include a reference energy model, considering the energy harvesting restrictions of nanodevices due to their tiny size (and, therefore, pointing to the available area in the nanodevice for the nanogenerator) and the environment under study. So, this reference model would establish a more solid starting point to quantifying important aspects of communication, such as coverage area, size of the message to transmit, etc., which can be consistently used to develop realistic communication protocols. Furthermore, from our point of view, the standardization of both maximum and recommended power transmission values would be relevant, in order to set a common power consumption model for nanodevices forming the nanonetwork. If these power transmission values could be set, it would be possible to estimate the amount of energy that a nanodevice can waste (most of the required energy is dedicated to transmitting a message [6]). These values could vary depending on the application environment of the nanonetwork. In addition, an SNR value recommendation should be taken into consideration by the standard, to appropriately demodulate the signal arriving to the receiver. Power transmission and SNR, together with the path loss model obtained for each physical medium (e.g., human body tissues) would clearly determine the transmission range of each nanodevice for the scenario under study, which would be useful, for instance, in the planning of the required number of nanodevices deployed to cover a particular area.

As regards the data link layer, some techniques are needed to improve the data transmission robustness between neighboring nanodevices. We divide them into four subgroups: (i) media access, (ii) flow control, (iii) addressing, and (iv) error detection/correction. Firstly, due to the very high density of nanodevices expected for nanonetwork deployment, straightforward media access control should regulate the access to the radio channel, to manage simultaneous transmissions in the transmission medium. For instance, by using random seeds to activate the nanodevice transceiver and listen to the medium, message collisions will be mitigated. In the case that a medium access control technique is not employed, messages dispatched by neighbors could collide, corrupting a high percentage of the transmitted data. Secondly, for the same reason, a flow control mechanism is essential to coordinate the communication between nanodevices. For example, a simple acknowledgement reply to confirm the reception of a message, together with a waiting timer for retransmissions (when collisions occur) could be enough to control the traffic load in the network. Thirdly, every single nanodevice in the network requires a unique ID to be identified, facilitating the transmissions from a source nanodevice to a remote destination. Finally, error detection methods are mandatory to evaluate the standard metrics, such as sensitivity or specificity, since false positives must be properly detected. Hence, we believe the standard should include these data link layer aspects, to provide a more robust and reliable nanoscale communication framework.

| Table 3. Weaknesses and open issues for the IEEE P1906.1 standard for EM communications |
|-----------------------------------------------|-----------------------------------------------|
| **Standard weaknesses for EM communications** | **Open issues**                                |
| Excessively open definition of nanoscale communication network. | More detailed definition of nanoscale EM communication devices. Two separate chapters for molecular and EM nanocommunication are suggested. |
| Lack of a reference energy model. | Definition of a general enough energy model, but easily adapted to the technology employed. Energy restrictions should be better quantified to design a nanonetwork offering a real service. |
| SNR is not contemplated in the reference communication model. | Standardization of SNR values expected at reception to calculate appropriate receiver sensitivity thresholds. |
| Lack of layer 2 techniques to enhance communication robustness. | Recommendation of techniques referring to media access control, addressing scheme, flow control and error detection. |
| Equivalent layer 3 OSI reference model functions are not rigorously addressed. | Definition of routing procedures to allow multi-hop end-to-end communications. Design of a complete network topology. |
| Interconnections between a nanoscale communication network and macroscale devices are not addressed. | Design and development of a link between the nano and macroscale worlds. |
Table 3 summarizes the identified limitations of current standard and associates them with their corresponding open issues. Note that even a simple solution to these open issues is a real research challenge at the nanoscale.

5. CONCLUSIONS

The IEEE P1906.1 standard establishes a set of recommended practices with the aim of allowing researchers to advance in the development of effective nanoscale communication systems. Even though it supposes a sound step forward, more concreteness is necessary to envisage a common framework which can become a solid foundation for designing forthcoming EM nanonetworks. Keeping this premise in mind, we have first reviewed the main body of the standard, highlighting those definitions, metrics, and components related to EM communications. In addition, we have taken advantage of the general communication model proposed by the standard, and contributed with a refined reference communication model adapted to EM communications. Secondly, we have identified some relevant shortcomings of the standard, dividing them into four main groups. The first discusses the generality of the definition of the term “nanoscale communication network” itself, while the three remaining groups reveal important deficiencies in each of the three lowest layers of the OSI reference model (physical, data link and network layers). Finally, we have offered possible guidelines for addressing each detected weakness in order to enhance the feasibility and capabilities of EM nanoscale communications.

REFERENCES


TASIS: TREND ANALYSIS SYSTEM FOR INTERNATIONAL STANDARDS

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ABSTRACT

Recently, text mining has risen as an advanced technology that analyzes meaningful trends and topics in document collections. Despite its increasing use in various research areas, there have not been previous studies using document collections of international standards. In this paper, we propose the Trend Analysis System for International Standards (TASIS), which automatically performs topic modeling and trend analysis on document collections of the International Telecommunication Union Telecommunication Standardization Sector (ITU-T) Recommendations, based on a latent dirichlet allocation (LDA) algorithm. For providing Web services, the TASIS performs topic modeling by exploiting user-defined parameters, such as the number of topics and iterations, and the results show a list of the documents that each keyword in the topic is included in. The TASIS also describes a TreeMap with the size of the extracted topic as a graphical expression for easier understanding.

Keywords— Text Mining, Latent Dirichlet Allocation, International Standards, Topic Modeling, Trend Analysis

1. INTRODUCTION

Text mining is broadly describing a range of technologies for analyzing and processing semi-structured and unstructured text data [1]. Particularly, as text data is becoming more important because of the explosion of Internet users [2], text mining can summarize documents as well as analyze human emotions [3, 4]. Additionally, research has been carried out to identify technology trend patterns from patent documents, and there have been cases where the evolution of patents related to specific products and technologies is found and the direction of next-generation development suggested [5].

Here, we apply text mining to standard documents to better understand trend analysis and research trends. International standard documents are a record of societal orientation, and have great historical value for technologies. Therefore, we analyzed the Recommendations in the International Telecommunication Union Telecommunication Standardization Sector (ITU-T) to perform objective analysis of international standards and information technology (IT) research.

While topic modeling, a text mining technique, is a statistical inference model developed for finding hidden topics in a text, it has not been used for the analysis of international standards. Therefore, we have collected the international standard documents published by ITU-T, an international standard organization, and examined topics of the international standards by performing topic modeling experiments based on a latent dirichlet allocation (LDA) algorithm [6]. Additionally, we have developed the Trend Analysis System for International Standards (TASIS), which performs topic modeling and trend analysis automatically, making it possible to analyze trends at various points, in accordance with user requirements.

2. RELATED WORK

2.1. Trend Analysis

A trend is defined as a method of identifying and describing specific changes over a long period of time, and the future can thus be predicted using past patterns [7]. Trend analysis for predicting the rapidly advancing IT field is becoming increasingly important. Qualitative research and trend analysis methods based on the opinions of the experts have the probability of individual subjectivity. On the other hand, quantitative research and trend analysis methods are employed for performance evaluation and predicting the future using collected data, such as papers and articles. Therefore, researchers are trying to overcome these limitations by combining quantitative and qualitative research methods [8, 9]. One of the solutions for solving these limitations is a text mining methodology that analyzes trends based on text data. Trend analysis using text mining is a technique for extracting meaningful patterns from digitized text in unstructured data. As such, we can extract main topics in related fields based on accumulated research literature or papers, and determine trend patterns using international standard documents.

Trend analysis research using text mining has been conducted in various fields. First, research on determining the topics of recent active research have been implemented using topic modeling for text mining in Proceedings of the National Academy of Sciences (PNAS) abstracts [10]. Second, there are studies on topic detection and trend analysis methodology using LDA algorithms [11]. Moreover, research has contributed to the realization of business intelligence for banks by analyzing its application from 2002 to 2013 using an LDA algorithm [12].
2.2. Latent Dirichlet Allocation (LDA)

Topic modeling is a document analysis model that predicts the structure of a document by expressing it as a stochastic mixture of topics and each topic as a distribution of words. In other words, it is a statistical inference model for determining hidden topics in documents. One of the most popular topic modeling techniques is the LDA algorithm. The algorithm is attracting attention as a new paradigm of semantic expression, which overcomes the disadvantages of Probabilistic Latent Semantic Indexing (PLSI)-based topic representation techniques [13].

As previously mentioned, the LDA algorithm is a generation model that finds hidden topics in a document. The generation model is the process of creating the actual document, and models what subjects are included in each document to create it. Therefore, it infers hidden variables such as document structure through observed variables such as words. As a result, we can understand the subject of an entire document set from each topic. This relationship can be expressed as a stochastic graph model as per Figure 1 [14].

The N plate denotes the collection of words and the D plate the collection of topics. The K plate denotes the number of clusters. Each node is a random variable, and is labeled according to its role in the generative process. The LDA algorithm can predict hidden variables, such as topic proportions (θ), per-word topic assignment (Z), and topic (β) using observed variables such as words and documents. These parameters are extracted based on the dirichlet parameters (α, η). The dirichlet parameters are the word counts, including each cluster.

![Fig. 1. Probabilistic Graph Model of LDA](image)

3. INTERNATIONAL STANDARDS DOCUMENTS

ITU was established in May 1865 under the United Nations, comprising three sectors: the radio-communication sector, which deals with issues such as radio regulations and frequency allocation; the telecommunication sector, which deals with issues of telecommunication technology and operation; and the development sector, which deals with policy and technical support for network modernization.

The ITU-T is a standardization-related sector in ITU, related to telecommunication technology. In this study, we collected a total of 252 ITU-T Recommendations data of Y series from the ITU official site to analyze international standard trends [15]. The data is in PDF format and categorized by each series, for a total of 23 series. The series are then categorized into international standard documents related to each subject.

The ITU-T International Standard document consists of cover, summary, and contents [16]. First, the cover has a representative title. Second, the summary summarizes the document. Finally, the content contains descriptions such as scope, references, definitions, abbreviations, conventions, content, annex, and bibliography as per Table 1. Many individuals, such as researchers and developers, develop technologies based on the standards written in each international standard document. Since each international standard document is based a title, it becomes important data for topic modeling. Therefore, the entire text in each standard document is the main data for trend analysis.

<table>
<thead>
<tr>
<th>Number</th>
<th>Table of Contents</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scope</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>References</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Definitions</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Abbreviations and acronyms</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Conventions</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Overview of big data</td>
<td>3</td>
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<td>7</td>
<td>Cloud computing based big data</td>
<td>6</td>
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<td>8</td>
<td>Requirements of cloud computing based big data</td>
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<td>9</td>
<td>Cloud computing based big data capabilities</td>
<td>14</td>
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<td>10</td>
<td>Security considerations</td>
<td>16</td>
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<td>Appendix 1</td>
<td>Use cases of cloud computing in support of big data</td>
<td>17</td>
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<tr>
<td>Appendix 2</td>
<td>Use cases of cloud computing based big data analysis services</td>
<td>26</td>
</tr>
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<td>Appendix 3</td>
<td>Mapping of big data ecosystem roles into user view of ITU-T Y.3502</td>
<td>29</td>
</tr>
<tr>
<td>Bibliography</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

4. TREND ANALYSIS SYSTEM FOR INTERNATIONAL STANDARDS (TASIS)


We have designed a system architecture for TASIS using text mining as per Figure 2. First, we collected ITU-T Recommendations documents and created a document set. Second, we preprocessed a document set for analysis converting it from PDF to TXT, and then we deleted unnecessary data and unified the data format using Java language. In other words, it is designed to integrate keywords by deleting symbols and specific characters and applying preprocessing techniques, such as lemmatization. The database consists of two tables. The document table is used to show the results of the LDA algorithm. This table is used as a database for the topic modeling function. The topic table is constructed to show the representative topic of each document. This table is used as a database for trend analysis and the document find function.
The TASIS has one configuration step and two functions. The configuration step is user configuration, designed to enable the actual web service by setting the series and year ranges of international standard document that the user wants to directly analyze. Additionally, the number of clusters and of iterations can be set when applying the LDA algorithm for topic modeling. The Topic Modeling Function is designed to allow users to easily recognize the size of each topic, while receiving the topic modeling results after applying the LDA algorithm. Another function is the Trend Analysis and Document Find Function, which represents trend graph for the keywords in the user-selected topic and then provides a list of relevant international standard documents for the keyword.

4.2. Database Construction
The entire collection of international standard documents has been downloaded from the International ITU web page. We are collected 252 documents for the Y series (global information infrastructure, internet protocol aspects, and next-generation networks) of the ITU-T international standard [15]. As previously mentioned, the collected PDF files were converted to text for analysis. We removed from them stop words, symbols in documents, and then implemented lemmatization to obtain the correspondence between keywords.

We designed following two tables in our database schema, so that TASIS implements the corresponding functions according to their purposes. The document table, whose key value is the number of the document (Series ID), is constructed from the actual data of each document. As shown in Figure 3, the document table is composed of the title of the document (Title); series of the document (Series), such as Y; year of publication (Year); content (Content); and the URL link to download the document (Link). After implementing the LDA algorithm to extract a representative topic from the document table, we constructed the topic table, whose key value is the number of the document (Series ID), and is constructed from representative topics for topic modeling. This table is composed of the representative topic (Topic) extracted by applying the LDA algorithm, Dirichlet parameter (Dirichlet Parameter), and occurrence rate normalized by the dirichlet parameter (Occurrence Rate).

Particularly, the value of the dirichlet parameter in the Topic table is the word count value as the representative topic of each document [6, 14], which has been extracted by performing the LDA algorithm after configuring, as the number of clusters and iteration is one. The LDA algorithm is based on the expectation-maximization algorithm in unsupervised learning algorithms [17]. Therefore, if the number of clusters is one, the word count value is extracted regardless of the number of iterations.

Since the number of words in each document is different, we need to perform a normalization that allows all documents to be viewed equally. The total sum of the dirichlet parameters for each document is divided by the dirichlet
parameter of the keyword in the topic representing each document as per the expression below, and the total sum of the occurrence rate is 100.

\[
\text{Occurrence Rate(\%)} = \frac{\text{Dirichlet Parameter}_i}{\sum_{i=1}^{\text{Total Dirichlet Parameter}}} \times 100
\]

As per Table 2, the keywords of the representative topics of Recommendation ITU-T Y.3501: Cloud computing – Framework and high-level requirements document are service, cloud, CSP, CSC, computing, datum, capability, application, resource, note. By calculating the occurrence rate, TASIS can provide that the “service” keyword is a keyword that accounts for 24.7% of the representative topics in the Y.3501 international standard document.

<table>
<thead>
<tr>
<th>Series id</th>
<th>Topic</th>
<th>dirichlet_parameter</th>
<th>occurrence_rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y.3501</td>
<td>service</td>
<td>204</td>
<td>24.7</td>
</tr>
<tr>
<td>Y.3501</td>
<td>cloud</td>
<td>177</td>
<td>21.5</td>
</tr>
<tr>
<td>Y.3501</td>
<td>CSP</td>
<td>103</td>
<td>12.5</td>
</tr>
<tr>
<td>Y.3501</td>
<td>computing</td>
<td>67</td>
<td>8.1</td>
</tr>
<tr>
<td>Y.3501</td>
<td>datum</td>
<td>56</td>
<td>6.8</td>
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<td>Y.3501</td>
<td>capability</td>
<td>48</td>
<td>5.8</td>
</tr>
<tr>
<td>Y.3501</td>
<td>application</td>
<td>44</td>
<td>5.3</td>
</tr>
<tr>
<td>Y.3501</td>
<td>resource</td>
<td>40</td>
<td>4.8</td>
</tr>
<tr>
<td>Y.3501</td>
<td>note</td>
<td>33</td>
<td>4</td>
</tr>
</tbody>
</table>

4.3. Topic Modeling Function

Topic modeling, performed by user-defined values, is implemented using the Mallet API for the topic results provided by LDA algorithm. Mallet API is a machine learning for language toolkit [18], being an API based on Java, which can perform various machine learning functions, such as text natural language processing, document classification, document clustering, topic modeling, and information extraction. Additionally, TASIS provides a graph based on the number of dirichlet parameters. The graph is represented in TreeMap. It recursively subdivides area into rectangles [19]. As a result, the topic that represents the range by the cluster of the largest colored area among all clusters is the representative topic in Figure 4.

