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A Strategy for

Innovation in Future Networks in Europe

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Abstract

This current view of the SRA from the Net!Works platform is based on all the white papers that identify strategically important applications in smart cities and broadband communication technologiesfor research and innovation in Europe. It contains also topics from editions of the SRA previous to the last one that are still relevant, as well as inputs from the COST Action IC1004. These research topics are grouped into the following areas: Applications and Requirements, Spectrum Crunch, Broadband Wireless, Networks for the Next Generation of Wireless-Optics Communications, Architectures and Management of Future Networks, Networks as National Critical Infrastructures, Networks for Cloud Computing and Service Platforms.

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Executive Summary

EXECUTIVE SUMMARY

This report is the result of extensive discussions and brainstorming with more than 70 experts from Europe's industry and academia on strategically important research, development, innovation, and applications in future smart cities. The identified applications and technologies are those that experts believe Europe should invest and carry collaborative research. The societal challenges identified in the EU Digital Agenda and the EC Innovation Union have been the basis of the proposed technologies and applications. This report is based on the previous edition of the Strategic Research Agenda (SRA Version 9), which was updated with recent Net!Works' White Papers, and Position Paper from COST Action IC1004, and selected topics for earlier editions of the SRA.

This report is structured into six chapters, besides the ones with the Introduction, and Conclusions and Recommendations. Chapter 2 addresses Smart Cities Applications and Requirements, where, besides dealing with the economic, social and privacy Implications, four key areas are identified: E-Government; Health, Inclusion and Assisted Living; Intelligent Transportation Systems; and Smart Grids, Energy Efficiency, and Environment. Each of these areas is analysed from the perspective of applications description, potential, challenges, technical requirements, and roadmaps. Chapters 3 to 7 present the topics related to Spectrum Crunch, Networks for the Next Generation of Wireless-Optics Communications, Architectures and Management of Future Networks, Networks as National Critical Infrastructures, and Networks for Cloud Computing and Service Platforms. Each of these chapters is approached from the perspective of identifying rationale, research priorities, technology roadmap, and recommendations. Some of the topics are present more than once, mainly showing that they are transversal to several areas.

A number of essential technologies that offer great potentials in addressing the mismatch between rates of increase in the demand and capacity are considered strategic, in the sense that, if developed, they will lead to greater economic and social impact as the result. Investment in these technologies, in the form of funding of research, is expected to contribute to enhancing Europe's leadership and competitiveness in the global market. These technologies address issues grouped into: Users' Requirements for Communications in 2020; Telecom Industry Challenges; and Grand Societal and Economic Challenges towards a Sustainable Future and Digital Single Market. The topics to be addressed are identified as being part of the following

“problems”: smart communication systems; context-based networking; user profiling mechanisms and technologies; machine-to-machine communications; small cell technologies; infrastructure sharing; support of a fully multi-dimensional approach; information centric networks; hybrid of optical fibre and wireless technologies; optical networks; new communication technologies; systems co-design; energy efficient systems; standard interfaces; trust, security, and privacy. A total of 33 recommendations on specific topics to be addressed in an R&D programme are presented in the end.

The need for a more holistic, coordinated and strategic approach spanning the research to business spectrum is clear. One needs to develop master plans to address the opportunities, avoiding fragmentation of efforts and optimising the chances of success in the market. A seven-year Framework Programme should provide theflexibility to incorporate and capture these dynamics, hence maintaining relevancy over the period. Efforts should be made to shorten the process from proposal submission to contract signature to less than 6 months. Current instruments for collaborative research, such as IPs and STREPs, are effective and should be maintained. Another recommendation is on co-financing of projects, being recommended that one single source of funding accessible by organisations from all member states on the same basis is used, as it is currently used in FP7.

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List of Acronyms

3D	Three Dimensional
3GPP	3rd Generation Partnership Project
A/D	Analogue to Digital
API	Application Programming Interface
BAN	Body Area Network
CAPEX	Capital Expenditure
CC	Cloud Computing
CDMA	Code Division Multiple Access
CNM	Cognitive Network Management
CNO	Cognitive Network Operation
CoMP	Coordinated Multi-Point
CPU	Central Processing Unit
CR	Cognitive Radio
CRN	Cognitive Radio Network
D/A	Digital to Analogue
DG	Directorate-General
DSA	Dynamic Spectrum Access
DSL	Digital Subscriber Line
E2E	End to End
EC	European Commission
EU	European Union
FCCC	Fast, Cheap, Clean and Cognitive
FDD	Frequency Division Duplex
FDN	Fibre Distribution Network
FIA	Future Internet Assembly
FN	Future Networks
FP7	Framework Program 7
FTTH	Fibre to the Home
FW	Framework
GDP	Gross Domestic Product
GPS	Global Positioning System
HCI	Human Computer Interfaces
HSPA	High Speed Packed Access
IaaS	Infrastructure as a Service
ICT	Information and Communication Technologies
IMT	International Mobile Telecommunications
INFSO	Information Society
INM	In-bound Network Management
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technologies
ITS	Intelligent Transportation Systems
ITU-R	International Telecommunications Union – Radiocommunications Sector

LE3S	Latency, Energy efficiency, Spectral efficiency, Scalability and Stability
LED	Light Emitting Diode
LTE	Long Term Evolution
LTE-A	Long Term Evolution – Advanced
M2M	Machine to Machine
MAC	Medium Access Control
MIMO	Multiple Input Multiple Output
NaaS	Network as a Service
NGN	Next Generation Networks
NUM	Network Utility Maximisation
OAM	Operation, Administration and Maintenance
OECD	Organisation for Economic Co-operation and Development
OEO	Optical-Electrical-Optical
OFDM	Orthogonal Frequency Division Multiplexing
OPEX	Operational Expenditure
OSI	Open Systems Interconnection
OSS	Operations and Support Systems
PA/D	Photonic A/D
PC	Personal Computer
PD/A	Photonic D/A
POF	Plastic Optical Fibre
PON	Passive Optical Network
PPDR	Public Protection Disaster Relief
QoE	Quality of Experience
QoS	Quality of Service
R&D	Research & Development
RAN	Radio Access Network
RAT	Radio over Fibre
RoF	Radio Resource Management
RRM	Radio Resource Management
SAA	Strategic Applications Agenda
SaaS	System as a Service
SARA	Strategic Applications and Research Agenda
SDK	Software Development Kit
SDR	Software Defined Radio
SFN	Single Frequency Network
SH	Spectrum Hole
SLA	Service Level Agreement
SME	Small Medium Enterprise
SoftN	Software Defined Network
SON	Self-Organising Networks
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TMN	Telecommunications Management Network
TV	Television
UHF	Ultra High Frequencies
UMTS	Universal Mobile Telecommunications System

US	United States
UK	United Kingdom
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VoIP	Voice over IP
VPN	Virtual Private Network
WCDMA	Wideband Code Division Multiple Access
WDM	Wavelength Division Multiplexing
WDMA	Wavelength Division Multiple Access
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WRC	World Radio Conference
WS	White Space

Introduction

1

1. Introduction

1.1 Realizing Potentials and Transformative Powers

Maintaining a strong lead in Information and Communication Technologies (ICT) is essential to the future of the economy and jobs in Europe. ICT infrastructures are the basis of global commerce and communication, included in national critical infrastructure plans, and according to the United Nations, it is such an essential part of everyday life that it now constitutes a human right.