4.4. Trend Analysis and Document Find Function

By clicking each keyword in the table, the corresponding Trend Analysis and Document Find Function provides trend analysis and the international standard document list in Figure 5. TASIS shows an international standard document list represented by the occurrence rate in the topic table. The documents can be sorted in descending order using the occurrence rate of the keyword. The table displayed on the web page is composed of a document number (Document), publication year (Year), occurrence rate (Occurrence Rate), and a title of the document (Title). Additionally, the user is provided with a detailed document page and a link for downloading, by implementing the hyperlink function in the document number.
The trend analysis function is implemented to display the graph by summing the occurrence rate of each document for each year. This function is implemented using the FusionCharts API [20]. The occurrence rate is the percentage of a representative keyword in the topic that represents each document, an important criterion for trend analysis.

5. EXPERIMENTS AND RESULTS

5.1. Experimental data

We collected 252 documents of Y series (Global information infrastructure, internet protocol aspects, and next-generation networks) from the ITU-T Recommendations in Table 3. To experiment with the Topic Modeling Function and the Trend Analysis and Document Find Function, we used all Y series documents.

Table 3. Documents for Experiments

<table>
<thead>
<tr>
<th>Documents</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y.100 - Y.999</td>
<td>Global information infrastructure</td>
</tr>
<tr>
<td>Y.1000 - Y.1999</td>
<td>Internet protocol aspects</td>
</tr>
<tr>
<td>Y.2000 - Y.2999</td>
<td>Next Generation Networks (NGN)</td>
</tr>
<tr>
<td>Y.3000 - Y.3999</td>
<td>Future networks</td>
</tr>
<tr>
<td>Y.3500 - Y.3999</td>
<td>Cloud Computing</td>
</tr>
<tr>
<td>Y.4000 - Y.4999</td>
<td>Internet of things (IoT) and smart cities and communities</td>
</tr>
</tbody>
</table>

5.2. Results

We implemented three different experiments to show the effects of the number of topics and iterations in Table 4. For the topic modeling experiments, we set the elements of TASIS to Y series and the year range from 1998 to 2016. In the experiment, each cluster is a topic. At first, after the TASIS implemented 1 topic and 1000 iterations, we can see that service, network, and function are keywords with high weights in Y series documents (a). It is only shown to word count. Second, the TASIS performed 10 topics and 1 iteration and then sorted in descending order the topics by the dirichlet parameter (b). The result are based on the word count because of the one iteration. As the LDA algorithm for topic modeling of the TASIS is based on the expectation-maximization (EM) algorithm [16], if the number of iterations is set to 1, the optimized result cannot be extracted. Finally, the TASIS implemented 10 topics and 1000 Iterations (c). As per (c), we have also verified topic 0, which includes service, ngn, and network, and extracted it as high proportional topic, and topic 1, which includes service, resource, and cloud, being confirmed the second highest proportional topic. We can thus understand various topics representing Y series documents. As a result, the topic modeling using LDA to extract qualified topics is necessary to specify appropriate the topic number and iterations.

As per Figure 5, TASIS extracted the documents related to the IoT as the result of the experiment for the Document Find Function. Among the 252 documents, the most relevant international standard documents are Recommendation ITU-T Y.2074: The Requirements for Internet of things devices and operation of Internet of things applications during disasters and Y.2066: Common requirements of the Internet of things. On the other hand, the
### Table 4. Results of Cluster and Iteration Experiments using Topic Modeling

<table>
<thead>
<tr>
<th>Topic</th>
<th>Keywords / Dirichlet Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 service</td>
<td>network 19994 9553 8436 8171 3680 6946 6750 5974 5579</td>
</tr>
</tbody>
</table>

(a) Cluster: 1, Iteration: 1000

<table>
<thead>
<tr>
<th>Topic</th>
<th>Keywords / Dirichlet Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 service</td>
<td>network function user information application support control capability ngn</td>
</tr>
<tr>
<td>1 service</td>
<td>network function information user application control support resource management</td>
</tr>
<tr>
<td>2 service</td>
<td>network function information user application control support capability management</td>
</tr>
<tr>
<td>3 service</td>
<td>network function information user application control support resource management</td>
</tr>
<tr>
<td>4 service</td>
<td>network function information user application support control access capability</td>
</tr>
<tr>
<td>5 service</td>
<td>network function information user control application support capability management</td>
</tr>
<tr>
<td>6 service</td>
<td>network function information user control application support capability access</td>
</tr>
<tr>
<td>7 service</td>
<td>network function user information application support control access capability</td>
</tr>
<tr>
<td>8 service</td>
<td>network function information user application support control capability management</td>
</tr>
<tr>
<td>9 service</td>
<td>network function information user application control support capability access</td>
</tr>
</tbody>
</table>

(b) Cluster: 10, Iteration: 1

<table>
<thead>
<tr>
<th>Topic</th>
<th>Keywords / Dirichlet Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 service</td>
<td>ngn 2949 2693 2319 1563 1496 1357 1350 1222 1195</td>
</tr>
<tr>
<td>1 service</td>
<td>resource cloud management user virtual network function application component</td>
</tr>
<tr>
<td>2 service</td>
<td>function network service control functional user information access multicast</td>
</tr>
<tr>
<td>3 service</td>
<td>content service function network user capability information functional PTV delivery</td>
</tr>
<tr>
<td>4 service</td>
<td>network layer service VPN plane node control information function management</td>
</tr>
<tr>
<td>5 service</td>
<td>application device capability int datatm service support information management</td>
</tr>
<tr>
<td>6 service</td>
<td>network ipv6 id address broadcast ngn data user access ipv4</td>
</tr>
<tr>
<td>7 service</td>
<td>packet network ip performance traffic service service qos parameter measurement delay</td>
</tr>
<tr>
<td>8 service</td>
<td>connection information request service path network multi flow access control</td>
</tr>
<tr>
<td>9 service</td>
<td>ATM network ip mpls MPLS ip packet layer label field</td>
</tr>
</tbody>
</table>

(c) Cluster: 10, Iteration: 1000

<table>
<thead>
<tr>
<th>Topic</th>
<th>Keywords / Dirichlet Parameter</th>
</tr>
</thead>
</table>
| other documents, except documents including the international standard document list, did not include the IoT keyword as the representative topic. Therefore, it is not included in the international standard document list. In conclusion, the occurrence rate of each keyword in each document is the main element for trend analysis and finding related documents.

TASIS extracted topic keywords by performing topic modeling by the year range and using 252 documents of the Y series as per Table 5. We constitute a year range of four years, because of the period for ITU-T Recommendations. Service and network are common keywords in the subject of Y series. The IP and GII of 10 keywords are extracted from 1997 to 2000 as keywords. GII is global information infrastructure and subject of recommendations Y.100–Y.999. IP is internet protocol. Documents including the keyword have also been published, such as Recommendation ITU-T Y.1001: IP frame work and Y.1231: IP Access Network Architecture, and so on. From 2001 to 2004, the TASIS extracted ATM (automated teller machine) and MPLS (multiprotocol label switching). These keywords are correlated because the technologies have developed together and international standards have been published together, such as Recommendation ITU-T Y.1411: ATM-MPLS network interworking—Cell mode user plane interworking

### Table 5. Results of Topic Modeling by Year Range with Y Series

<table>
<thead>
<tr>
<th>Year Range</th>
<th>Keywords</th>
</tr>
</thead>
</table>
Challenges for a data-driven society

and Y.1712: OAM functionality for ATM-MPLS interworking. From 2005 to 2008, PSTN (public switched telephone network) and ISDN (integrated service digital network) are extracted by TASIS. These keywords have a correspondence relationship such as Recommendation ITU-T Y.2031: PSTN/ISDN emulation architecture. NGN (next generation network), IPv6 (Internet protocol version 6), and IPTV (internet protocol television) are extracted by TASIS from 2009 to 2012. NGN and IPv6 have a correspondence relationship such as NGN based on IPv6 [21]. Additionally, NGN and IPTV have correspondence relationship such as Recommendations ITU-T Y.1900–Y.1999: IPTV over NGN. Finally, Cloud and IoT are extracted by TASIS from 2013 to 2016. These keywords have recently been described as hot trend keywords. For example, the subject of Recommendations ITU-T Y.3500–Y.3999 is Cloud Computing and subject of Recommendations ITU-T Y.4000–4999 is Internet of Things and Smart Cities and Communities. Therefore, TASIS shows that many international standard documents including the cloud and IoT keywords have recently been published. In addition, Gartner Trends are also extracted these keywords [22].

6. CONCLUSION

We proposed TASIS, which automatically performs topic modeling and trend analysis on document collections of the ITU-T Recommendations. The TASIS based on an LDA algorithm provides the results of topic modeling to users and a list of the documents relevant to each keyword in a topic. Moreover, TASIS also describes a TreeMap and trend analysis graphs for easier understanding.

Experiments with the Y series of ITU-T Recommendations using TASIS have shown a limit in understanding the comprehensive trend analysis pattern. In future work, analysis of the entire documents in the ITU-T Recommendations will be conducted. Additionally, research to predict the publication of international standards for the future technologies such as artificial intelligence or block chain will be implemented.

ACKNOWLEDGEMENTS

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REFERENCES


EXPLOITING MULTI-RADIO COOPERATION IN HETEROGENEOUS WIRELESS NETWORKS FOR ABSOLUTE SECURITY AGAINST EAVESDROPPING

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ABSTRACT

In this paper, we consider a heterogeneous wireless communication scenario, which is comprised of a source (S) and a destination (D) in the presence of an eavesdropper (E), each equipped with multiple heterogeneous radio access interfaces. In order to enhance the transmission security against eavesdropping, we propose a multi-radio cooperation (MRC) scheme, where the multiple radio interfaces at S are simultaneously utilized to transmit a source signal to D along with a weight design. For the convenience of performance comparisons, the conventional multi-radio switch (MRS) scheme is also considered as a benchmark scheme, in which only the single “best” radio interface is selected at S to transmit the source signal. We evaluate the secrecy capacity and intercept probability (IP) of conventional MRS and proposed MRC schemes over Rayleigh fading channels. It is proved that the proposed MRC scheme can achieve an absolute security with zero IP, which is further validated through Monte-Carlo simulations. Numerical results show that the proposed MRC scheme performs better than conventional MRS scheme in terms of their secrecy capacity and IP.

Keywords— Heterogeneous wireless communication, multi-radio cooperation, physical layer security, absolute security

1. INTRODUCTION

Nowadays, mobile communication systems have evolved to a heterogeneous wireless network with the coexistence of multiple radio access technologies for meeting the demand of different wireless terminals. Due to the vulnerability of heterogeneous wireless networks, there are various kinds of security threats [1], and the wiretap attack is an important part of them. With the rapid development of quantum computers, the traditional secret key encryption is very difficult to completely prevent wiretap attacks, because eavesdroppers can decrypt the secret key with powerful computing. To is end, researchers devote to exploring physical layer security against eavesdroppers by making full use of the physical characteristics of wireless channels. In [2], the secrecy capacity, defined as the difference between the capacity of main channel and that of wiretap channel, was presented to characterize the secrecy performance of wireless communication. If the secrecy capacity is always positive, absolute confidentiality is achieved.

At present, cooperative physical-layer security has attracted much attention of researchers, which is capable of enhancing the secrecy performance in wireless fading environments. In [3], Lu investigated opportunistic relay and jammer cooperation in multiple-input multiple-output buffer-aided relay networks in which several relays are selected to protect the transmission of legitimate users and other relays are used to act as jammers to interfere the eavesdroppers. In [4], the authors proposed relay selection for protecting the physical layer security of wireless transmissions from secondary transmitter to secondary destination against eavesdroppers in a cognitive radio network. In [5], Zou studied a source cooperation aided opportunistic jamming scheme for enhancing the secrecy performance of wireless communication against eavesdropping for spectrum sharing systems. The author also derived the closed-form intercept probability (IP) expression for the proposed opportunistic jamming scheme over Rayleigh fading channels. It was shown that the IP performance of spectrum sharing systems is improved significantly by exploiting opportunistic jamming.

With the continuously increasing requirements of wireless network performance, researchers focus their attention on the study of multi-radio cooperation (MRC) [6]-[8], for heterogeneous wireless networks. The existing MRC technology is mainly used for the integration of heterogeneous wireless networks to reduce the multi-radio switch delay, expand the coverage of wireless network, improve channel capacity and reduce energy consumption. To the best of our knowledge, less attention has been paid to employing MRC to improve physical layer security in heterogeneous wireless networks. Motivated by the above observation, we explore the use of MRC technology to defend against eavesdropping in heterogeneous wireless networks. We propose a MRC scheme, where the multiple radio interfaces at S are simultaneously utilized to transmit a source signal to D along with an optimal weight design. For convenience of performance comparison, the conventional multi-radio switch (MRS) scheme is also considered as a benchmark, in which only the single “best” radio interface is selected at source S to transmit the source signal. We evaluate the secrecy capacity and IP of conventional MRS and proposed MRC schemes over Rayleigh fading channels. It is proved that the proposed MRC scheme can achieve an absolute security with zero IP, which is further validated through Monte-Carlo simulations. Numerical re-
The reminder of this paper is summarized as follows. Section II shows the system model of heterogeneous wireless networks and proposes the MRC scheme. For comparison purposes, the conventional MRS scheme is also presented in this section. Also, we characterize the secrecy capacity and IP of both MRS and MRC schemes. Furthermore, in Section III, we present the proof of an absolute security with zero intercept probability for the proposed MRC scheme. Next, numerical and simulation results are shown in Section IV. Finally, Section V gives some concluding remarks.

2. MULTI RADIO COOPERATION IN HETEROGENEOUS WIRELESS NETWORKS

2.1. System Model

Fig. 1 shows a block diagram of proposed MRC scheme for heterogeneous wireless networks consisting of a source and a destination in the face of an eavesdropper.

Fig. 1. A block diagram of proposed MRC scheme for heterogeneous wireless networks consisting of a source and a destination in the face of an eavesdropper.

sults show that proposed MRC scheme performs better than conventional MRS scheme in terms of their secrecy capacity and intercept probability.