Europe and its ICT industries have the capacity and know-how to transform and modernise business across the continent, helping organisations become more productive and to innovate. Europe's ICT exports are currently worth more than three times the exports of Korea or the US, and there is real potential for continued growth. The sector is also well-positioned to take the lead on the new wave of broadband networking technologies.

7 out of the 10 largest telecom operators (British Telecom, Deutsche Telekom, Orange, Telecom Italia, Telefonica, Telenor, and Vodafone,), as well as the world's major telecom manufacturers (Alcatel-Lucent, Ericsson, Nokia, and Nokia Siemens Networks) have their headquarters and origins in Europe. In 2009, the global Research & Development (R&D) investment made by these manufacturers exceeded € 10.1 Bn, resulting in global sales of € 76.3 Bn, and the employment of 290 000 people[EuCo10c]. The European ICT industry has created and pioneered leading standards, such as GSM, UMTS, LTE, LTE-A, ADSL and optical broadband. Current estimates suggest that the mobile industry in Europe will deploy around € 145 Bn in capital expenditure to 2013, creating direct and indirect employment for over 4.7 M people [GSMA09].

Europe also has the globally largest concentration of SMEs in the ICT sector and is second, only to the US, in terms of innovation. For example, the UK Business Innovation and Skills (BIS) [BIS10] "top 1 000 UK companies" from 2010 shows the communications and broadcast industries as representing revenues of £ 129 Bn (second only to Oil and Gas) and an R&D spend of £ 3.7 Bn (second only to Pharma and Bio) [DCKT10].

In the current economic climate, investment in telecommunications networks infrastructures has already proven to be an effective economic stimulus. An 8% change in telecommunications investment corresponds roughly to a 1% change in GDP. In the high income countries, such as those in the OECD, use of broadband by 10 subscribers per 100 inhabitants has corresponded to a 1.2%

increase in per capita GDP growth [OECD09]. Currently, the ICT sector is directly responsible for 10% of Europe's GDP, with an annual market value of € 660 Bn, and directly accounts for 3% of employment (6.1M) [EuCo10d]. The ICT sector contributes considerably more to European GDP by improving growth through productivity in other sectors - 20% directly from the ICT sector and 30% from ICT investments. The establishment of a Digital Single Market in Europe is expected to increase GDP by an additional 4% [Hohe11].

1.2 Trends and Drivers

The number of mobile users and the scale of mobile traffic are increasing at a staggering exponential rate. Cisco [Cisc11] predicts that by 2015, global mobile data traffic will increase 26-folds. It will increase by 1000- fold 2020, according to Huawei's [Huaw11] and Docomo's [Kais11] forecasts. These statistics are all relative to the 2010 traffic levels, implying a doubling of traffic per year. Moreover, Cisco [Cisc11] predicts that, in 2015, every person in the world will have a mobile phone and two thirds of the world's mobile traffic will be video. In this time scale, one second of video traffic uploaded on the network will take one persontwo years to watch. Additionally, mobile to mobile traffic is expected to reach 295 PetaBytes per month in 2015.

Portio Research (an industry insight provider) suggests in the "Worldwide Mobile Industry Handbook 2011-2015" [Port11] that in 2010 consumers and business users have spent more than 1 Trillion USD on mobile services, comfortably exceeding their expenditure on software, medicine, IT hardware, or semiconductors. It is evident that the mobile services industry is still growing strongly. By 2015, this report projects that the number of mobile users around the globe will reach 7 Billion, while expenditure on mobile services will grow to over 1.7 Trillion USD. This continuous growth is attributed to the appeal of smart phones, as well as the increasing penetration of basic mobile services in developing and emerging markets.

Additionally, in several reports, and notably in the EU Digital Agenda[EuCo10a], emphasis is placed on the role of ICT and its transformational power in the modernisation of other industries. ICT has also been recognised as an effective enabling technology in addressing the "Grand Societal Challenges" of climate change, energy shortage, transportation, health and demographic changes.

In summary, traffic demand is doubling every year whilst capacity is only doubling every ten years. This gap between demand and supply will becontinuously increasing unless major technological advancements are made.This unprecedented technical challenge also offers unique opportunities for Europe, should timely investment in appropriate technologies be made by funding organisation. The purpose of this report is tocreate awareness and help in mobilising the research community to focus their efforts on strategically important technologies that can lead to greater market and employment opportunities in Europe.

1.3 This Report

This report is the result of extensive discussions and brainstorming with more than 70 experts from Europe's industry and academia on strategically important research, development, innovation, and applications in future smart cities. The identified applications and technologies are those that experts believe Europe should invest and carry collaborative research. The societal challenges identified in the EU Digital Agenda [EuCo10a] and the EC Innovation Union [EuCo10b]have been the basis of the proposed technologies and applications.

This report is based on the previous edition of the Strategic Research Agenda, SRA Version 9 [NetW11a], which included the following White Papers:

- Smart Cities Applications and Requirements [NetW11b],
- Broadband Wireless beyond 2020 [NetW11c],
- Next Generation Networks: Wireless-Optical Technologies [NetW11d],
- Future Networks and Management [NetW11e].

Three new White Papers were released afterwards, which represent novel contributions to the current edition of the SRA:

- Spectrum Crunch [NetW12a],
- ICT as a National Critical Infrastructure [NetW12b],
- Networking and Telecommunications for Cloud Computing and Service Platforms [NetW12c].

In addition, a Position Paper from COST Action IC1004 [Card12] was also taken as input, as it contains valuable information for the goals of the current report. Finally, selected topics for earlier editions of the SRA [eMob07], [eMob08], [eMob10b] were also accounted for, since they still currently present challenges and open problems.

It is important to note that in the process of short listing the topics (research and technologies), those that fall in the following categories were purposely excluded:

- currently on-going research projects in EU FP and National programmes;
- extensively covered in previous SRA versions and no longer presenting a long term challenge;
- currently under full investigation in standardisation bodies;
- no economic and societal impact potential.