The received signal at a destination (D) is given by

\[ y_d = k_i h_{id} x + n_d, \quad i = 1, 2, \ldots, N \]  \hspace{1cm} (1)

where \( h_{id} \) is the fading coefficient of the S-D channel in the i-th mode, \( x \) is the signal to be transmitted by S, \( n_d \) is the AWGN encountered by D, \( k_i = \sqrt{G_i G_r \lambda_i^{1/2}} d^{-n_i} \) and \( G_i \) and \( G_r \) are the antenna gains of transmit and receive power, respectively; \( \lambda_i \) represents the wavelength of signal in the i-th mode; \( d \) represents the distance between devices, and \( n_i \) is the path loss factor in the i-th mode. Meanwhile, the received signal at E for the i-th mode is expressed as

\[ y_e = k_i g_i x + n_e, \quad i = 1, 2, \ldots, N \]  \hspace{1cm} (2)

where \( g_i \) is the fading coefficient of the S-E channel in the i-th mode, and \( n_e \) is the AWGN encountered by E. According to Shannon’s formula and combining (1) with (2), the capacity of main channel (from S to D) and wiretap channel (from S to E) in the i-th mode can be written as

\[ C_{id} = \log_2(1 + \gamma |k_i h_{id}|^2) \]  \hspace{1cm} (3)
and
\[ C_{se} = \log_2(1 + \gamma||w^T g||_2^2), \]  
respectively. Hence, we can obtain the secrecy capacity as
\[ C_s^{\text{MRC}} = \log_2 \left( \max_{w} \frac{1 + \gamma||w^T h||_2^2}{1 + \gamma||w^T g||_2^2} \right) \]
s.t. \[ ||w||_2^2 = 1. \]
We consider optimization problem:
\[ \max_{w} \frac{1 + \gamma||w^T h||_2^2}{1 + \gamma||w^T g||_2^2} \]
s.t. \[ ||w||_2^2 = 1. \]
By taking the constraint into the objective function, (13) is rewritten as
\[ \max_{w} \frac{\mathbf{w}^H (\mathbf{I} + \Upsilon \mathbf{h} \mathbf{h}^H) \mathbf{w}}{\mathbf{w}^H (\mathbf{I} + \Upsilon \mathbf{g} \mathbf{g}^H) \mathbf{w}}, \]
where superscript \( H \) represents the conjugate transpose factor. For convenience’ sake, letting \( A = \mathbf{I} + \Upsilon \mathbf{h} \mathbf{h}^H \) and \( B = \mathbf{I} + \Upsilon \mathbf{g} \mathbf{g}^H \), it can be readily observed that \( A \) and \( B \) are Hermitian matrices [9]. Define a new vector \( \mathbf{w}_1 = \mathbf{B}^{1/2} \mathbf{w} \) and substitute \( \mathbf{w}_1 \) into (14), (14) is calculated as
\[ \mathbf{w}_1^H (\mathbf{B}^{-1/2})^H A (\mathbf{B}^{-1/2}) \mathbf{w}_1, \]
which means the generalized Rayleigh quotient of matrix pencil \((A, B)\) is equivalent to the Rayleigh quotient of matrix \((\mathbf{B}^{-1/2})^H A (\mathbf{B}^{-1/2})\). According to Rayleigh quotient theorem [9], if vector \( \mathbf{w} \) is the corresponding eigenvector of \( \lambda \), the largest eigenvalue of \((\mathbf{B}^{-1/2})^H A (\mathbf{B}^{-1/2})\), \( \lambda \) is called as the largest generalized Rayleigh quotient of \((\mathbf{B}^{-1/2})^H A (\mathbf{B}^{-1/2})\). And the eigenvalue decomposition of \((\mathbf{B}^{-1/2})^H A (\mathbf{B}^{-1/2})\) is equivalent to the eigenvalue decomposition of \( \mathbf{B}^{-1} A \). Thus, if we want to maximize the generalized Rayleigh quotient as shown in (14), the vector \( \mathbf{w} \) must be the eigenvector corresponding to the largest eigenvalue of the matrix pencil \((A, B)\). Based on the above analysis, in order to maximize (14), the optimal vector of (14), denoted by \( \mathbf{w}^* \), should be the corresponding eigenvector of the largest eigenvalue of \((\mathbf{I} + \Upsilon \mathbf{g} \mathbf{g}^H)^{-1}(\mathbf{I} + \Upsilon \mathbf{h} \mathbf{h}^H)\), denoted by \( \lambda_{\text{max}} \). Furthermore, \( \lambda_{\text{max}} \) is the result of (14), which means
\[ C_s^{\text{MRC}} = \log_2 \left( \frac{(\mathbf{w}^*)^H (\mathbf{I} + \Upsilon \mathbf{h} \mathbf{h}^H) \mathbf{w}^*}{(\mathbf{w}^*)^H (\mathbf{I} + \Upsilon \mathbf{g} \mathbf{g}^H) \mathbf{w}^*} \right) = \log_2(\lambda_{\text{max}}). \]

Additionally, the IP of the MRC scheme can be expressed as
\[ P_{\text{MRC}}^{\text{int}} = \Pr \left( C_s^{\text{MRC}} < 0 \right) = \Pr \left( \log_2(\lambda_{\text{max}}) < 0 \right) = \Pr \left( \lambda_{\text{max}} < 1 \right). \]

### 3. PROOF OF ABSOLUTE SECURITY OF THE PROPOSED MRC SCHEME

From the simulation results of (17), we are surprised to find that the MRC scheme can achieve an absolute security with
zero IP under the condition that the channel state information could be obtained by S, which encourages us to verify this phenomenon. We first provide a theorem that will be used later.

**Theorem 1** Let a and b be two known n-dimensional non-zero vectors (n > 1) [10].

1) if a = ξb for a certain scalar ξ, aa^H − bb^H has only one non-zero eigenvalue, which is equal to (ξ^2 − 1) ||b||^2 with the corresponding unit eigenvector b/||b||^2.

2) if a^Hb = 0, aa^H − bb^H has only two non-zero eigenvalues λ_1 = ||a||^2, λ_2 = −||b||^2 with corresponding unit eigenvector a/||a||^2 and b/||b||^2, respectively.

3) if a ≠ ξb and a^Hb ≠ 0, aa^H − bb^H has only two non-zero eigenvalues λ_1 = ||a||^2 − c_2||a||^2||b||^2 − 2c_2||a^Hb||, λ_2 = ||a||^2 − c_4||a^Hb|| < 0 with the corresponding eigenvectors u_1 = c_1^2(1 + c_2^2(ν−φ))a = c_3^2(1 + c_4^2(ν−φ))b, where

\[ c_1 = ||a||^2 + c_2^2||b||^2 - 2c_2||a^Hb||, \]
\[ c_2 = \frac{||a||^2 + ||b||^2 - ||a^Hb||^2}{2||a||^2||b||^2} - 4||a^Hb||^2, \]
\[ c_3 = ||a||^2 + |c_4|^2||b||^2 - 2c_4||a^Hb||, \]
\[ c_4 = \frac{||a||^2 + ||b||^2 + ||a^Hb||^2 - 4||a^Hb||^2}{2||a||^2||b||^2}. \]

Because it is simple to prove theorem 1, we omit the process of the proof. Below, we prove that λ_{max} of (14) is greater than 1, which means that the MRC scheme can achieve an absolute security with zero IP.

\[ \lambda_{max} = \lambda_{max} \left( I + \Upsilon g g^H \right) = \lambda_{max} \left( I + \Upsilon g g^H \right) \left( I + \Upsilon h h^H \right)^{-\frac{1}{2}} \left( I + \Upsilon h h^H \right)^{-\frac{1}{2}}. \]

\[ \text{Letting } Z = \left( I + \Upsilon g g^H \right)^{-\frac{1}{2}} \left( I + \Upsilon h h^H \right) \left( I + \Upsilon g g^H \right)^{-\frac{1}{2}}, \text{ then (18) can be transformed into} \]
\[ \lambda_{max} \left( I + \Upsilon g g^H \right)^{-1} \left( I + \Upsilon h h^H \right) = \lambda_{max} (Z). \]

Since
\[ Z = \left( I + \Upsilon h h^H \right)^{-\frac{1}{2}} \left( I + \Upsilon g g^H \right) \left( I + \Upsilon g g^H \right)^{-\frac{1}{2}} = \left( I + \Upsilon h h^H \right)^{-\frac{1}{2}} + \Upsilon \left( I + \Upsilon g g^H \right)^{-\frac{1}{2}} h h^H \left( I + \Upsilon g g^H \right)^{-\frac{1}{2}}, \]
and \( \left( I + \Upsilon g g^H \right)^{-1} = I - \frac{\Upsilon g g^H}{1 + \gamma ||g||^2} \), we can obtain
\[ Z = I - \frac{\Upsilon g g^H}{1 + \gamma ||g||^2} + \gamma \left( I - \frac{\Upsilon g g^H}{1 + \gamma ||g||^2} \right) h h^H \left( I - \frac{\Upsilon g g^H}{1 + \gamma ||g||^2} \right)^{-\frac{1}{2}} \]
\[ = I + \gamma U A^2 U^H h h^H U A^2 U^H = \frac{\gamma g g^H}{1 + \gamma ||g||^2}, \]
From (20), we can obtain
\[ \lambda_{max} (Z) = 1 + \lambda_{max} \left( \gamma U A^2 U^H h h^H U A^2 U^H - \frac{\gamma g g^H}{1 + \gamma ||g||^2} \right). \]

Letting \( x = \sqrt{\gamma} U A^2 h h^H \) and \( y = \sqrt{\gamma} ||g||^2 \), we can obtain \( \lambda_{max} (Z) = 1 + \lambda_{max} (x x^H - y y^H) \), where \( \lambda_{max} \) represents the largest eigenvalue of xx^H − yy^H. According to theorem 1, we can obtain \( \lambda_{max} (x x^H - y y^H) > 0 \). As a result, \( \lambda_{max} (Z) > 1 \) is proved.

### 4. NUMERICAL RESULTS AND DISCUSSIONS

In this section, we present numerical and simulation results for MRC and MRS schemes in terms of secrecy capacity and IP. Throughout the numerical performance evaluation, we assume that the background noise at any node in the heterogeneous wireless network shown in Fig. 1 has the same variance \( N_0 \). And we also assume that the transmission link in any mode shown in Fig. 1 is modeled by the Rayleigh fading channel with the consideration of large-scale path loss. For notational convenience, let \( \sigma_{h_1}^2 \) and \( \sigma_{h_2}^2 \) denote \( \mathbb{E}(|h_1|^2) \) and \( \mathbb{E}(|g|^2) \), respectively, and let \( \sigma_{h_1}^2 / \sigma_{h_2}^2 \) refer to as the main-to-eavesdropping ratio (MER), where \( \sigma_{h_1}^2 \) and \( \sigma_{h_2}^2 \) satisfy equations \( \sigma_{h_1}^2 = k_1^2 \sigma_{h_2}^2 \) and \( \sigma_{g_1}^2 = k_2^2 \sigma_{g_2}^2 \), respectively.

Fig. 2 depicts the secrecy capacity comparison between MRC and MRS schemes with \( \sigma_{h_1}^2 = 1 \) and \( \sigma_{g_2}^2 = 0.1 \). It is shown from Fig. 2 that no matter the number of radio modes \( N = \frac{1}{2} \).
2 or 4, the secrecy capacity of MRC scheme is always higher than that of MRS scheme. Furthermore, as $N$ increases from 2 to 4, the secrecy capacity of MRC and MRS schemes increases significantly. Based on the above analysis, we can conclude that the performance of the proposed MRC scheme is much better than the conventional MRS scheme.

Fig. 3 shows the IP versus MER of MRC and MRS schemes for different number $N$ with $P = 10W$ and $\sigma_g^2 = 0.1$. It can be observed from Fig. 3 that as MER increases, the IP of MRS scheme decreases accordingly. Meanwhile, as the number of $N$ increases from 2 to 4, the IP of the MRS scheme decrease wholly. Furthermore, we can obviously find that no matter $N$ is equal to 2 or 4, the IP of the MRC scheme is always equal to 0. This means that MRC scheme can achieve an absolute security with zero IP.

Fig. 4 shows secrecy capacity versus main-to-eavesdropper ratio of MRC and MRS schemes with $P = 10W$ and $\sigma_g^2 = 0.1$. From Fig. 4, we can find that the secrecy capacity of the MRC scheme is always greater than that of the MRS scheme, which shows that MRC scheme is significantly better than MRS scheme in terms of secrecy capacity. And the secrecy capacity of both the two schemes increases with the augment of MER.

Fig. 5 presents the IP versus input signal power of MRC and MRS schemes for different number $N$ with $\sigma_h^2 = 1$ and $\sigma_g^2 = 1$. Observing from Fig. 5, as input signal power increases, the IP of MRS scheme remains unchanged for different $N$, which confirms (7) well. And it is unsurprised for us to find that the IP of MRC scheme is always equal to 0, which means that MRC scheme can achieve an absolute security with zero IP again.

5. CONCLUSION

In this paper, we considered the use of multi-radio cooperation to protect wireless communications against eavesdropping and proposed a so-called MRC scheme. Conventional MRS method was also considered for the purpose of comparison. Specifically, the proposed MRC simultaneously exploits the multiple radio interfaces of $S$ in a weighted manner, whereas only the single radio interface is selected for use in the MRS method. It was proved that the proposed MRC scheme achieves an absolute security against eavesdropping under the condition that the channel state information of both main channel and wiretap channel is known by $S$. Additionally, numerical performance comparisons between the conventional MRS and proposed MRC schemes were provided in terms of their secrecy capacity and IP. It was shown that the secrecy performance of proposed MRC scheme is always better than that of conventional MRS method.

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REFERENCES


THE IMMUTABILITY CONCEPT OF BLOCKCHAINS AND BENEFITS OF EARLY STANDARDIZATION

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ABSTRACT

The blockchain technology can be regarded as a groundbreaking invention with the potential to bring the digital revolution to the next stage by helping to realize peer economy solutions. The blockchain technology and the concept of blockchain immutability is discussed. The benefits of early standardization of the blockchain technology are argued based on the literature and the analysis of the central blockchain immutability characteristic. From this, a framework is proposed aimed at understanding the dimensions and boundaries of blockchain immutability. The resulting framework is suggested as a good practice standard for the implementation of blockchain systems. Based on these efforts, the article supports initiatives to better exploit the blockchain technology’s full potential by standardization.

Keywords— blockchain, standard, immutability, peer economy

1. THE PEER ECONOMY AND THE ROLE OF THE BLOCKCHAIN TECHNOLOGY

The digital revolution has been heavily impacting organizations, economies and modern societies in the last decades ([1] p. 4-9). As one of the latest waves of IT innovations following social media, mobile devices, the internet as well as personal and mainframe computers in the last decades ([2] p. xii), the blockchain technology, spearheaded by the innovative Bitcoin application, has emerged as a potentially disruptive IT innovation [3][4][5].

The disruptive effects of the blockchain technology do not only concern business models by bringing intermediaries under competition, as it allows intermediary services without single trusted actors [6][7][8]. It has as well the potential to be an answer to the global change in markets driven by automation: Digitization is not just about the ubiquitous use of algorithms and ICT that revolutionize labor and consumer markets, but it also enables new opportunities in the form of IT-supported collaboration in the "peer economy" ([1] pp. 243): Tasks are split and sourced to a crowd instead of using well defined organizations. Peer-to-peer exchanges and collaboration between people allow them to crowd-participate in innovating markets ([1] pp. 241-247), to which the decentralization enabled by the blockchain technology offers a promising solution (see [2] p. 27, [4], [9], [10] p. 272). By virtue of immutable and redundantly held data records as well as distributed consensus mechanism, blockchains can further contribute to controlling the flood of digital data by providing common single reference points to share data and to evaluate key data (see [2] pp. 30-31, [4], [11]).

Following the introduction, the blockchain technology is presented and then discussed with the case of the "DAO wars". In the fourth chapter the need for early standardization of blockchain technology is elaborated. Subsequently, a framework is introduced in order to contribute to development of the technology by early standardization.

2. HISTORY AND CENTRAL CHARACTERISTICS OF THE BLOCKCHAIN TECHNOLOGY

The blockchain technology advent began in 2008 with the Bitcoin application. Following the publication of the Bitcoin whitepaper by Satoshi Nakamoto (pseudonym) in 2008 [12], the cryptocurrency Bitcoin was set up in 2009. It was used for the first time commercially in 2010 in order to purchase pizza for the price of 10,000 bitcoins [13]. From a price for a pizza order in 2010, the value of the 10,000 bitcoins rose until October 2017 to more than a 400,000 US$ (see [14]), illustrating Bitcoin’s strong dynamics.