The following steps were taken, Figure 1, in an iterative manner as a first approach, in order to reach essential technologies and the evolution of their associated features over time:

- Vision: it captures the market trends and user requirements in years beyond 2020.
- Requirements: they consist of several interrelated factors, as shown inFigure 2.
- Technologies: Enabling technologies viewed as essential by the experts, in addressing the majority of the identified requirements, mainly focusing the effort on networking technologies. The enabling technologies helped to facilitate the identification of strategically important research topics that were considered essential in their realisation. The research topics were those that deemed to be essential in solving the technological challenges in the face of scarcity of resources, such as energy and spectrum, as well as those that help to hide or simplify the cost and complexity of usage and deployment of the technologies.
- Roadmap: it captures the availability of technology in a time scale. It was decided to have a 5-year timescale for the technology roadmap, as shown in Figure 3, influenced by market drivers, as well as quantitative and qualitative aspects. As a specific technology can evolve over time with its new features to full sophistications, this was useful in identifying when a specific feature will be available and fully standardised, so that no further research effort will be required.

Figure 1 – Steps taken for each technology area.

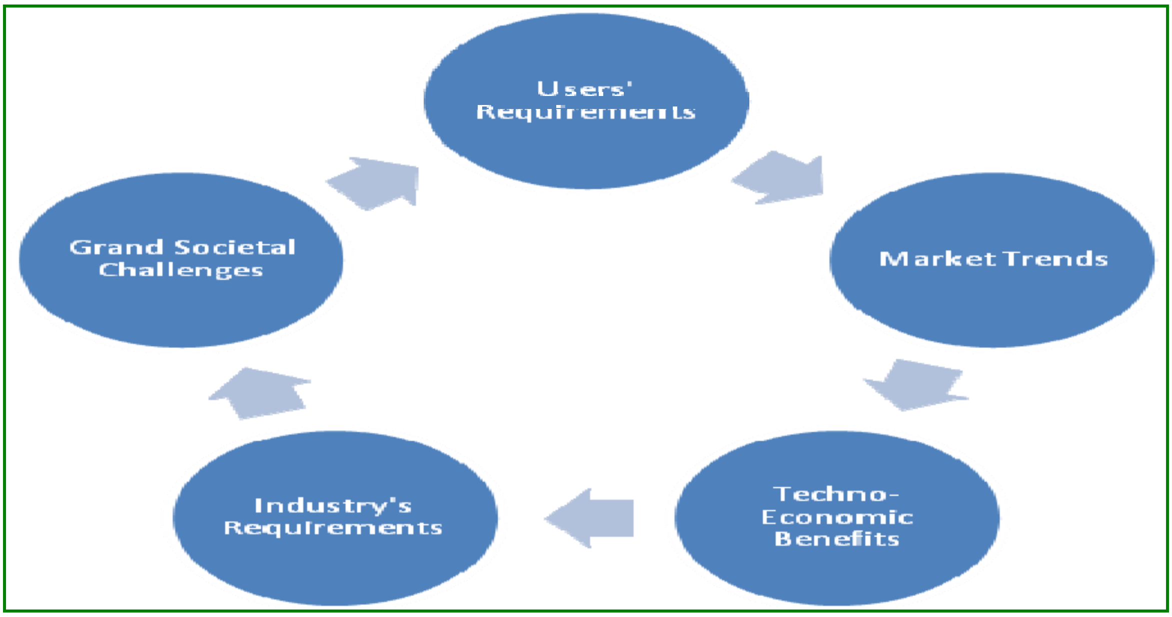

Figure 2 – Interrelated factors for requirements.

Timeline	In 5 Years	In 10 Years	Beyond 10 Years
Technology 1			
Technology 2			

Figure 3 – Technology Roadmap Timeline.

This report is structured into six more chapters, plus the final one with conclusions and recommendations. Chapter 2 addresses Smart Cities Applications and Requirements, where, besides dealing with the economic, social and privacy Implications, four key areas are identified: E-Government; Health, Inclusion and Assisted Living; Intelligent Transportation Systems; and Smart Grids, Energy Efficiency, and Environment. Each of these areas is analysed from the perspective of applications description, potential, challenges, technical requirements, and roadmaps. Chapters 3 to 7 present the topics related to Spectrum Crunch (update of Broadband Wireless Beyond 2020), Networks for the Next Generation of Wireless-Optics Communications, Architectures and Management of Future Networks, Networks as National Critical Infrastructures, and Networks for Cloud Computing and Service Platforms. Each of these chapters is approached from the perspective of identifying rationale, research priorities, technology roadmap, and recommendations. Some of the topics are present more than once, mainly showing that they are transversal to several areas.

Smart Cities Applications and Requirements

2

2. Smart Cities Applications and Requirement

2.1 Introduction

Cities have a massive impact in the economic development of a country, being the “platform” where many people live and work, where services are provided to citizens in a wide range of ways, and where local government officials have a close contact with citizens. It is only natural then that ICT plays an increasing role in the life of both people, and private and public entities that are part of a city.

The concept of Smart Cities is gaining increasingly high importance as a means of making available all the services and applications enabled by ICT to citizens, companies and authorities that are part of a city’s system. It aims to increase the citizens’ quality of life and to improve the efficiency and quality of the services provided by governing entities and businesses. This perspective requires an integrated vision of a city and of its infrastructures, in all its components, and extends beyond the mere “digitalisation” of information and communication: it has to incorporate a number of dimensions that are not related to technology, e.g., the social and political ones.

When looking at the potential impact that telecommunications, and the services made available by them, may have in cities, a number of opportunities, challenges and barriers can be identified. The deployment of these services implies that other sectors need to be brought to work together with the telecommunications one, hence, requiring that the latter is aware of a number of requirements and constraints, coming from the many applications made possible in a Smart City environment. This matter was recently addressed by the European Commission, via two strategic documents, i.e., the Digital Agenda [EuCo10a] and the 2020 Flagship Initiative [EuCo10b].

Several projects have been developed in Europe addressing Smart Cities in their various dimensions, e.g., [Smar11a], [Smar11b], and [SmSa12]. A total of 6 dimensions have been identified in [Smar11b], which describe the global perspective that is required: economy (competitiveness), people (social and human capital), governance (participation), mobility (transport and ICT), environment (natural resources), and living (quality of life). Furthermore, in [KaLi09] the authors examine barriers to solve urban problems, presenting an approach on communities, and to turn problems into an opportunity to reduce costs, to improve services to communities, and to make cities smarter.

The intention of this chapteris to identify major topics of Smart Cities that will influence the ICT environment, as covered by Net!Works. In order to provide a significant contribution for on-going discussions in the context of future target settings, e.g., for enabling platforms, co-operative research, and public funding, an analysis is provided here, centred on the following aspects:Potential, Challenges, Technical requirements, and Roadmaps.

Based on the work of Net!Works, and on the past experience with eMobility's SAA (Strategic Applications Agenda) [eMob10a]and SARA (Strategic Applications and Research Agenda) [eMob10b], this chaptergroups the various dimensions into 5 topics:

- Economic, Social & Privacy Implications
- Developing E-Government
- Health, Inclusion and Assisted Living
- Intelligent Transportation Systems
- Smart Grids, Energy Efficiency, and Environment

In the sections that follow, these topics are addressed individually.

2.2 Economic, Social and Privacy Implications

2.2.1 Definition(s) of Smart Cities

While almost all cities (and municipalities and regions) want to be "smart", there is no accepted definition of what this means in practice – be it in technological, developmental, or administrative terms. A Smart City is more than a digital city. A Smart City is one that is able to link physical capital with social one, and to develop better services and infrastructures. It is able to bring together technology, information, and political vision, into a coherent programme of urban and service improvements.

It is a mistake to think that making smarter cities requires just more investment in IT – what cities need to be able to do is to use IT as a means to deliver local (and national and EU levels) aims and objectives. The most important issue confounding efforts to make cities smarter is not the development of appropriate technologies per se, but to tackle the difficulties in changing organisations and existing ways of working to use these new technologies to deliver smarter cities.

The concept of Smart Cities has also been used in different ways: to describe a cluster of innovative organisations within a region; the presence of industry branches that have a strong focus on ICT; business parks; the actual educational level of the inhabitants of a certain city; the use of modern technologies in an urban context; technological means that increase government efficiency and efficacy; etc. A clear definition remains elusive.

The authors of [GFKK07], describing medium-sized European Smart Cities, define a Smart City by using six characteristics in which such a city "performs in a forward-looking way": Smart Economy, Smart People, Smart Governance, Smart Mobility, Smart Environment and Smart Living. They use these six concepts to describe specific factors that can be important when describing a Smart City, which are presented in Figure 4.

SMART ECONOMY (Competitiveness)	SMART PEOPLE (Social and Human Capital)	SMART GOVERNANCE (Participation)
▪ Innovative spirit ▪ Entrepreneurship ▪ Economic image & trademarks ▪ Productivity ▪ Flexibility of labour market ▪ International embeddedness ▪ *Ability to transform*	▪ Level of qualification ▪ Affinity to life long learning ▪ Social and ethnic plurality ▪ Flexibility ▪ Creativity ▪ Cosmopolitanism/Open-mindedness ▪ Participation in public life	▪ Participation in decision-making ▪ Public and social services ▪ Transparent governance ▪ *Political strategies & perspectives*
SMART MOBILITY (Transport and ICT)	**SMART ENVIRONMENT (Natural resources)**	**SMART LIVING (Quality of life)**
▪ Local accessibility ▪ (Inter-)national accessibility ▪ Availability of ICT-infrastructure ▪ Sustainable, innovative and safe transport systems	▪ Attractivity of natural conditions ▪ Pollution ▪ Environmental protection ▪ Sustainable resource management	▪ Cultural facilities ▪ Health conditions ▪ Individual safety ▪ Housing quality ▪ Education facilities ▪ Touristic attractivity ▪ Social cohesion

Figure 4 - Characteristics and factors of a Smart City (extracted from [GFKK07]).

This definition of domains and factors can serve as a good starting point for the crystallisation of the Smart Cities concept. The authors of [CaDN09], looking for an operational definition of Smart Cities, base themselves on the study mentioned above and propose their own definition: *"We believe a city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance.".*

While this definition remains broad, the Smart Cities concept does entail many diverging elements, which are all in some way captured by it.

Given the broad definition of the Smart City concept, and the wide array of domains it may impact on, its potential is equally broad. In its most basic and general interpretation, the idea behind a Smart City should be an increase in quality of life for its citizens and travellers. This goal can be reached by increasing efficiency and efficacy of government, developing environment-friendly applications, increasing mobility, providing better health services, stimulating economic prowess, etc. In order to reach these and many other goals, it is vital that a city intending to become smart clearly outlines them in policy making, then defines a strategy that is founded in research to reach them, and which role(s) the city should play, e.g., as a service facilitator/incubator, service provider, network provider, etc.

2.2.2 Privacy, Security and Trust

All the domains discussed in this chapter raise new challenges in security and privacy, and although security is not the main selling point for most applications, users implicitly expect systems to be secure and privacy-preserving. If users deem a system as insecure or threatening their privacy, it will not be able to establish itself successfully in the market. Important social challenges stem from the necessity to adapt Smart City services to the specific characteristics of every user. A service has many configurations options, depending on user expectations and preferences; the knowledge of these preferences usually means the success or failure of a service. In order to adapt a service to the specific user's preferences, it is necessary to know them, and this is basically done based on a characterisation of that specific user. Nevertheless, a complete characterisation of user preferences and behaviour can be considered as a personal threat, so the great societal challenge for this, and for any service requiring user characterisation, is to assure user's privacy and security. Thus, in order to achieve user consent, trust in, and acceptance of Smart Cities, integration of security and privacy-preserving mechanisms must be a key concern of future research. Furthermore, the storage of user information for further transactions requires a categorisation, so that sensitive information can be detected and stored in a secure way, in order to protect users from data misuse that could endanger their privacy; non-sensitive information can then be shared between different services in order to enhance the user experience, always under user's consent.

The overall priority must be to establish user confidence in the upcoming technologies, as otherwise users will hesitate to accept the services provided by Smart Cities. Although Smart Cities are not a new technology concept by itself, but rather denote the intelligent combination of currently established systems, new challenges arise in the area of security and privacy. These challenges can be classified into two aspects.

First, by interconnecting systems that serve totally different purposes (e.g., traffic control and energy management), and thereby creating a "system of systems", the complexity of such collaborating systems increases exponentially. As a result, the number of vulnerabilities in a Smart City system will be significantly higher than that of each of its sub-systems. Furthermore, the pure interconnection of two systems might open new attack vectors that have not been considered before, when securing either of the individual systems. Therefore, research into ways of handling the increasing complexity of distributed systems from the security perspective is required, which includes: cost-effective and tamper resistant smart systems or device architectures (crypto and key management for platforms with limited memory and computation); evolutionary trust models (i.e., trust is not static but dynamic, and associated values can change along time) for scalable and secure inter-system interaction; abstract and comprehensive security policy languages; self-monitoring and self-protecting systems, as well as development of (formal) methods for designing security and privacy into complex and interdependent systems; overall thread models that allow to take multiple sub-systems into account.

Second, the number of users, and the volume and quality of collected data, will also increase with the development of Smart Cities. When personal data is collected by smart meters, smart phones, connected plug-in hybrid electric vehicles, and other types of ubiquitous sensors, privacy becomes all the more important. The challenge is, on the one hand, in the area of identity and privacy management, where, for instance, pseudonymization must be applied throughout the whole system, in order to separate the data collected about a user (which is required in order to provide high-quality personalised services) from the user’s real identity (which is required for purposes such as accounting); this includes that the usage of addressing identifiers, such as IP or MAC addresses, for the purpose of identification must be avoided in future systems. On the other hand, security technologies, such as advanced encryption and access control, and intelligent data aggregation techniques, must be integrated into all systems, in order to reduce the amount of personal data as far as possible, without limiting the quality of service. For future research, work towards interoperability of different identity management systems, as well as automatic consideration of user’s preferences, is required. The latter aspect goes along with the development of privacy policy languages, which allow users to express their preferences on service quality and data minimisation.