Soon after its launch, a wide array of further blockchain technology applications were developed ranging from so-called "colored coins" building on the Bitcoin blockchain [15] to new blockchain implementations such as Ethereum [16] or Hyperledger [17]. Currently, the blockchain tracking website coinmarketcap.com lists about 1,150 cryptocurrencies and other applications [18].

We propose, that a blockchain can be defined as "a distributed database that is practically immutable by being maintained by a decentralized P2P network using a consensus mechanism, cryptography and back-referencing blocks to order and validate transactions.” [19].

A related term is "distributed ledger”. It was found that both terms correlate and that, based on the last data of spring 2017, “blockchain” is the leading one [20]. There is however no clear consensus on the definitions yet, as a distributed database does not have to use blockchain technology [21]. For the purpose of this article, we consider the usage of the blockchain technology as defined, which is...
shortly described afterwards. At the core of blockchain technology is the decentralization of the database control ([6], [22] p. 219), which can be in its extent considered as a "revolutionary new computing paradigm" allowing a new level of coordination and collaboration ([2] p. 92).

The blockchain developer Richard G. Brown described the decentralization of trust (see [2] p. vii, [23]) as shifting the "trust boundary" from protecting a whole system against the outside by controlling access and centrally ensuring data validity, down to the individual participants in a blockchain network ([24], see also [12]). As blockchain network participants no longer need to trust each other or a third party to cooperate, dynamic online networks can form to share resources such as data and processing power or interact for different purposes in a peer to peer network.

A central property for the participants' trust in the blockchain is the immutability of the data records [3][11]. This means, that recorded data cannot be manipulated or modified after being accepted by the blockchain network. As discussed later in the case of the "DAO wars" and subsequent chapters, the concept of immutability is also extended to the rules and even the functions of blockchain applications by parts of the blockchain community.

The shift of the trust border to the individual user level is realized by technical principles of blockchain technology: Information is stored in a chain of data blocks, each of which references the preceding data block by an alphanumeric string derived from the preceding block (typically using a hash function), which makes it improbable to manipulate the data published in a block without being noticed, as the reference values would no longer fit the referenced data blocks ([10] pp. 64-65, [12]).

New data is integrated by a distributed consensus mechanism leading to a convergence towards a commonly accepted state, which in the case of the Bitcoin blockchain means, that each participant creating data blocks selects the longest valid blockchain in order to attach new blocks ([10] pp. 65-68, [12]). The creation of blocks is for example in the Bitcoin blockchain, so-called "mining", is motivated by a block creation reward and transaction fees in Bitcoins, but which is in principle possible. One example is an attack on Bitcoin's consensus mechanism: If one possesses a computational power which is higher than 50% of the computational power of the whole network, one can try to delete a transaction from the blockchain by sending a modified blockchain as consensus. Bitcoin's hash power sums up to more than 10,000,000 TH/s at the end of October 2017 [29], which means that about 740,741 units of one of the strongest miner (Antminer S9, 13.5 T H/s, 1265 dollars apiece as of 4th October, 2017, see [30] and [31]) are needed. This would cost around 937 million dollars not including electricity costs and other needed efforts.2

Therefore, and in all cases known to the authors, immutability was so far only breached by forks, meaning different distributed software versions of the same blockchain existing in parallel, as will be discussed in the case of the DAO in chapter 3. The ability to validate the recorded blockchain data and the authentication of users by encryption keys as digital signatures are as well central to form a decentralized consensus without the need to know and trust the participants in a blockchain network [22][32]. There are also additional measures to be taken into account, e.g. to counter misbehavior and attacks. A more detailed and encompassing discussion of the technology can be found in [10][32][33].

Enabling new forms of peer collaboration and coordination and thus novel business models and applications, blockchain technology is attracting wide interest as shown in various implementations and applications (see [18], [34], [35]). As it is an emerging and still maturing technology, solutions are needed to clarify and standardize its basic terms and concepts, as the next chapter will demonstrate.

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1 Several versions of consensus mechanisms are developed for blockchains, see e.g. [3].

2 Smaller networks may face higher risk, but may as well offer less incentives for would-be attackers.

3 With the cryptographic keys the user input is authenticated - the anonymity is a design choice.
3. THE CASE OF THE DAO WARS

Besides its industry-wide publicity, the blockchain technology also experienced setbacks. Among the most prominent incidents were the one of the Bitcoin exchange Mt. Gox with a tremendous damage of $350m in Bitcoin cryptocurrency [36] and of the Ethereum-based "Decentralized Autonomous Organization" (DAO) with an initial damage of $50m in the cryptocurrency ether [37]. Such adverse events could jeopardize user trust in the blockchain technology significantly.

The latter case with the hack of the DAO or the so-called "DAO wars" caused fundamental discussions regarding the concept of immutability as a central characteristic of blockchains [38][39][40].

The DAO blockchain is one of the first attempts to form a decentralized crowd-funded organization on the Ethereum blockchain by which users can obtain shares by buying so-called DAO tokens [38]. These tokens give them proportional voting rights on the investment into specific projects and accordingly the corresponding economic rents [38]. The blockchain code and the immanent rules and automatisms were not supposed to be subjects of change and thus were regarded as "immutable" [40]. In June 2016, an attacker used a only recently noticed breach in the DAO code to appropriate tokens from other participants equivalent to about $50 million [37].

As the implemented code delayed payout, the DAO and Ethereum community had four weeks to react to "the attacker’s" transfer. Due to the DAO’s significance in the Ethereum ecosystem, a controversial discussion evolved within the blockchain communities, such as on the Reddit forum, whether to undo the breach exploitation in that time [38][41][42]. If the DAO were a traditional centrally managed organizational software, the common procedure would have been to solve the breach in the code and transfer the $50m back to its original owners. However, the DAO structure building on blockchain technology requires a network consensus on how to proceed [38][39].

One viewpoint advocated a correction of the Ethereum protocol to fix the consequences of the breach in the DAO code. The second most prevalent view of the community argued, that there should be no ex-post modification as undoing the manipulations would be a violation of the "immutability principle", which sees the code as the single point of truth [38][39].

In the end the majority decided on a protocol correction resulting in a split into two different Ethereum blockchains, breaching the immutability by a fork [38], but without solving the discourse about the perception of blockchain immutability. The "DAO wars" have shown, that the central attribute immutability is not commonly understood within the blockchain developer community.

Besides others incidents, this revealed the ambiguity of blockchain concepts in the field of blockchain technology. Misconceptions like these challenge the future development and jeopardize trust in such blockchain solutions significantly.

It is also noteworthy, that the principle of using blockchain tokens for investments, so-called "initial token offerings" (ICO), is a popular financing method for blockchain startups, which underlines the significance of clarifying the concept of immutability.

We argue, that this issue can be addressed by appropriate standards specifying fundamental blockchain terms, concepts and characteristics, an appropriate business to customer communication regarding these characteristics as well as regarding the resulting rights and duties on the side of the blockchain developers and users. Following the need for early standardization revealed by the case of DAO, the benefits of early standardization will be argued in the next section.

4. NEEDS AND CHALLENGES FOR EARLY STANDARDIZATION OF BLOCKCHAINS

Standards play a central role for industrial societies and international technology systems [43]. They can be understood as a consensual, public document from a recognized institution for the "achievement of the optimum degree of order in a given context." ([44] p. 12). In addition, besides consolidated scientific and technological contributions, standardization also considers learning from practitioner experiences to optimize community benefits from standards [44].

According to [45][46], four categories of standards can be distinguished:

- semantic standards,
- measurement and testing standards,
- interface standards and compatibility standards and
- quality standards and variety-reducing standards.

Regarding the product life cycle, [47] identified three types of standards: Anticipatory, participatory, or responsive standards. Anticipatory standards are standards "that must be created before widespread acceptance of devices or services". Participatory standards "proceed in lock-step with implementations that test the specifications before adopting them" and responsive standards "occur to codify a product or service that has been sold with some success" ([47], p. 2).

This paper refers to participatory standards, although it could be argued, that the suggested framework as well as consortia efforts or some international standardization committees have an anticipatory character as well, since they set the road for a broader implementation. It is directed as a quality standard towards supporting technology diffusion and acceptance.

Regarding innovative areas, the benefits of standards may refer, for example, to R&D and the diffusion of innovation, the time-to-market of new products, support for the technology transfer and the creation of critical mass (see [48], [49] for overviews of the advantages of standardization).
Besides the long list of advantages, which standards may provide, they can also introduce risks, such as monopoly power, regulatory capture and raising costs of competitors or reduced choice on markets [48]. An example of how to mitigate the risks is given in [50]. [48] explicitly emphasizes the positive influence of standards on innovations as well. Likewise [46] shows various benefits that standardization of an emerging technology such as the blockchain field can achieve. As the understanding of the very concept of what a blockchain is still ambiguous (see [51], [52], [53]), early standardization efforts could help significantly to clarify mutual understanding.

It is found in [54], that users are willing to use a blockchain, if the blockchain technology is easy to use concerning both the technological and business side, useful in terms of effectivity and efficiency benefits and incurs only acceptable risks regarding security, privacy or stability. Trust impacts these user assessments [54] and standards can support both the evaluation of a blockchain application as well as the trust in the technology itself.

In line with these considerations, [55][56] specify as the current needs for standardization reference architecture, taxonomy as well as ontology. In that respect, the concept of the immutability concerns both taxonomy and ontology of blockchains. [57] adds, that international standards, standards that assist a new emerging technology to be rolled out and deployed with greater clarity, certainty and market confidence, shared solutions for customer requirements as well as for smart contracts are important.

According to [57], leading standardization organizations, in particular, ISO, ITU and CEN respond to these needs. ISO for example, created a roadmap, covering a three year period between April 2017 and April 2020. Key issues, addressed by ISO working groups and study groups, include "Terminology", "Taxonomy / Reference Architecture", "Identity", "Interoperability", "Governance", "Security & Privacy", "Use Cases" and "Smart Contracts". Additionally, large industry-supported consortia such as Hyperledger Fabric of the Linux Foundation have been evolved to develop modular blockchain solutions [58][59].

This article adds to these efforts by (a) introducing and explaining the fundamental blockchain immutability characteristic in chapter 2 and 3 as well as (b) suggesting an appropriate user and investor communication as well as management of this characteristic in the next chapter.

In line with the findings of [56][57], it is essential that the recorded data and the rules of cooperation in the blockchain network are reliable for the participants to trust the network. This requires a clarification of its immutability characteristics, respectively the conditions under which the active blockchain can be modified (see [42]) furthering trust and customer confidence. The question has thus to be posed, under which circumstances should a blockchain be subject to modifications, while at the same time ensuring a non-manipulable consistent consensus between the networks’ participants. To achieve consensus, but also to incorporate the user requirements, the early involvement of all stakeholders is critical in defining such requirements.

5. SUPPORT OF TECHNOLOGY USAGE BY MANAGEMENT OF IMMUTABILITY

A remarkable characteristic of the blockchain evolution is its technology development in open as well as distributed communities. The knowledge exchange is driven by the sharing of whitepapers and realized often informally or even anonymously by means such as forums and blogs or face-to-face discussions and conferences (see also [60], [61]).

The dynamic, large and varied field of proposed blockchain solutions makes it also difficult to accurately pinpoint the benefits of the proposed and typically unsolved solutions. Taking as well the immature state of the technology and ambiguity of concepts into account as discussed before, the development of the blockchain technology can be described as chaotic. In [53] an approach to define terms for the complex blockchain technology development is proposed. However, as the DAO case has shown, the central role of immutability requires further considerations.

Consequently, guiding quality standards for operation and implementation are needed to better handle the chaotic technology development. Supplementing committee discussions on term definitions to promote common understanding, on references to compare and test, or on data exchange specifications for compatibility, the presented framework focuses on the system aspect of the blockchains and the support of its management.

In the following, an approach to clarify the principles of blockchain immutability is proposed as a participatory quality standard to support the roll-out and deployment by clarifying the central concept of immutability and its management for operations. With a layered framework, the implementation of immutability is made manageable for blockchain developers and users.

The immutability concept concerns both the data and the code of the blockchain as discussed before. The immutability of the data is generally seen as an uncontroversial aspect realized by the technical properties of the blockchain data structure as discussed in chapter 2.

It has to be pointed out, that blockchain solutions have limits in what they can achieve: While immutability of recorded data may be ensured, the data may be erroneous before entry into the blockchain. The consensus system may be used to verify entry data, but this has limits in what the participants can reliably deliberate and consent on (see [62]).

The immutability of the code is however a highly controversial concept, as shown in the DAO case in chapter 3. No code is created in perfect state integrating all operative requirements from the start. A blockchain code has to be, and in all popular cases known to the authors is, continuously adapted. For a distributed consensus system, there are differences in how far users are affected by a code change. Adding a function for comfort, fixing a bug or improving the handling of a data format has a different impact for the users than changing the rules of the system.
that concern trust: The privileges of data integration, the miner incentives, the consensus finding system and so on.

As discussed beforehand, the blockchain technology still has technological issues such as scalability, security, privacy, functionality, efficiency and reliability that needs to be improved ([63], [64], [65], [66], [67], [68], [69]) making software updates necessary. An update would be successful, if the blockchain network participants use the new code and drop the outdated code version. The acceptance is of critical concern, as it has the potential to cause inconsistent and incompatible versions to coexist (forks), divide the network and impact trust. From the impacted users’ perspective, a blockchain code could be modified in several ways assuming the required IT infrastructure to operate the network as given:

(a) The software code could be modified to improve the code execution or remove specific weaknesses without altering key properties (e.g. "Performance Improvements" in [70] or "Test for LowS signatures" in [71]). Users can simply acknowledge such changes.

(b) The software code could be modified to offer additional functions concerning data administration (e.g. "Standard script rules relaxed for P2SH addresses" in [72] or "Block file pruning" in [73]). Users have to inform themselves about the new possibilities or potential limitations.

(c) The software code modification could alter or affect key blockchain network properties (e.g. the discussed "correction" of the DAO hack or an update to the cryptographic proof of work in the Bitcoin blockchain as discussed in [74]). In such cases, users need to review the changes and consent to them.

The presented framework takes the distinctive perspective of the network participants, who have to place their trust in the system, to help manage the inherent conflict within the concept of conditional immutability of a blockchain. From the described differences in impact on the system users, four layers are derived (see figure 1):

(1) The execution layer at the bottom of figure 1 represents the software code execution running locally on the users’ hardware and that operates on the IT infrastructure. It forms the basis for the following layers. Changes on this layer are performance, stability or security improvements. They do not alter functionalities for participants, carried data, network properties or consensus mechanism as experienced by the users.

If well documented and transparent, e.g. as blog entries on a regular schedule, such changes are part of the maintenance work and will not in general negatively impact the trust of the users.

(2) The function layer concerns the related functions allowing the users to work with the data. Changes on this layer between local execution and system layer may be a concern for trust and consistency, as decisions to cut or add data may concern central blockchain properties such as historical completeness. On the other side, additional functions to implement a contract or function to check data may not be a great concern for trust, but part of regular application development, which needs to be communicated. Therefore, functional changes have to be verified for their system impact and if necessary handled purely under the system layer. In case neither data nor system rules are changed, the changes can be handled as code updates. Changes only on the function and execution layer can and will typically occur frequently and are not of concern for the immutability of a blockchain.