Furthermore, user privacy and security is of paramount importance when developing e-government, and more specifically when citizens are involved in democratic decision processes (e.g., referenda, elections, etc.). In these cases, transparency is also a key factor to guarantee the integrity of the processes and achieve citizen trust an acceptance. Organisations such as the Council of Europe [CoEu11]introduced security guidelines on transparency for e-enabled elections.

A study performed some years ago [CoWi07] recognised the importance of data privacy and personal identity among the aspects to be dealt with not only on technical grounds, but also concerning legal and communication aspects. Figure 5 shows a roadmap on how the technological development should be accompanied with these other aspects.

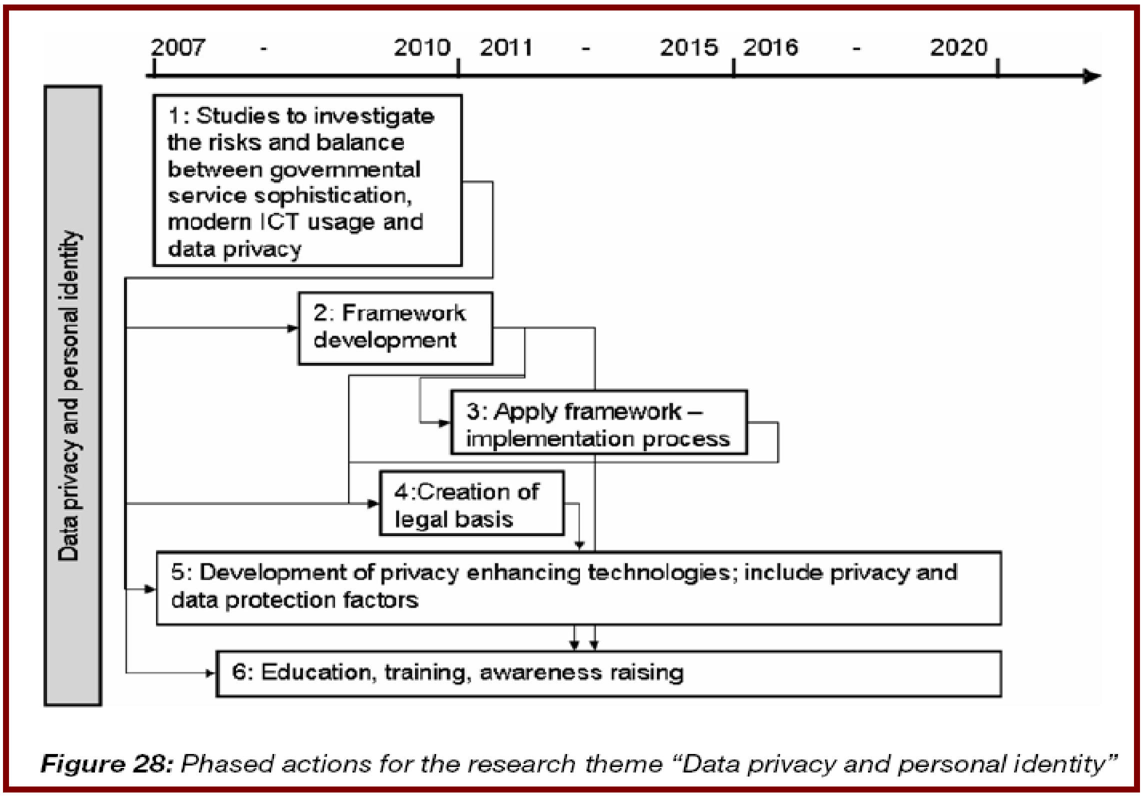

Figure 5 – Phased actions concerning data privacy and personal identity (extracted from [CoWi07]).

2.2.3 Business Models, Platformisation, Interoperability and Open Data

One of the critical elements that will be of ever increasing importance for the Smart Cities of the future is which role(s) the city will take up as an actor within an increasingly complex value network. The ecosystems of mobile and fixed communications service provision are in a constant state of flux, as commercial and public entities aim to find strategic fits, while adapting their business models. New players enter the market, actors shift their business strategies, roles change, different types of platforms emerge and vie for market dominance, technological developments create new threats and opportunities, etc.

This existing complexity increases exponentially, when considering the involvement of cities as actors in the value network, with all the agencies and domains they entail, and the potentially large differences between cities themselves. When discussing the creation of Smart Cities, one must remember that is trying to facilitate the development of thousands of urban areas across Europe; they bring together a wider range of different institutions (emergency services, health, planning, education, economic development, etc.) that are trying to deliver a range of complex and different services to citizens and businesses, within a variety of national, regional, state and local political and administrative structures. These urban areas are at radically different stages of technological, political and administrative development; these differences in administrative and technological maturity will both shape and constrain the ability of individual cities to become smarter.

In this tumultuous field, cities have to explore closely which roles they want to take up in these new value networks, as various options exist, centred around two axes: the network and the services. As far as the networks are concerned, the trend of cities aiming to offer ubiquitous coverage of different technologies (WiFi, WiMAX, FTTH, etc.) to its inhabitants seems to be subsiding, after several failed experiments around the world. However, one can expect that the focus on the network side will shift to Wireless Sensor Networks, allowing for the connection among locations, everyday objects, and devices. Such ubiquitous connectivity needs to be facilitated (e.g., by building sensors into new and existing city infrastructures), and has to be supported by relevant services and applications (potentially in all the domains identified in this chapter).

Apart from infrastructure, high-quality services will be the focal point in all the domains in the years to come. From a business model perspective, similar questions arise as the role of the city as an actor, or even as a platform. In the last decade, one has assisted to the surge of platforms, not only as coordination mechanisms between agents, but also acting as a driver for innovation. Even if the most popular ones are situated around the offers of mobile vendors, platforms have a long standing in the computer industry, with examples such as Wintel (Windows and Intel), as well as in other sectors. Platforms provide a combination of constraints, value propositions, and revenue sharing mechanisms, aimed at maximising network effects and creating a virtuous cycle. However, despite of the extraordinary success and popularity experienced by some platforms, the public sector has been very slow in translating this concept into its own specific context, and implementations are limited to a few low-impact experiments. Cities should carefully decide on their strategy with relation to platforms, depending on the policy goals they wish to achieve, as many approaches (technological development, subsidies, public-private partnerships, open data provision, etc.) are possible, each with different consequences. The roles of intermediaries, the impact of decisions on platform strategies, and their potential direct and indirect “cost” recovery, should be thoroughly studied, before a city decides on an approach to service creation and distribution.

An element related to the trend of platformisation is cloud computing, which is increasingly helping the private sector to reduce cost, increase efficiency, and work smarter. From a business perspective, cloud computing is a key concept to enable a global ecosystem, where organisations are able to be more competitive. The sharable and the on-demand nature of cloud computing are compelling for today’s highly distributed yet collaborative-driven workforce.