(3) The system layer concerns the users’ interactions with the blockchain on the network level, respectively system properties such as participation incentives, encryption, anonymity, consensus mechanism or network permissions. Changes on this layer require common understanding within a peer network about the specific modalities of the modifications (if, when and how) before implementation, as they have the potential to affect common agreement and subsequently trust so strongly, that they can cause network splits as demonstrated by the "DAO wars" (see chapter 3). They should be clearly marked and communicated well in advance to allow a sufficient discussion. Even more important is however, the predefinition of the modalities for such cases to set a clear frame for the handling. Changes on the system layer are thus to be considered possible, if the conditions for them are described and agreed in advance. Due to this, system properties are only conditionally immutable. The conditions are of interest to users, investors and regulators and have to be published upfront ideally within the first whitepaper and.

(4) The data layer concerns the data stored on the blockchain and thus data immutability, as any non-consensual changes of data violates the historic consistency and completeness of the blockchain. In general, data is only added and there are no conditions under which data on the blockchain can be removed. The historic data is to be seen as immutable. It has to be noted however, that it can be temporarily uncertain, whether data is already consensually accepted depending on the duration of the convergence process in the distributed blockchain network.

Figure 1: Layers of blockchain immutability

The potential impact of changes on the blockchain network participants has to be carefully considered and clearly communicated depending on the corresponding layer in the
framework. As a quality standard, the developers should specify any potential changes corresponding to the four levels, their conditionality (if, when and how) and their possible impact in detail upfront based on the proposed framework to increase trust and promote the diffusion of the technology.

A suitable mechanism of how to agree on proposed changes on the system layer would depend on the type of blockchain and its consensus mechanism.

The "immutability of a blockchain" is thus in general the immutability of its recorded data and the conditional immutability of its system rules and properties. The disclosed conditionality of changes to blockchain network properties can be seen as the constitution of a decentralized organization, which is realized by a blockchain.

As a final comment, the so-called smart contracts, which are in principle program code distributed with the blockchain, offer powerful possibilities to work with data on blockchains depending on inputs and are in general part of the function layer. The blockchain system does only guarantee the validity of them as far as the consensus or automated checks validate their properties and results. Their power to affect data or system properties should be clearly described and checked.

6. CONCLUSION AND OUTLOOK

Blockchain technology has the potential to become a cornerstone of the digital revolution by enabling decentralized cooperation in networks, when technological development continues to address user requirements. The development of early standards and good practices can also offer fundamental support for the technological development and its market acceptance.

An essential network property is the trust placed in the recorded data respectively transactions as well as in the rules of the decentralized network. As a result, the ambiguous concept of immutability has evolved in the blockchain community, but remained elusive as discussed in the DAO wars case. To ensure the success of the blockchain technology field, we have discussed the need for quality standards specifying good industry practice. The whitepaper documentation of blockchain solutions should describe clearly the conditions under which code or even system rules may yet change. For this purpose a classification has been provided to support maintenance and updates, while specifying the system property of immutability.

When the decentralizing and coordinating potential of the blockchain technology can be successfully exploited, applications in many fields such as in the manufacturing sector, the financial service sector, the health sector, E-government or the internet of things may be realized and drive a wave of economic and social changes (see also [2] pp. 101-104).

To support this development standardization has been recognized as an important topic.

Continuing research should address especially technical short-comings to improve usability of the technology, the competitive implementation of specific use cases to demonstrate its potential as well as economic and legal aspects to clarify user benefits for the different types of blockchains and to reduce market uncertainty about future regulation.

In addition, the development of crowd-sourcing and collaboration applications using the blockchain technology should be further investigated.

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STANDARDIZATION IN EMERGING TECHNOLOGIES: THE CASE OF ADDITIVE MANUFACTURING

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ABSTRACT

Additive Manufacturing provides an important enabling technology for the digital transformation of the economy. As an emerging technology it has seen a remarkable development over the last three decades. Nevertheless, it is far from a broad adoption with several barriers to overcome yet. One of the major challenges is the lack of standards. The critical role of standardization for innovation is generally recognized, still the topic too often has been neglected in strategic roadmapping exercises for emerging technologies. Too little is known about the complex dynamics and interrelations of standardization and innovation. The anticipation of standardization needs and the timely and efficient implementation of standards is challenging. This paper aims at contributing to a better understanding of the role that standards play in the multi-dimensional system of innovation. It analyzes the trajectories of innovation in Additive Manufacturing in a systematic and holistic way, focusing on standardization activities with regard to coordination, stakeholders involved, the timing and types of standards developed. Putting standardization in context of the multi-dimensional innovation system of Additive Manufacturing the research shows where standards can support the diffusion of an emerging technology.

Keywords— Additive Manufacturing, emerging technologies, technological innovation, standards, standardization, 3D-Printing

1. INTRODUCTION

Additive Manufacturing (AM) has seen a remarkable development since the technology was first introduced in the 1980s. Since then, worldwide sales in products and services have increased to 5.17 billion USD in 2015 compared to 291 million USD in 1995 [1, 2]. Forecasts predict sales to go up to 21 billion USD by 2021. This development has been enabled through extensive research, leading to improved and innovative processes and applications and decreasing costs over time. Starting as a rapid prototyping technology, AM has evolved towards direct digital manufacturing applications in areas such as aerospace, automotive, biomedical and many more. Most recently 3D printers have found their way into the homes of end consumers [3, 4]. Although opinions on its disruptive potential differ, AM will play an important role in the industrial production and is heavily discussed in the context of smart manufacturing [5, 6]. Along with the trend towards mass customization and the progressive digitalization of industrial processes AM can make significant contributions to a more flexible production without major cost disadvantages [5]. Despite these prospects and the tremendous advancements made so far, AM is still in its early stages of maturity and not yet broadly adopted. One of the barriers that is often stated is the lack of standards in that field [6-9].

The decisive role of standards for innovation is well acknowledged in research [10-13]. Still it remains challenging to anticipate the standardization needs during the emergence of a new technology since innovation and standardization are both complex and dynamic phenomena. Yet with the increasing complexity and rapid evolution of modern technological systems and industries the need rises for timely and efficient standardization [14].

This paper discusses the role of standards in the diffusion of AM, employing a systematic framework developed for standards mapping [15]. The case study aims at helping to improve our understanding of the complex dynamics between innovation and standardization. The remainder of the paper is structured as follows: the second section introduces the phenomena of emerging technologies in the context of standardization as well as frameworks developed to map them. It proceeds with an introduction to the AM technology. The research methodology applied is summarized in Section 3. The fourth section presents the case study on standardization in AM including a quantitative analysis on available standards. The paper concludes with a summary of results.

2. THEORETICAL BACKGROUND

AM is an emerging technology that has evolved over different phases, seeing constant technological and commercial advancements. By definition, emerging industries “are high-technology industries that build on scientific breakthroughs and which require years, if not decades, of further R&D, product development and market testing before realising their commercial potential in the market” [16]. Processes of technological innovation and industrial emergence are characterized by complexity, coevolution, self-organization and path-dependency. Such processes and systems are structured through different phases and transitions, influenced by various significant factors, events and activities making it a complex and interactive phenomenon [17, 18]. It has been shown that different types of standards play various roles within and between the stages of the research and innovation process [10]. These functions and structures have to be considered when looking at the interplay of research and standardization and the role of standards in emerging technologies such as AM. This research shall contribute to our understanding of the role that different types of standards play at different stages of innovation and the diffusion of new technologies, taking AM as example. As an in-depth case study it will reveal the dynamics and interaction patterns with other activities and events along the innovation and technology development journey.
2.1. Frameworks on the role of standards in innovation and technological emergence

Depicting the complexity and dynamics of standards and innovation is a challenging task considering the different types and functions of standards that exist, the constant evolution and number of stakeholders involved. Several frameworks and concepts have been developed over time that each focus on specific aspects of standards (see [13] and [11]).

The framework of Blind and Gauch (2009) illustrates the various roles of different types of standards within and between the different phases of the research process from pure basic research towards market diffusion. It depicts well the functions and importance of terminology, testing, interface, compatibility, quality and variety-reducing standards at different stages of the research process. Their availability is crucial for the further development and diffusion of the emerging technology [10].

Failing in a timely standardization can hinder or slow down the diffusion of a new technology [19]. Applying the model on the case of nanotechnology they show the specific role of each type of standard in the innovation process of this emerging technology [10]. Further empirical evidence is provided by Ho and O’Sullivan (2013) who investigate photovoltaic technology, building upon existing frameworks and technology roadmapping to account of the complexity of technological innovation systems [17].

In search for a more comprehensive and holistic framework that considers the innovation system at large, Featherston et al. (2016) proposed a framework based on technology roadmapping that allows to link different types of standards to other innovation activities (Fig. 1). This makes it possible to indicate interdependencies and consequently observe the complex dynamics that exist. In this two-dimensional framework, innovation activities in different categories are mapped along a timeline. These categories comprise activities related to market, product, and technology development, and can be adapted and customized according to the specific technical domain under investigation. The canvas helps identifying relevant stakeholders and where standards and related activities can help to diffuse information, supporting the overall innovation system of an emerging technology [15].

2.2. Additive Manufacturing technologies

AM is defined as “processes of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing fabrication methodologies” (ASTM 2792). Synonyms such as additive fabrication, additive layer manufacturing, or freeform fabrication have been used over the evolution of this technology. The most common synonym is ‘3D printing’, though technically being only one subcategory of AM processes. The standard further defines seven different process categories that can be distinguished according to material choice, build speed, layer thickness, surface quality, cost, and feasible part geometries [20]. The AM concept allows the direct automated production of customized parts and products in small to medium size lots, enabling the transition from conventional mass-production to customer specific, need-oriented manufacturing requirements [21]. What makes AM superior compared to traditional manufacturing approaches is the capability of making even complicated geometries and designs, using only the material necessary. This leads to significant reduction of waste and costs. AM technologies are used for a variety of applications in engineering industry, but also in medicine, education, architecture, cartography, toys and entertainment [22].

AM represents a complex system with diverse areas of application and multiple technological approaches which poses grand challenges to its wide adoption. Despite the great opportunities and promising scenarios that this technology offers, its broad diffusion has been hampered by several barriers and challenges, such as process time, cost issues, repeatability and reliability of processes [7]. The lack of standards is one of the most pressing challenges.

2.3. Why standards are important for Additive Manufacturing and its diffusion

It is commonly agreed that the development of standards is significantly important for the diffusion and adoption of AM [6, 7, 9, 23, 24]. International consensus based standards are supposed to bridge the gap between the knowledge and capability gained through R&D and the requirements for the actual market introduction and widespread use of AM technologies [9].

Standardized vocabulary e.g. is required to find a common language. Standards assist users to assess the different AM processes to decide for the appropriate technology [25]. Standards for materials, processes, calibration, testing and file formats are needed to ensure the quality of produced parts, repeatability, and consistency of the processes [26]. Without standards the same digital design may lead to broad variations concerning material and surface properties of the produced part, depending on the individual production conditions such as the machine used, the person operating the machine or the exact specification of the input material [20]. The AM industry so far is, however, largely dependent on proprietary specifications of manufacturers, informal and industry standards [23, 27]. Users often simply follow trial and error iterations to meet adequate feature requirements, processes or surface characteristics [26].

Defined processes and material properties are essential for AM to be accepted for industrial application. Various industries have special requirements that need to be considered. Especially in critical applications such as in aircraft engines or medicine, standardization is essential since established standards will allow the products to be certified for use and can be necessary to demonstrate conformity with legal requirements. Such requirements for material performance factors range from fatigue, creep, and tests of flammability and toxicity to process sustainability. Costs are high in these areas. Thus, manufacturers depend on established material and process standards to ensure the consistency with these legal requirements. Standards for products, processes and materials will boost the application of AM not only in such critical sectors [7, 9, 28].
2.4. Obstacles and barriers for the adoption of Additive Manufacturing standards

Though the foundational technologies and inventions in AM root in the 1980s and early 1990s it was not before 2009 that with the ASTM F42 the first dedicated official technical committee within a formal standards body was established [28]. Due to the lack of formal standards, many of the AM standards in use today are proprietary, with single companies developing their own individual guidelines [27]. Standardization faces multiple challenges associated with the number of diverse applications, variety of materials used, differences in processes and technologies [6, 24]. This diversity even increases with the rapid proliferation of AM technologies. Besides this, Gao et al. (2015) also point out that producers of machines have a financial interest in offering their individual consumables and spares similar to the document printing industry which might compete against the need for standardization [26]. Nonetheless, the need for standards to drive the adoption of AM is commonly acknowledged with initiatives by stakeholders worldwide. Already in the 1990s early advocates and pioneers of standardization in AM pointed out the need for formalized consensus standards especially with regard to the growing number of applications, technologies and users [23]. However, it took more than a decade for the first formal standards to be published.

3. RESEARCH METHOD

An empirical case study on AM was conducted, gathering data on important events for the development of the technology. An event in the context of a technological innovation system (TIS) “can be defined as an instance of change with respect to actors, institutions and/or technology which is the work of one or more actors and which carries some public importance with respect to the TIS under investigation. Examples of such events are studies carried out, conferences organised, plants constructed, policy measures issued etc.” [29].

Many different events and stakeholders have influenced the development and diffusion of AM over the last 30 years. Starting with the emergence of the technology along the innovation journey until today the standards and innovation structure in AM is analyzed by aggregating different events, indicators, milestones and activities in the TIS. This empirical approach includes data regarding standardization, technological development, the industrial environment (market and applications), and others such as policy and society. An empirical analysis is conducted on the different types of standards developed in the different phases of the technological evolution. The analysis is aimed at identifying possible patterns and trends regarding different functions and kinds of standards along the technology innovation journey and their interaction with other innovation activities.

The investigation is embedded into the framework of industrial emergence adapted from previous work of Featherston et al. (2016) as described above. This framework helps to map the different types of standards and standardization activities together with important dimensions of emerging technologies related to market, products and technology development, showing how standards and related activities can support the overall innovation system. Following Ho & O’Sullivan (2016), standardization in AM is analyzed by investigating the technology elements to be standardized, the reasons for standard needs, the timing and sequence, as well as the stakeholders involved.

The first steps in this case study was to gather the data through an extensive systematic desk research and literature review (including peer reviewed journal databases, newspaper articles, websites and publications of standard developing organizations, professional associations, etc.). Based on this, the dataset was built, listing the identified and evaluated important events and activities in chronological order. Special emphasis in this step was given to milestones related to standardization. Finally, the events were categorized and clustered according to the framework proposed by Featherston et al. (2016), adapting the framework categories according to the particularities of AM. The events and sequences of events were then mapped over time to identify the interrelations and dependencies between them along the trajectory of the technology. This was the basis for the following analysis of the dynamics.

4. ANALYSIS - THE CASE OF ADDITIVE MANUFACTURING

4.1. Development phases of Additive Manufacturing

The foundations of modern AM lie in the 1980s with the inventions of the major AM technologies. These heavily built upon research done in the decades before, including advancements in computer technology, laser, Computer Aided Design (CAD) and Computer Numeric Control (CNC). Research efforts in the 1970s provided proof of concept for modern AM processes that have subsequently been developed and patented since the mid-1980s [20, 30]. The adoption process of AM can be classified into three overlapping phases determined by different end usages of the technology. Originally used for Rapid Prototyping (RP) the technology was progressively applied to create molds and tools (Rapid Tooling), and end-products (Rapid or Direct Manufacturing). Being adopted by end-users at home 3D printing has recently entered the next evolutionary phase (Home Fabrication). The transition into new phases is influenced by improvements in technology, including processes and use of materials, and the associated costs [4, 31]. The remainder of this section explores the complex dynamics of innovation and standardization over the historical development of AM. Various significant activities and events that influenced the evolution are tracked and causal relationships drawn. Focus lies on standardization, with undertakings by different stakeholders and achievements identifying the role of standards in the diffusion of AM.