In the context of this ever-increasing complexity and platformisation, interoperability between systems will be exceedingly important. One could envisage a flexible, secure, and open communication platform, which could also be referred to as middleware, allowing different systems to share information, enabling the creation of services that combine data, and spanning the different domains described in this chapter. Standardisation is clearly an important task, affecting all levels of middleware implementation, assuring transparent and reliable interfaces to the middleware, as well as interoperability between products and services across very different domains. Thus, interoperability and standardised ways of communication between systems is an important research subject, crosscutting all Smart City domains.

One particular challenge in the context of Smart Cities relates to open data business models. As services become pervasive and ubiquitous, the matter of opening up databases will become more important. Open Data is hardly a new concept, its origins being easily traced to Open Science data, a fairly common practice among scientists (its translation to governmental data is credited to Edd Dumbill in the 2005 XTech conference, acknowledged by the OECD [OECD04], and supported by Tim Bray and Tim O’Reilly in 2006 [BrRe06]). Cities will have to decide to what extent they want to share information with third parties, such as application developers or commercial companies, without losing a competitive advantage, or worse, violating the privacy of its inhabitants. In general, services and applications that leverage user information provide higher quality experiences when such information is used in a balanced way, e.g., when its benefits outweigh the “costs” (of sharing private information); however, it is an exercise in balance, which can have a negative impact on the service uptake if it is not achieved. Transparency towards the end user on how his/her information is being used, with clear opt-in options and secured environments, has to be the starting point when providing services that leverage personal data.

The use of open data as described in EU’s Public Sector Information directive is an opportunity to trigger innovative Future Internet enabled services in Smart

Cities. The Public Sector Information re-use and utilisation of open data introduces a paradigm shift that will impact many people working in public administration. This change covers not only processes, but also alters our understanding of the role of public authorities, and thus, the role and perceived importance of its employees. It is understandable that different stakeholders might only reluctantly embrace these concepts, and that they might strive to find arguments against them. Public Sector Information re-use will help creating a better and more efficient public administration, as well as opening new ways for the administration, the general public and the commercial sector to be involved in societal processes.

The following activities are necessary for Public Sector Information provision and re-use: improving communication about the advantages and boundaries of open data; analysing current skills in the public sector, identifying necessary expertise, and bridging any existing gaps with external support and internal capability building; adapting existing information producing processes in the public sector, so that regular provision of data to according platforms becomes routine; creation of easy-to-use guidelines for public authorities on how to start with data provision; achieving most easy comparability and comprehensibility through furthering meta-data and data standardisation; alleviating retracing of the data sources, by developing an attribution schema and enabling a data source to sign published data; and supporting the publishing of more fine granular data through mechanisms for automatic anonymisation or pseudonymisation of data sets.

2.3 E-Government

2.3.1 An Approach to Smarter Cities

Eighty per cent of Europe's population already lives and works in cities of more than 10 000 people. Cities are the key pathway to delivering better and more effective e-government, and to the delivery of a range of EU and national economic and environmental objectives.

The development of efficient and effective e-government is a prerequisite for the development of Smart Cities. E-government applications and technologies must be able to address the fundamental questions of how cities work, how they are organised, and how they can be made to work in more intelligent ways for citizens and businesses. A Smart City will be able to bring together technology, information, and political vision into a coherent programme of urban and service improvement. The development of Smart Cities will affect thousands of urban areas across Europe, which are at very different stages of technological, political and administrative development: these differences in administrative and technological maturity will shape and constrain the ability of individual cities to become "smarter".

The lack of horizontal and vertical integration across the various e-government and urban initiatives in EU states, and the relatively low level of interest shown by many national authorities, limit efforts for the systemic development and implementation of local e-government. One needs a coherent integration of related interventions across policy fields and administrative structures, to facilitate the development of Smarter Cities. The adoption of technologies that make cities smarter and provide better e-government will require significant organisational and structural changes, on the part of both the cities themselves and the institutions that work with cities.

2.3.2 Priorities and Challenges

Cities will take different paths and become smarter at different speeds and in different ways. However, there are a number of technologies that will be required for the underlying infrastructure that is needed to help support this process. Fundamental technologies that are key to the development of the Digital Single Market, such as authentication and privacy, are key to the development of e-government in Smart Cities. The development of transnational authentication systems for citizens and businesses, the development of agreed frameworks for data privacy, and the sharing and collection of individual and business data, are key. Citizens and businesses will need standardised ways to identify themselves electronically to networks, applications, and service providers. Robust political and policy frameworks are required to address common privacy issues associated with the use and re-use of personal data across Europe.

Standardisation and interoperability are key requirements for the widespread adoption of technologies and services to provide e-government at the city level. Cities need to be able to integrate new services and technologies with their existing services and infrastructure – this requires the development of open and common approaches, based on the development and use of shared and public APIs (Application Programming Interface), which support the continuous development and evolution of Smart Cities.

Cities will need to be able to better integrate wireless networks. European cities are currently characterised by heterogeneous wireless access technologies, provided by a diverse range of operators. Smart Cities will integrate wireless technologies and operators, making provision seamless and transparent. Many cities already have fragmented, partial coverage of wireless networks: the next step will be to find ways to help these public and private networks to converge or integrate into city-wide networks, which will require both technical developments and regulatory changes.

Cities will increasingly move from being service providers to platform ones. This will cover both the development and integration of wireless networks that bridge multiple providers and multiple communication technologies, and the development of infrastructures to facilitate more active and smarter urban networks and applications. By creating these platforms and applications, Smart Cities will provide an infrastructure that enables the development of a broad range of public and private applications and services.

Cities and urban networks will need to become increasingly active, aware, and smart, compared to current passive and intelligent networks. The current system of fragmented and passive information networks will need to be replaced by active, integrated networks that are able to link citizens, businesses, governments, and infrastructure. Standardised technologies and infrastructures that are necessary to provide personalised and location-based services need to be developed – this includes solving the technical challenges of developing location frameworks and integrating wireless offerings, while also developing the knowledge infrastructure and ecosystem that are necessary to provide the content needed by citizens, travellers, businesses, etc.

The development of Smart Cities will also imply the use of ICT tools to let citizens be able to participate in elections and decision-making processes by means of e-participation and e-voting services. Therefore, the capacity of citizens, businesses and other organisations to be pro-active in society will be increased. However, it is of paramount importance that the security of these services, from viewpoint of privacy and integrity, is ensured.

2.3.3 Roadmap

The development of Smart Cities requires a pragmatic approach to technological development and deployment that is based on open standards and interoperability, which is vendor neutral and focused on the needs of cities, citizens, and businesses. Technologies need to be deployable, and supported by sound business models.

Smart networks and infrastructures need to be developed in order to exchange information from person to person, from people to machines, from machines to people, or from machines to machines. Only by developing robust, shared solutions can one develop cities that are smart, and which are able to increase innovation, improve the quality of life, and raise standards of living.

Smart Cities need to be able to integrate themselves into national, regional and international infrastructures, e.g., to share location data about businesses or development land, or to establish the marital status of citizens. The development of data and service standards, ensuring application interoperability and data exchange are key to this. Institutional and organisational processes need to be developed, to facilitate the shared development and deployment of e-government applications across cities.

The development of open data and data sharing is also a requirement for the development of e-government in Smart Cities. Public data needs to be made open and accessible, through the establishment and use of a repository of definitions and taxonomies that makes data consistent throughout Europe. This will provide a standardised foundation for developers to use and re-use government content – including address and location service information, data, maps, transport information, timetables, etc.

Although the implementation aspects depend strongly on national, regional and local authorities, European wide recommendations and directives will definitely contribute to accelerate the deployment of Smart Cities in their e-government perspectives. Studies for the increase of trust in e-government in Europe have been conducted [CoWi07], and a roadmap has been established, Figure 6, but plans extend beyond Europe, and, e.g., Japan [JaGo10] has also a calendar that impacts on the usage of ICT in e-government, Figure 7.

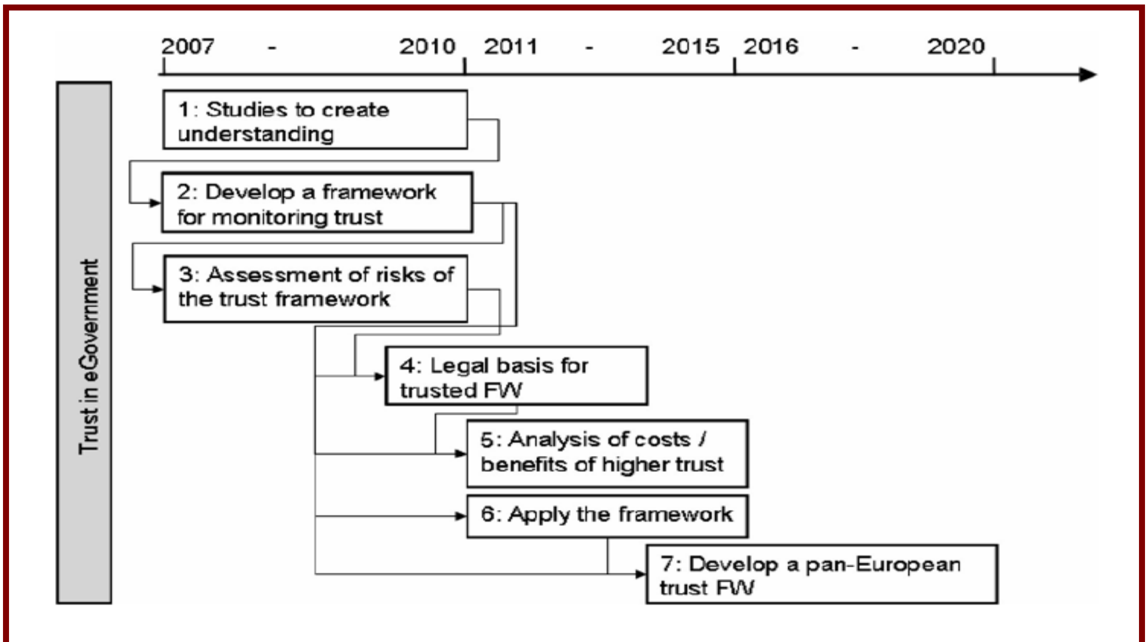

Figure 16: *Phased actions for the research theme "Trust in eGovernment"*

Figure 6 – Roadmap for the increase of trust in e-government in Europe (extracted from [CoWi07]).

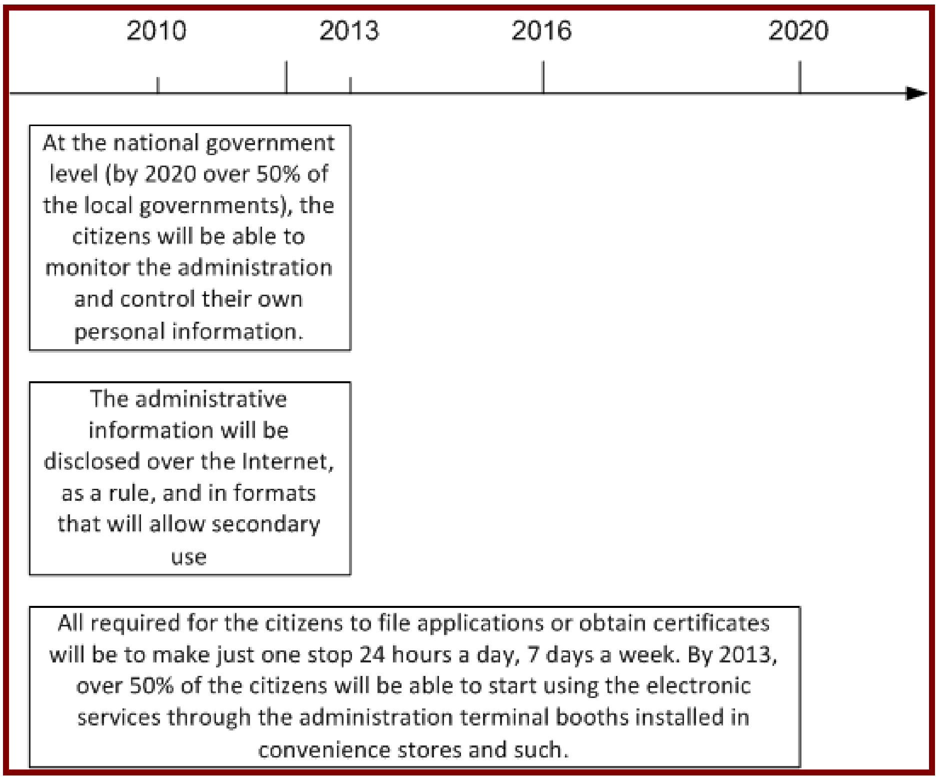

Figure 7 – Roadmap for the introduction of e-government in Japan (extracted from [JaGo10]).

European-level regulation will be a key driver for the adoption of "smart" urban technologies, particularly for the development of new urban infrastructure and new buildings. Developing technical and regulatory frameworks to drive improvements in existing infrastructure (e.g., through improving energy efficiency) will be a key challenge for policy makers.

2.4 Health, Inclusion and Assisted Living

2.4.1 Application

The world's population is aging, while it is getting sicker at the same time. By 2050, the number of people in the 60+ category will reach 2 billion, while half of the developed world is projected to become chronically ill [UnNa07]. A recent study revealed that local hospitals and access to healthcare facilities were cited among the most important features for city inhabitants [Phil10], while ICT plays an instrumental role in bringing unique responses to these needs. Many existing and potential technologies under development for the maintenance and/or supervision of health and wellbeing offer a great promise, ranging from health monitoring services and falls detection to "lifestyle monitoring" (detecting changes in behaviour patterns) [BBBC00]. Within this realm, research in ICT platforms for elderly and people with chronic diseases test ideas of generic health monitoring platforms, addressing people with chronic conditions, [Chro12], [Hear11], and assistive mobile devices, [Enab11], among others. Smart Cities need to incorporate these aspects into their overall structure and roadmap.