4.1.1. Rapid Prototyping

The first AM technologies were developed in parallel in Japan, France and the USA in the early 1980s. Having similar concepts of adding materials layer by layer to produce an object, it was Charles Hull who was the first inventor to successfully apply for a patent in 1984. He then started commercialization of his “Stereolithography” printer, establishing the company 3D Systems two years later and introducing the first available AM machine in 1987. Carl Deckard invented and commercialized the second important AM process “Selective Laser Sintering” in 1986. In 1989 Scott Crump filed for a patent on his invention of “Fused Deposition Modelling” and founded Stratasys, still one of the major players in the market today [20, 30]. Several other processes were invented and launched to the market in the late 1980s and early 1990s that have been the core technologies in use until today, such as 3D Printing, Electron Beam Melting, or Selective Laser Melting. The various approaches differ with regard to the deposition technique, the type of materials used or the way they are fused [5].

The first machines were used by architects, artists and product designers to rapidly build models and prototypes. The new machines offered a real benefit by speeding up and facilitating this
The capabilities and comfort of RP at that time were quite limited with regard to the quality of the finished prototypes and the level of detail. Furthermore, printing was slow, expensive and restricted to plastics, producing only small parts. Improvements regarding those limitations fueled the wider adoption of RP, with the US automotive industry beginning to use it at scale [4, 20]. Considering the growing number of users, the need for standards became apparent. Concerns have been expressed regarding limitations of applied industry practices [23]. Conventional standards for other technologies are not always applicable to AM which has distinct requirements [21]. Having had no explicit formal standards for RP, the community mainly relied on informal or industry standards, “benchmark” parts that have been developed for particular user communities or specifications for RP materials [23]. Finally, in 1997, the US National Institute of Standards and Technology (NIST) hosted the industry workshop “Measurement and standards issues in rapid prototyping” with the intention to gather information on industry needs regarding standards and to develop priorities for future work. Despite the general consensus and awareness for the importance of the topic [23], it took more than 10 years before the first formal standard committee was established.

4.1.2. Rapid Tooling and Rapid Manufacturing / Direct (Digital) Manufacturing

Around the turn of the millennium important improvements in AM processes and materials were achieved which allowed a transition from using the technology merely for RP towards the use for Rapid Tooling (RT) and Rapid Manufacturing (RM) or Direct (Digital) Manufacturing [20, 30]. Advancements such as better lasers and scanners as well as faster layer deposition considerably enhanced the speed and accuracy of the processes. Furthermore, the range and quality of available materials have significantly improved. Parts can now be made of almost any material, such as metals, polymers, ceramics, or composites. Additionally, better performing software tools were available and machines were equipped with additional features such as the ability to print in color or with multiple materials [20]. The amount of research efforts and technological advancements are reflected in an exponentially growing number of patent applications from the year 2000 onwards [32]. The number of scientific publications shows a significant uptake as well from 477 in the year 2000 to 1,506 publications in 2012 [1].

Together with decreasing costs for machine and materials as well as the general growing awareness of the potential of AM [5, 28] these developments enabled the use of the technology to produce finished goods, ready for end-use, defining a new area of manufacturing [31]. Especially in automotive, medicine, and aerospace the technology has been well adopted [33]. Adoption has further increased recently due to the emergence of online 3D printing platforms such as Materialise, Sculpteo or Shapeways that print and deliver objects from files provided by users directly [4]. This development led straight to a new phase in AM.

4.1.3. Home Fabrication

Whereas the first 20 years of AM were reserved for RP and industrial applications, since 2005 a consumer market has been emerging and growing constantly. Final consumers now can have their own personal 3D printer to directly manufacture at home. This third phase of AM has certainly caused a hype around 3D printing and was triggered by several factors. Relevant patents such as the original patent for Fused Deposition Modeling expired which allowed the creation of RepRap, an open source hardware community. Building on RepRap, MakerBot, founded in 2009, was the first company to launch affordable 3D printers. With printers and software becoming cheaper, faster and more reliable, 3D printing was experiencing an annual average growth rate of 346% between 2007 and 2011 [4]. In 2011, consumer machines outsold professional machines for the first time [20].

The technology is currently at a very early stage, the absolute number of sold personal 3D printers remains relatively low (35,508 units in 2012) and the further adoption is expected to be slow and limited due to prices and immaturity of the technology [4]. Despite the technological improvements, growing interest and expanding application, AM for the production of final products is regarded to still being in the “innovator” phase as well due to a lack of robust AM machines and high-volume production systems which impedes the transformation of AM into a serial production technology [6]. Final products need to meet all the requirements of conventionally produced products and processes regarding quality, durability, repeatability and consistency [26]. With the progressive adoption especially in performance and safety-critical application areas such as medicine or aerospace, the importance of standards to support acceptance and diffusion of AM rose [33].

4.2. Recent activities in standardization it their drivers

Though the need for standards has already been expressed in the mid-1990s, it took many years before formal standardization started. It was the Association of German Engineers (VDI) which first came up with technical regulations for AM responding to growing pressure from its community. Established in 2003, the VDI technical committee (TC) “Rapid Prototyping” (later renamed into “FA 105 Additive Manufacturing”) published the first dedicated AM standards for terminology and AM processes (VDI 3404 and VDI 3405) whose content was later adapted to a large extent in the international standards ISO/ASTM 52792 and ISO 17296-2,3,4. Until today, VDI ensures an active and well positioned representation of German interests in international standardization through its work [34, 35].

Also in the USA activities were triggered by an engineering association: Recognizing the pressing need for standards in AM, the Society of Manufacturing Engineers (SME) initiated a cooperation with ASTM International, forming the ASTM Committee F42 on Additive Manufacturing Technologies, the first official TC for AM in a formal standards body. Through the cooperation of both organizations, the participation of SME’s AM community in the standards development process was facilitated, helping to bring a broad global membership to the committee [36]. Currently more than 550 members from 26 countries are working in the committee, having published 14 standards so far, with 17 more currently under development.

Many actors and events have shaped and influenced standardization, covering governments, R&D initiatives, technological, market and societal developments. The US administration recognized the importance of AM for their economy and competitive position, governments worldwide have been implementing and funding research projects to advance the technology and support their domestic industry [5]. The Obama Administration e.g. launched a public-private partnership named “America Makes”, the leading and collaborative partner in AM research. This initiative recognized as well the need for standards and a coordinated and strategic approach in standardization – together with the claim for U.S. leadership and coordination in that domain. In cooperation with the American National Standards Institute (ANSI) the Additive Manufacturing Standardization Collaborative (AMSC) was founded in 2016 in order to accelerate the development of standards. The AMSC has
published a standardization roadmap for AM that is meant to help setting priorities and focus resources [27]. A standardization roadmap for AM has also been developed in 2015 by the European research project “Support Action for Standardization in Additive Manufacturing (SASAM)” funded by the European Commission within its Framework Programme 7 (2007-2013). Based on views collected from mainly European stakeholders, the roadmap identified existing standards, gaps and challenges, and indicated timing and topics for AM standardization. SASAM also emphasized the need to have one global set of standards and to have ISO, ASTM and the newly established European committee CEN/TC 438 jointly work together in standards development [9]. The CEN/TC 438 has no intention for any own standardization work above that of ASTM and ISO, but rather sees its function in adopting their standards in Europe, following the Vienna Agreement, and strengthening the link between European research programs and standardization [25, 37]. By funding AM projects the EU as well as countries like Germany (a major player in this industry) seek to support a technology that is supposed to re-shore production from lower wage regions back to Europe in order to spur on innovation and create sustainable growth [6]. Indeed, the formal standards organizations started to follow a coordinated, international and strategic approach: ASTM and ISO, that had just established a TC for AM, concluded a Partner Standards Development Organization (PSDO) cooperation agreement in 2011 governing the standardization activities of both TCs [28]. They successively implemented instruments such as a Joint Plan for Additive Manufacturing Standards Development (2013) and an AM standards structure that shall help identify gaps, develop modularized standards, improve the usability and acceptance of the standards, and guide the work of the experts and SDOs (2016) in order to jointly align roadmaps and efficiently elaborate one set of standards, thus avoiding double work [38, 39]. Governments’ initiatives and actions not only have influence on standardization through funding and support of R&D programs, but also through their regulatory requirements which need to be met by manufacturers. The pressure to achieve conformity spurs the need for dedicated standards that meet the specific features of AM. Furthermore, the state is also a user of the technology e.g. especially in defense and aerospace applications, thereby having an own interest in the availability of standards. As more and more research activities were conducted and governments and companies invest in R&D, the number of patents grows rapidly since the turn of the millennium. Especially the pioneering companies – market leaders today – such as Stratasys or 3D Systems are the main patent holders, driving innovation that led to new and advanced processes and applications [40]. Improved technology and decreasing costs have spurred adoption – and the need for standards necessary to apply the technology with confidence and ensure quality and reliability of processes and manufactured parts. The ongoing digitalization of production (Industrial Internet of Things) further drives the recognition of AM technologies which, however, requires standardized interfaces for data transfer and integration. Home fabrication, where different machines and technologies are used compared to industrial applications, in turn requires dedicated standards for this domain, especially e.g. regarding safety standards. Hazards connected with the materials, machines and processes used, need to be addressed in all domains, requiring new safety and testing standards that meet the specific features of AM.

Table 1 summarizes milestone events and activities in AM standardization. The following section gives an overview on the types of standards developed and the drivers behind.

<table>
<thead>
<tr>
<th>Year</th>
<th>Event/Activity</th>
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<tbody>
<tr>
<td>1997</td>
<td>NIST industry workshop “Measurement and standards issues in rapid prototyping” to identify standards needs</td>
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<tr>
<td>2003</td>
<td>VDI TC „Rapid Prototyping“ founded (later renamed into FA 105 Additive Manufacturing)</td>
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<tr>
<td>2009</td>
<td>SME and ASTM begin cooperation in standardization</td>
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<tr>
<td>2009</td>
<td>ASTM F42 AM Technologies founded</td>
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<tr>
<td>2010</td>
<td>DIN NA 145-04-01 AA FB Section AM founded</td>
</tr>
<tr>
<td>2011</td>
<td>ISO TC 261 AM founded</td>
</tr>
<tr>
<td>2011</td>
<td>cooperation agreement between ASTM and ISO</td>
</tr>
<tr>
<td>2012</td>
<td>EC SASAM project initiated</td>
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<tr>
<td>2013</td>
<td>ASTM and ISO intensify collaboration with the Joint Plan for AM Standards Development</td>
</tr>
<tr>
<td>2015</td>
<td>CEN TC 438 AM founded</td>
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<tr>
<td>2015</td>
<td>SASAM Standardization Roadmap</td>
</tr>
<tr>
<td>2015</td>
<td>3MF consortium founded (3MF file format)</td>
</tr>
<tr>
<td>2016</td>
<td>America Makes &amp; ANSI Additive Manufacturing Standardization Collaborative (AMSC) founded</td>
</tr>
<tr>
<td>2016</td>
<td>AM Standards Structure released by ASTM and ISO</td>
</tr>
<tr>
<td>2017</td>
<td>AMSC standardization roadmap for AM published</td>
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### 4.3. Quantitative analysis

In an extensive search through websites, databases and publications a total number of 40 dedicated AM standards has been identified that have been published by SDOs worldwide (as of March 2017). This number includes revisions and standards that have been withdrawn later. The organizations comprise the SDOs discussed above (ASTM, ISO, VDI) plus IPC, AWI, AFNOR and AENOR. The identified standards have been categorized with respect to the developing organization, year of publication, material used, and subject matter. The latter was based on the ASTM F42 committee categories materials and processes, test methods, design, and terminology. 

Fig. 2 displays the development of those standards over time. It shows well that standardization slowly started in 2009 with the first standard published by VDI. 2013 and 2014 saw a peak in the publication of standards with the newly founded ASTM and ISO TCs having finished first projects. At this time there was also a new peak in the number of issued patents and published patent applications [40], following the expiration of key patents and the growing commercial and public interest in the technology. This continuing trend of intensified research activities and recognition in industry is also fueling the demand for standards and activities in standardization.

Corresponding to the model of Blind and Gauch (2009), which describes the sequence of standards development, Fig. 3 shows that the first published standards were terminology standards (VDI 3404:2009 and ASTM F2797:2012, revised and adopted as
Terminology standards are especially important for emerging technologies since they allow a common understanding of basic components and elements, facilitating efficient communication and transfer of knowledge in research and standardization. Terminology issues need to be addressed and solved in early stages in the innovation cycle in order to avoid a diversion of understanding of a technology [10]. In AM they not only contributed to knowledge transfer in R&D but also to a better orientation for consumers concerning the diverse technologies and applications in AM, bridging R&D and markets. The figure also shows well a soon beginning focus on material and process standards since they are a key to greater reliability, accuracy and repeatability. This became increasingly important with the application in manufacturing e.g. in aerospace or automotive industry. Not only with the integration in an ongoing digitalization of production in the context of the industrial internet of things, but also with advancements in the AM technology itself such as the possibility of multi-color- or multi-material printing, the importance of interoperability and compatibility standards grew. In general, they are of particular importance for the transition of a new technology into the mass market since they ensure the interoperability and smooth operation between products or whole systems [10]. Suitable, comprehensive file formats are essential to communicate and transfer data in the AM process [41].

Addressing the shortcoming of the long used de facto standard STL with regard to the newly developed features in AM [42], a new ASTM standard was introduced in 2011 (ASTM 2915, later adopted as ISO/ASTM 52915:2013, new version in 2016). Despite its advantages, this new format AMF is no complete solution and has never been fully adopted by the industry that reacted hesitantly, each vendor waiting for a move of the other actors [42]. The difficulty in finding a neutral efficient and capable standard is high from a technological but also market perspective. Many of the information and data are currently in vendor specific proprietary formats which stirles full and open competition and consequently innovation and development [27]. A Microsoft-led consortium introduced a new standard 3MF which is expected to widely spread due to the market dominance of the consortium [37]. The consortium claims the same smooth printing experience as in 2D printing, irrespective of the used hard- and software, as well as other advantages over the existing AMF format [43].

Consortia in general have seen a rise over the past years, especially in the ICT domain [10, 44] and it needs to be seen whether and how this standard will disseminate. In June 2016 ASTM and the 3MF consortium signed a liaison agreement to potentially collaborate on data exchange formats with the aim of sharing information and jointly developing standards [45].

According to the model of Blind and Gauch, safety, reliability and testing standards become more and more relevant with the further development of the technology and its adoption. This can be seen in AM as well, where many of the ongoing standardization projects deal with testing methods, quality control and safety issues. These topics are increasingly important for manufacturers who have to deal with the hazards associated with the production process and materials. These risks include e.g. toxicity through airborne emissions, burning, electrical or mechanical hazards [8]. Quality assurance is considered one of the most important barriers to a broader adoption of AM, especially in metal applications. Meeting regulatory requirements poses grand challenges to manufacturers: especially in industries such as medicine, aerospace or defense where critical components are manufactured, failures need to be avoided and the production process and input materials need to be qualified. This requires reliable quality and testing standards. The sheer number of parameters that influence the output (more than 130) makes finding the right settings challenging. Standards can help to come up with the desired quality performance, e.g. in terms of required density of parts or surface characteristics. Certified input materials will help manufacturers in making the right purchase decisions for their purpose [46]. The data show increasing standardization activities in that field with ongoing projects on new test methods, especially non-destructing, quality control, but also more and more standards for materials and processes. Analyzing the development of AM standards, it can be seen that many of them have been revised or withdrawn over time. Egyedi and Sherif distinguish internal and external causes for such changes [47]. The latter kind of change accompanies the evolving nature of the technology which can be seen in the example of AM terminology standards that have been revised several times over the years caused by the technological progress in terms of processes and applications. Also the file format standards have to be changed due to changes in technology and new performance requirements. As the technology matures, standards will become more stable [47].

Fig. 4 shows that the majority of standards published so far are applicable to AM in general with no specific focus on any material used. However, it can also be seen that great efforts are made with regard to standards for metal based processes and materials which find application in industrial contexts, especially aerospace, automotive and defense – early adopters which are in need for standards for compliance with regulation and high market requirements.

Many more standards are currently under development: 52 ongoing projects have been identified during the research, most of them in ASTM, ISO or VDI. With the rise of desktop 3D printers for end users, the need for standards for that domain has risen. IEEE currently develops a dedicated standard for consumer 3D Printing (IEEE P3030). It can also be seen that more and more standards for specific AM applications are being developed such as medical 3D printing or Printed Electronics, but also a growing number of standards for quality and safety.

Fig. 5 illustrates the innovation system in AM, mapped onto the framework developed by Featherston et al. (2016). Major
developments and activities of innovation and standardization as well as the interrelations between them are visualized, depicting their complex dynamics. Though limited to terminology, compatibility, process and material standards only for better readability, the framework shows well how standards support innovation activities and the diffusion of the technology along its evolution by facilitating knowledge transfer and communication.

5. CONCLUSIONS

Considering different frameworks on standardization and innovation [10, 11, 13-15], the overall innovation ecosystem of AM and the linkages to standardization were systematically assessed and analyzed. The analysis of standardization activities comprised the technology elements to be standardized, the reasons for standard needs, the timing and sequence, as well as the stakeholders involved. Considering the complexity of the technology due to diverse processes and applications at different levels of maturity, the standards mapping is not trivial. Still, several lessons for standardization in emerging technologies can be learned.

Actors and events from politics, market, society, research and technology along the innovation trajectories have shaped the development of AM and its adoption, having an impact also on the standardization activities and outcome. With technological advancements, new applications and a raising awareness of the potential of AM, the user base grew – as did the need for standards to ensure reliability, repeatability, safety and conformity to regulatory requirements. Having had no formal standards for long, a coordinated, strategic approach by various standards bodies was then followed seeking to enable an efficient standardization through cooperative agreements, roadmaps and joint action plans.

The case study supports the view that standards play a significant role for the diffusion of emerging technologies, with different types of standards having different functions at the various stages of innovation [10]. The development of different types of standards over time follows well the model of Blind and Gauch (2009), with terminology standards being the first ones to be published, enabling a better communication and guidance along the different technical approaches and applications. An earlier availability of this type of standards thus could not only have spurred further standardization activities, but finally also supported a faster diffusion. With the growing adoption in industrial contexts due to technological advancements, there was then a focus on standards for processes and materials which are needed to ensure repeatability and reliability – particularly important for industrial metal applications where failures in the printing process are especially expensive. Ongoing standardization projects reflect the need for more standards on testing and quality which is typical for the broad diffusion of a new technology. Furthermore, new application areas with distinct requirements that emerge, such as medicine or aerospace, are increasingly addressed with dedicated standardization projects. Trying to align the development of new standards with the strategic exercises conducted by cooperating stakeholders such as gap analyses, roadmaps, and standards structures, progressively more standards are developed, with more than 50 projects currently running.

Learning from the experiences in AM, but also in the cases of nanotechnology or photovoltaic [10, 17], a systematic, comprehensive standardization strategy from the very beginning of an emerging technology, supports its diffusion. The development of standards is, however, not uncoupled from the general evolution of the innovation system, but rather has interrelations and dependencies with other activities by various stakeholders. This requires an intensive and targeted collaboration of stakeholders and alignment with all relevant dimensions of the innovation system of the emerging technology.

Since AM represents a very diverse technology covering multiple applications and technological approaches with different levels of maturity, future research could focus more on a specific area, e.g. metals in industrial settings such as aerospace industry, in order to gain deeper insights into the interrelations of standardization and the overall innovation system of an emerging technology. This can allow for the identification and analysis of clearer patterns and developments. AM can furthermore possibly contribute an interesting case to investigate the relation of standards and patents since it has been observed in this case study that standardization took off once first patents expired. These expirations clearly triggered the diffusion of AM, making standards become more necessary. Considering not only the growing number of standards but also the vasty increasing number of patents for AM, an analysis of standard essential patents in AM constitutes an interesting field of research. Finally, AM is a nice case to look at for an analysis of the role of standards consortia and which of the different file format standards, covering de facto, formal and lately consortia standards (.stl, .amf, .3mf), will finally become widely accepted for which reasons.

REFERENCES

ABSTRACTS
<table>
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<th>Session 1: Towards a universal, shared and integrated data ecosystem for the benefit of all¹</th>
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| **S1.1** | Invited paper: Legal challenges for data-driven society  
*Liu Duo (President, China Academy of Information and Communication Technology (CAICT))*

A legal system should bring to society expectations of stability, and should balance rights and obligations. But the emergence of revolutionary new technologies can change and even break the current order and balance. Big data applied to the everyday life of people is such a technology; it is deemed to create a brand new social paradigm bringing about entirely different perspectives in people’s observations of the world. This poses a challenge to the existing legal system, such as how to balance the utilization of big data and the security of data resources, and the exploitation of the data available and the protection of personal privacy. Other challenges concern how to determine the ownership of data, and how to determine the rights and obligations in exchange of data.

This paper mainly discusses the changes that big data is bringing to society and the legal challenges that the data-driven society will be confronted with. It puts forward suggestions regarding the development and security of big data industry, protection of personal privacy through the establishment of commercial rules for big data and through international coordination mediated by international organizations.

| **S1.2** | Open data & digital identity: Lessons for Aadhaar  
*Vinod Kotwal (Ministry of Communications and IT, India); Smriti Parsheera (National Institute of Public Finance and Policy, India); Amba Kak (Mozilla Foundation, India)*

Aadhaar, the largest biometric identification system in the world, has been lauded for its promise to bring efficiencies to government service delivery, and the stimulus to private sector innovation. However, its claims have been contested, and criticised for excesses in terms of potential threats to privacy on account of the vulnerabilities of biometric data, mandatory linkage with numerous schemes and the possibility of mass surveillance through linked databases. Even as the debate continues, every day, large volumes of data are being generated through the use of Aadhaar-enabled authentication and eKYC systems, both by government as well as private entities. There has been relatively less exploration of the resulting 'open data' potential of Aadhaar and the manner in which it can contribute to research, policymaking as well as strengthening accountability of the Aadhaar authority (UIDAI) itself. The challenge is to find ways to nudge UIDAI and all users of Aadhaar towards greater sharing of data, in privacy-protecting ways that do not create risks for Aadhaar-number holders. At this stage, we lean towards aggregate statistics as a means to open data while following the strictest standards of privacy.

¹ Papers marked with an “*” were nominated for the three best paper awards.
Open data development of countries: Global status and trends*  
*Esmeralda Florez Ramos (Technical University Berlin & Fraunhofer Institute for Open Communication Systems (FOKUS), Germany)

Open data plays a key role for governments strategy to deal with challenges of the future. It has the potential to improve public sector’s transparency, engagement of civil society, and economic growth. This paper contributes to answering the questions: Can open data have an impact on innovation? Under which condition is this the case? Which data can be used to assess the progress on a country level? Which countries are successful with open data? How successful are the government actions to support economic development through open data? The exploratory analysis investigates the relationship between open data readiness and measures on impact, and on changes in open data development level and the influence of the country’s level of ICT development, transparency and freedom. This paper also takes a specific look at economic impact scores and their correlation with government initiatives for training and innovation on open data. It was found that success on open data at the country level is based on good levels of ICT development, freedom and in the interest of becoming more transparent. There are indications that countries with low ICT development do not profit from open data, but the evidence is limited, due to the small number of countries observed. There is a strong correlation between support for entrepreneurship & business readiness and economic impact. However, the relationship between the development of these indicators during the time of the study and the measured impact is unclear.

Session 2: Envisioning future standards development

S2.1 A holistic approach to exploring the divided standards landscape in e-health research*  
*Doyoung Eom and Heejin Lee (Yonsei University, Rep. of Korea)

Based on the importance of standards in providing safe, interoperable, and quality healthcare, a growing body of literature explores e-Health services and systems in combination with standards and standardization. Yet a holistic approach to assess the state of academic research that involves standards and e-Health across diverse disciplines has not been taken up to date. To understand the dynamics of e-Health standards, particularly on the role and effect of those standards, this paper systematically reviews the standards landscape in e-Health research. We found three key themes: first, standards for e-Health in developed and developing countries; second, types of standards and their effects on interoperability, quality and security; third, implementation of standards in terms of adoption by healthcare organizations and application in the process of e-Health framework developments. This paper makes academic contributions by extracting common themes across disciplines and intends to provide practical implications for facilitating e-Health interventions while taking the benefits and challenges associated with standards into consideration.

S2.2 Intellectual property licensing tensions in incorporating open source into formal standard setting context – The case of Apache V.2 in ETSI as a start  
*Jingze Li (Tilburg University, The Netherlands)

Open Source Software is playing an increasing role in ICT standardizations on future technologies such as 5G and Internet of Things. Formal standard settings organizations (SSOs) are exploring ways to incorporate open source approach. This paper depicts the difference between open source licenses and the current SSOs legal framework in dealing with intellectual property rights, mainly the FRAND license commitment for patented technologies and the distribution for copyrighted software in specifications. Such difference might cause tensions in the two scenarios of interactions between SSO standards and open source: the implementation phase and the standardization activity phase. Some of the tensions are currently hypothetical. However, one recent and concrete example from ETSI, hosting an open source project under Apache v.2, might shed light on how SSOs can (cannot) avoid tensions by making changes to the governing framework.
| S2.3 | Governance within standards development organizations: Who owns the game?  
*Olia Kanevskaia (TILEC & Tilbury Law School, The Netherlands)*  

The past decade has witnessed the rise in prominence of interoperability and Internet standards in the wake of increased digitalization and technological advancement. Typically established by industry-driven association of professionals, often referred to as Standards Development Organizations (SDOs), standards and technical specifications are expected to address the needs of the industry and to benefit society. While SDOs arguably attempt to involve all directly and indirectly affected stakeholders in their standards development, the establishment of organizational rules and procedures, including Patent Policies, is often left to the discretion of the SDOs’ governing bodies and may not necessarily represent consensus of all interested parties. Placing procedural guarantees in the limelight of standardization research, this paper seeks to compare the actors and procedures of different SDOs as regards their standards development, governance processes and dispute resolution. It observes that procedural rules for standard-setting are not per se applicable to the decision-making in the governing bodies of the SDOs, and aims to suggest the possible consequences of this disconnection. |
| S2.4 | The standards revolution: Who will first put this new kid on the blockchain?*  
*Maria-Lluïsa Marsal-Llacuna, Miquel Oliver-Riera (Universitat Pompeu Fabra, Spain)*  

Blockchain is here to stay. Some affirm that it is the next big thing after the Internet. Blockchain is a network-based technology that rewards participants to assemble transactions which will next configure blocks and later be part of a chain. Blockchain guarantees immutability and integrity of data without the need of a third surveilling party. It is therefore a revolution in current systems of trust. It also brings automation and self-execution of processes thanks to its embedded smart contracts functionality. Current standards drafting and development processes can definitively benefit from blockchain technology, and perhaps see the standardization domain revolutionize, like it already happened in the fintech and insurtech arenas [1]. In this paper, we explain what these advantages are. And, before new standard drafting models emerge from the disruptive blockchain community, challenging traditional standard development models -with this paper-, we want to inspire and give tools to established standardization bodies for them to take the lead and initiate a transformation towards ‘Blockchained Standards’ so that they can keep their authority and leadership in the field going forward. |
### Session 3: Accelerating sustainable development through data

<table>
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<th>S3.1</th>
<th>Capability maturity models towards improved quality of the Sustainable Development Goals indicators data</th>
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<td>Ignacio Marcovecchio (United Nations University, Macao SAR, China), Mamello Thinyane (United Nations University, Macao SAR, China), Elsa Estevez (National University of the South, Argentina), Pablo Fillottrani (National University of the South, Argentina)</td>
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Achieving the Sustainable Development Goals (SDGs) demands coping with the data revolution for sustainable development: the integration of new and traditional data to produce high-quality information that is detailed, timely, and relevant for multiple purposes and to a variety of users. The quality of this information, defined by its completeness, uniqueness, timeliness, validity, accuracy, and consistency, is crucial for appropriate decision making; which leads to improvements in advancing national development imperatives for reaching the goals and targets of the sustainable development agenda. In this paper, we posit that the more mature the organizations within the national data ecosystems are, the higher the quality of data that they produce. The paper motivates for the adoption and mainstreaming of organizational Capability Maturity Models within the SGDs activities. It also presents the preliminary formulation of a multidimensional prescriptive Capability Maturity Model to assess and improve the maturity of organizations within national data ecosystems and, therefore, the effective monitoring of the progress on the SDG targets through the production of better quality indicators data. Furthermore, the paper provides recommendation towards addressing the challenges within the increasingly data-driven domain of social indicators monitoring.

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<th>S3.2</th>
<th>Advanced data enrichment and data analysis in manufacturing industry by an example of laser drilling process*</th>
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<td></td>
<td>You Wang (RWTH Aachen University, Germany), Hasan Tercan (RWTH Aachen University, Germany), Thomas Thiele (RWTH Aachen University, Germany), Sabina Jeschke (RWTH Aachen University, Germany), Tobias Meiesen (RWTH Aachen University, Germany), Wolfgang Schulz (RWTH Aachen University &amp; Fraunhofer Institute for Laser Technology, Germany)</td>
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Nowadays, the internet of things and industry 4.0 from Germany are all focused on the application of data analytics and Artificial Intelligence to build the succeeding generation of manufacturing industry. In manufacturing planning and iterative designing process, the data-driven issues exist in the context of the purpose for approaching the optimal design and generating an explicit knowledge. The multi-physical phenomena, the time consuming comprehensive numerical simulation, and a limited number of experiments lead to the so-called sparse data problems or "curse of dimensionality". In this work, an advanced technique using reduced models to enrich sparse data is proposed and discussed. The validated reduced models, which are created by several model reduction techniques, are able to generate dense data within an acceptable time. Afterwards, machine learning and data analytics techniques are applied to extract unknown but useful knowledge from the dense data in the Virtual Production Intelligence (VPI) platform. The demonstrated example is a typical case from laser drilling process.
### S3.3 Small data and sustainable development - individuals at the center of data-driven societies

*Mamello Thinyane (United Nations University, Macao SAR, China)*

At the centre of data-driven societies are individuals and end-users who not only generate data, but also benefit from the outcomes of the data-driven development. Extensive work has been undertaken to understand and explore the challenges and potential impact of data, in particular Big Data, for the private as well as the public sectors. Similarly work has been undertaken within the domains of Personal Informatics and life-logging, which has investigated the role of data, and specifically personal physical activity and health data towards improving the wellbeing of individuals. In this research we investigate the engagement of individuals in the use of data towards the achievement of the sustainable development imperatives as articulated in the 2030 Agenda for Sustainable Development. The paper presents: the awareness levels of the participants with regards to the Sustainable Development Goals; their attitudes and perceptions around monitoring of social indicators; key considerations associated with data ownership, privacy and confidentiality of data, as well as sharing of data within the data ecosystem. The paper subsequently discusses how these finding could inform the implementation of small data tools to support the active engagement of individuals in data-driven societies.

### Session 4: Smartening up society with data and new applications

#### S4.1 Fostering smart city development in developing nations: A crime series data analytics approach*

*Owowunmi E. Isafiade (University of the Western Cape, South Africa) and Antoine Bigomokero Bagula (University of the Western Cape, South Africa)*

Crime remains a challenge in many parts of the world. This is compounded in low-resource settings where police are short-staffed and there are not enough technological solutions in place to assist security agencies with knowledge-driven decision support. While most smart city initiatives have placed emphasis on the use of modern technology such as armed weapons for fighting crime, this may not be sufficient to achieve a sustainable safe and smart city in resource constrained environments, such as in Africa. In particular, crime series which is a set of crimes considered to have been committed by the same offender is currently less explored in developing nations despite its importance for public safety improvement. This research presents a novel crime clustering model, CriClust, based on a dual threshold scheme for crime series pattern (CSP) detection and mapping to derive useful knowledge from a crime dataset. Based on analysis of 5500 (rape) crime records across 40 locations (suburbs) in Western Cape, CriClust led to the identification of up to three series at some of the locations investigated. We present an effective web-based system that security agencies can use for timely CSP identification to aid strategic and viable means of combating crime in low resource settings.
### S4.2
Toward the data-driven "smart" and "green" hospital-care*

Vasileios (Basile) P. Spyropoulos (Technological Education Institute of Athens and National and Kapodistrian University of Athens, Greece), Avrilios Alexandropoulos (National and Kapodistrian University of Athens, Greece), Nada Boci (National and Kapodistrian University of Athens, Greece), Eleni Chatziapostolou (National and Kapodistrian University of Athens, Greece), Eleftheria Panagiota Frappa (National and Kapodistrian University of Athens, Greece), Nada Boci (National and Kapodistrian University of Athens, Greece), Eleni Georgiadou (National and Kapodistrian University of Athens, Greece), Ioannis Pantelakis (National and Kapodistrian University of Athens, Greece), Maria Poultsaki (National and Kapodistrian University of Athens, Greece), Marianna Kanella Xenaki (National and Kapodistrian University of Athens, Greece)

The Hospital is the most complex and representative establishment of the society and nowadays, among the most costly ones. ICTs may rationalize personnel-efforts and reduce energy and material-wasting, to enable health-care coverage, of unprivileged social-groups. The aim of the paper is to present the most effective and efficient means and tools, reducing unnecessary cost, as Mobile IP-network, Service-oriented architecture, provided to other components, through a communication protocol, over a network, Ubiquitous-computing, Femtocells, small, low-power cellular base-stations, typically designed for use in a hospital-department, ward-room or unit, Wireless mesh-networks, made-up of radio-nodes, organized in a mesh-topology, supporting intra-hospital data-exchange, training Multimedia-sharing over wireless networks, for real-time or compressed data-streaming over IP/wireless-networks for communication or archiving.

Green-computing in wireless-networks, are limiting people and material intra-hospital "circulation" and, thus, they are enabling the necessary environmentally friendly and smooth procedures. Standardization, policies and regulations for green communications and computing, in "green" Hospitals are indispensable and ICTs enable procedures optimization, solving energy- and material-waste problems, reducing the overall operational-cost, in the emerging "smart, green and networked" Hospital, in favor of the people in need.

### S4.3
Socio-economics and educational case study with cost-effective IoT campus by the use of wearable, tablet, cloud and open e-learning services*

Toshiki Ueda, Yoshikazu Ikeda (Otani University, Japan)

In this paper the authors show a case study reporting educational experiences in a Japanese university's digital campus supported by the cost-performance improvement in Information and Communication Technologies (ICT) including electronic devices and networks. The authors also report the use of wristband wearable devices to monitor walking and sleeping habits of a student and the influence on health consciousness. Considering education effectively on campus has become important in every country and area worldwide. In this regards, we have conducted a socio-economics case study with cost-effective ICT and Internet of Things (IoT) devices including tablet PC, wearable and e-learning services. In order to promote educational innovation regardless of economic and political status of each country, the standardization is urgent and important concerning education methods with advanced technologies. We propose ITU to study best practices in education in terms of network, devices, applications, contents and teaching methods. ITU should seek the quality of education methods including managing operational aspects like ISO 9001 Quality management and ISO/IEC 27001 Information security management. In this paper our case study consists of two parts, a deployment of large-scale tablet PCs and a successful improvement in student's Body Mass Index (BMI) implemented by wearable devices as a basic condition for study attitude.
Drone readiness index

Samuel Nzaramba (Carnegie Mellon University Africa, Kigali, Rwanda), Rene Kabagamba (Carnegie Mellon University Africa, Kigali, Rwanda), Kate Chandler (Georgetown University, Washington DC, USA), Aminata Garba (Carnegie Mellon University Africa, Kigali, Rwanda and Carnegie Mellon University, Pittsburgh, USA)

This paper proposes a new model for evaluating the robustness of the ecosystem for drone projects in a given country, considering nine factors ranging from the regulatory framework to economic and social impact. The objective of this study is to provide a tool in the form of an index that can be used to gauge countries readiness for drone projects. Governments, NGOs as well as commercial drone companies can use the index to gain insights into the possibilities of drones for non-military use. Notable successful projects using drones were used as a benchmark to chart out the various components of the Drone Readiness Index (DRI). We first reviewed selected projects that have attempted to use drone aircrafts for non-military activities, using secondary data. We then quantify the elements of the drone ecosystem and present derivations of the proposed drone readiness index. To show applications and examples of the proposed drone readiness index, we compute the values of the drone readiness index for selected African countries. These values are further presented in a website.

Session 5: Smartening up society with data and new applications

S5.1 Machine learning approach for quality adaptation of streaming video through 4G wireless network over HTTP

Dhananjay Kumar, Aswini Viswanathan (Anna University, MIT Campus, India); Arun Raj Lakshminarayanan (B.S.A Crescent University, Chennai, India); Hiran Kumar Singh (Vel Tech University, Chennai, India)

Video streaming over HTTP through 4G wireless network used for multimedia applications faces many challenges due to fluctuations in network conditions. The existing HTTP Adaptive Streaming (HAS) techniques based on prediction of buffer state or link bandwidth offer solution to some extent, but if the link condition deteriorates, the adaptation process may reduce the streaming bit rate below an acceptable quality level. In this paper, we propose a machine learning based method, State Action Reward State Action (SARSA) Based Quality Adaptation algorithm using Softmax Policy (SBQA-SP), which identifies the current state (Throughput), action (Streaming quality) and reward (current video quality) at client to determine the future state and action of the system. The ITU-T G.1070 recommendation (parametric) model is embedded in the SBQA-SP to implement adaptation process. The proposed system was implemented on the top of HTTP in a typical internet environment using 4G wireless network and the streaming quality is analyzed using several full reference video metrics. The test results outperformed the existing Q-Learning based video quality adaptation (QBQA) algorithm. For instance, an improvement of 5% in average PSNR and 2 % increase in average SSIM index over the QBQA approach was observed for the live stream.
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<th>S5.2</th>
<th>Modeling and analysis of spatial inter-symbol interference for MIMO image sensors based visible light communication</th>
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<tr>
<td><em>Rongzhao Wu, Yarong Guo, Peng Liu (North China Electric Power University, China); Jiang Liu (Waseda University, Japan)</em></td>
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In this paper, the basic model of MIMO image sensors based visible light communication system is researched. In the system, the space inter-symbol interference caused by the stray light degrades the system performance. The formation mechanism of the stray light and the influence of the space inter-symbol interference is analyzed. The mathematic expression of the system SNR and BER is given. The simulation result indicates that there is a critical communication distance in the system. Once the communication distance exceeds the critical value, the system BER increases sharply. In addition, an adaptive threshold detection method is introduced and the performance is simulated. By means of estimating the spatial inter-symbol interference noise power, the optimal detection threshold can be obtained and the system BER performance enhances significantly.

<table>
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<tr>
<th>S5.3</th>
<th>Secrecy energy efficiency optimization for artificial noise aided physical-layer security in cognitive radio networks</th>
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<tr>
<td><em>Yuhan Jiang, Jian Ouyang, Yulong Zou (Nanjing University of Posts and Telecommunications, China)</em></td>
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In this paper, the artificial noise (AN) is used to improve the secrecy energy efficiency (SEE) for underlay cognitive radio networks (CRNs). A joint zero-forcing (ZF) beamforming and power allocation problem is formulated to maximize the SEE under the constraints of the total transmit power, the secrecy rate (SR) of cognitive user (CU) and the quality-of-service (QoS) requirement of primary user (PU). As a consequence, we firstly transform the formulated non-convex optimization problem in fractional form into an equivalent one in subtractive form, and use the difference of two-convex functions (D.C.) approximation method to obtain an equivalent convex problem. Then, a power allocation algorithm is presented to obtain the optimal solution. Simulation results show the advantage of the proposed scheme.

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<th>S5.4</th>
<th>Data centric trust evaluation and prediction framework for IoT</th>
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<tr>
<td><em>Upul Jayasinghe, Abayomi Otebolaku, Gyu Myoung Lee (Liverpool John Moores University, United Kingdom); Tai-Won Um (Chosun University, Rep. of Korea)</em></td>
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Application of trust principals in internet of things (IoT) has allowed to provide more trustworthy services among the corresponding stakeholders. The most common method of assessing trust in IoT applications is to estimate trust level of the end entities (entity-centric) relative to the trustor. In these systems, trust level of the data is assumed to be the same as the trust level of the data source. However, most of the IoT based systems are data centric and operate in dynamic environments, which need immediate actions without waiting for a trust report from end entities. We address this challenge by extending our previous proposals on trust establishment for entities based on their reputation, experience and knowledge, to trust estimation of data items [1-3]. First, we present a hybrid trust framework for evaluating both data trust and entity trust, which will be enhanced as a standardization for future data driven society. The modules including data trust metric extraction, data trust aggregation, evaluation and prediction are elaborated inside the proposed framework. Finally, a possible design model is described to implement the proposed ideas.
### Poster Session

| P.1 | Contract theory based caching and pricing strategy for content centric networks  
*Chen Li, Jintian Li, Zhou Su, Qichao Xu (Shanghai University, China)*

Content centric networks (CCNs) have emerged to deliver a large amount of contents in the networks. However, it has become a new challenge to efficiently cache the contents in the CCNs. Therefore, in this paper, we design a contract theory based content caching scheme to improve the performance of CCNs. Firstly, a two-layer heterogeneous network model is introduced to study the interaction between users and content providers. Secondly, based on the contract theory, the optimal caching and pricing strategy can be obtained under two constraints in CCNs. Finally, simulation experiments are carried out to prove that our proposal can efficiently improve the cache performance of CCNs. |

| P.2 | The IEEE 1906.1 standard: Nanocommunications as a new source of data  
*Sebastian Canovas-Carrasco, Antonio-Javier Garcia-Sanchez, and Joan Garcia-Haro (Technical University of Cartagena, Spain)*

Nanoscale communications is a new paradigm encompassing all those concerns related to the exchange of information among devices at the nanometer scale. A network infrastructure consisting of a huge amount of nano-devices is envisaged to ensure robust, reliable and coordinated data transmission. This will enable a plethora of forthcoming applications and services in many different research fields, such as personalized medicine, synthetic biology, environmental science or industry, which will lead to outstanding and unprecedented advances. The IEEE P1906.1 standard provides a conceptual and general framework to set the starting point for future developments in nanoscale communication networks. This paper reviews the latest IEEE P1906.1 recommendations, observing their main features when applied to the electromagnetic (EM) nanocommunication area. We contribute by identifying and discussing the principal shortcomings of the standard, to which further research efforts must be devoted. We also provide interesting guidelines for focusing the object of future investigations. |

| P.3 | TASIS: Trend Analysis System for International Standards  
*Myeongha Hwang (University of Science and Technology, Rep. of Korea); Minkyo In, Suwook Ha, Kangchan Lee (Electronics and Telecommunications Research Institute, Rep. of Korea)*

Recently, text mining has risen as an advanced technology that analyzes meaningful trends and topics in document collections. Despite its increasing use in various research areas, there have not been previous studies using document collections of international standards. In this paper, we propose the Trend Analysis System for International Standards (TASIS), which automatically performs topic modeling and trend analysis on document collections of the International Telecommunication Union Telecommunication Standardization Sector (ITU-T) Recommendations, based on a latent dirichlet allocation (LDA) algorithm. For providing Web services, the TASIS performs topic modeling by exploiting user-defined parameters, such as the number of topics and iterations, and the results show a list of the documents that each keyword in the topic is included in. The TASIS also describes a TreeMap with the size of the extracted topic as a graphical expression for easier understanding. |
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<td>P.4</td>
<td>Exploiting multi-radio cooperation in heterogeneous wireless networks for absolute security against eavesdropping</td>
<td>Ming Sun, Yulong Zou, Mujun Qian, Quanquan Wang, Jia Zhu (Nanjing University of Posts and Telecommunications, China)</td>
<td>In this paper, we consider a heterogeneous wireless communication scenario, which is comprised of a source (S) and a destination (D) in the presence of an eavesdropper (E), each equipped with multiple heterogeneous radio access interfaces. In order to enhance the transmission security against eavesdropping, we propose a multi-radio cooperation (MRC) scheme, where the multiple radio interfaces at S are simultaneously utilized to transmit a source signal to D along with a weight design. For the convenience of performance comparisons, the conventional multi-radio switch (MRS) scheme is also considered as a benchmark scheme, in which only the single &quot;best&quot; radio interface is selected at S to transmit the source signal. We evaluate the secrecy capacity and intercept probability (IP) of conventional MRS and proposed MRC schemes over Rayleigh fading channels. It is proved that the proposed MRC scheme can achieve an absolute security with zero IP, which is further validated through Monte-Carlo simulations. Numerical results show that the proposed MRC scheme performs better than conventional MRS scheme in terms of their secrecy capacity and IP.</td>
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<td>P.5</td>
<td>The immutability concept of blockchains and benefits of early standardization</td>
<td>Frank Hofmann, Simone Wurster, Moritz Böhmecke-Schwafert (Technical University Berlin, Germany), Eyal Ron (Cryptom Technologies, Germany)</td>
<td>The blockchain technology can be regarded as a groundbreaking invention with the potential to bring the digital revolution to the next stage by helping to realize peer economy solutions. The blockchain technology and the concept of blockchain immutability is discussed. The benefits of early standardization of the blockchain technology are argued based on the literature and the analysis of the central blockchain immutability characteristic. From this, a framework is proposed aimed at understanding the dimensions and boundaries of blockchain immutability. The resulting framework is suggested as a good practice standard for the implementation of blockchain systems. Based on these efforts, the article supports initiatives to better exploit the blockchain technology's full potential by standardization.</td>
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<td>P.6</td>
<td>Standardization in emerging technologies: The case of additive manufacturing</td>
<td>Claudia Koch (BAM Federal Institute for Materials Research and Testing &amp; Technical University Berlin, Germany)</td>
<td>Additive Manufacturing provides an important enabling technology for the digital transformation of the economy. As an emerging technology it has seen a remarkable development over the last three decades. Nevertheless, it is far from a broad adoption with several barriers to overcome yet. One of the major challenges is the lack of standards. The critical role of standardization for innovation is generally recognized, still the topic too often has been neglected in strategic roadmapping exercises for emerging technologies. Too little is known about the complex dynamics and interrelations of standardization and innovation. The anticipation of standardization needs and the timely and efficient implementation of standards is challenging. This paper aims at contributing to a better understanding of the role that standards play in the multi-dimensional system of innovation. It analyzes the trajectories of innovation in Additive Manufacturing in a systematic and holistic way, focusing on standardization activities with regard to coordination, stakeholders involved, the timing and types of standards developed. Putting standardization in context of the multi-dimensional innovation system of Additive Manufacturing the research shows where standards can support the diffusion of an emerging technology.</td>
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