Current trends in personal health systems, enabled by the advances in ICT, biomedical engineering, healthcare technologies, and micro- and nano-technologies, can greatly contribute to the need for better health care and wellbeing solutions. Personal health systems offer pervasive solutions for health status monitoring, through vital signs measurements performed by bio-sensors, which will be exploited for the prevention and/or early diagnosis of harmful situations. Furthermore, efforts to support independent living encompasses social and medical assistance in the home or at an institution, in the form of face-to-face contact or assistance via tele-care services, in the shape of assistive technologies, personal monitoring, etc. One can consider three categories: health; enhancing digital literacy, skills and inclusion; and assisted living.

Participation in society, a healthy lifestyle, and good healthcare system are determinants of a healthy living. New technological advancements in the area of health, such as remote monitoring solutions, which can serve as a bridge between the hospital and the home, could enable cities' inhabitants to monitor their condition at home, ensuring that, when they get ill, they will be supported along the entire patient pathway (diagnosis, treatment, and long-term disease management).

Inclusion is concerned with minimising all barriers to learning and participation, whoever experiences them and wherever they are located in Smart Cities. Applications include: improving quality of life of users with digital content, taking multilingualism and cultural diversity into account; ensuring seamless access to ICT-based services, and establishing appropriate framework conditions for the rapid, appropriate, and effective convergence of digital communications and services; monitoring Smart Cities, through data collection and analysis of the development, availability, and use of digital communications services. Furthermore, the needs of people with physical impairments have also to be taken into account, and the way ICT will be used in Smart Cities must consider these needs.

Increased use of ICT among elderly people, the technologies used to be elderly friendly, and encourage elderly people to use the services, are also among the needs in this area. The main problems ageing people are facing when living independently are reduced physical abilities and isolation. Ageing well is also about independent life, and continued active and satisfying participation in social life and work. Independent living is the ability for elderly people to manage their life style in their preferred environment, maintaining a high degree of independence and autonomy, enhancing their mobility and quality of life, improving their access to age-friendly ICT, and personalised, social integrated, and health care services. A social problem is the creation of an economically sustainable model for the assistance of elderly people, and for their physical and psychological independence and wellbeing. The potential of ICT to support innovation in this area is large, and several applications and services already exist, which can be directly applied to this context. The major hurdle in this domain is the lack of familiarity of elderly people with such new services and technology, which so far has excluded them from the benefit of a diffuse information and communication network.

It is expected that a better access to ICT in the public sector can generate innovation chains, such as:

- *Increased use of social networking applications:* at present, elderly people are not using social networking application and are considering them with diffidence, hence, ICT emerges as an excellent opportunity to increase social contacts and reduce the sense of isolation.
- *A better quality of life for elderly people and their relatives:* geographical localisation and positioning allow for elderly people to visualise the position of people that are relevant for them, such as friends, relatives, and caregivers; services based on these systems will increase elderly people's control and social contact within their living area, thereby, increasing physical and social activity in their life, reducing the social distance between them and their neighbours, and reducing their feeling of loneliness and isolation.
- *New opportunities for elderly people to circulate their own knowledge: elderly* people are a resource for the community in which they live, and their personal knowledge and their skills could be valuable for many people around them; not only can they help each other, but they can also transmit their knowledge (e.g., cooking, gardening, knowledge of local history, etc.) to others.
- *Personalising home assistance to independent seniors:* provision of an integrated system of assistance, wherein (functional and psychological) support to elderly people could be provided in a shorter time and by the appropriate people.
- *New business opportunities also for private companies and service providers:* by using geographical information systems to support services that are relevant for independent senior people, private companies and public services can provide more personalised services, while increasing elderly people confidence in the new services.

- *Local ecosystems that accelerate social innovation:* the activation of a tracking network in a local area generates a sort of "augmented neighbourhood", in which the traditional channels of social interactions are backed up by virtual channels of communications supported by the new services; on this ground, new groups, new forms of association,and new local events can be created.

2.4.2 Potential

The demand for healthcare is rising, because ageing is changing disease composition, with a rise in chronic diseases [AkTs09], which treatment now accounts for around 70 to 80% of healthcare costs in Europe, and at the same time the number of healthcare professionals declines. Furthermore, healthcare systems are likely to face substantial challenges in the future, with public expenditure on healthcare likely to grow by 1.5% of GDP across the EU by 2060. In this context, the provision of healthcare services using immediate applicable innovative ICT is seen to be one of the elements helping the containment of healthcare delivery costs [AkTs09], while maintaining the expected levels of quality of care and safety [STSD07]. According to [ITU10], ICT for health is driven by governments to expand healthcare coverage, cut down unnecessary expenses, ease burden for traditional healthcare, and keep fairness of healthcare condition and facility in different areas. The impact on Smart Cities is undisputable.

2.4.3 Challenges

The challenges can be summarised into three different categories: Social, Market and Business, and Technical. The grand social challenges include: social communication, access to public and private services, healthcare assistance, policy and ethics, and safety of people living independently; use of ICT as the basis for increasing elderly people's socialisation opportunities; informal help exchange or a local exchange trade system. Market and business opportunities address: a revolutionary value chain to show relations within the ecosystem; new business opportunities, also for private companies and service providers; a Go to Market plan, which has to include product distribution chain/channel; economic and financial aspects, such as the pricing strategy, product life cycle, public demo together with a launch venue, beta customers, early field trail, and attracting venture capital for scaling-up. Finally, the grand technical challenges encompass: geographical localisation and positioning; interoperability and maintenance of connectivity context, while residing on a mobile device and traversing multiple networks (e.g., cellular and WLAN); pervasive borderless middleware platforms; configurable, adaptable, secure frameworks, and decision support systems.

A broader view can also be taken. Recent changes in society demand for new specific services. Such changes include an ageing society and ageing workforce, increasing life expectancy, changing family forms with an increase in people living alone. New challenges relevant to these changes have to be faced, such as chronic and degenerative diseases, addictions, obesity, depression, etc. The use of pervasive healthcare systems raises several challenges regarding energy, size, cost, mobility, connectivity, and coverage. Since these systems and services are to be used by beginners or moderately ICT literate users, it is of high importance to build them around user-friendly platforms, reducing complexity through better design.

More recently, there has been interest in the ethical implications of in-home monitoring of the elderly. A discussion in [MPWA07] notes the responsibility of researchers and technology developers to consider the needs and limitations of older adults regarding their interface with technology. In-home monitoring technologies must be used with precaution, taking user communities into account, as well as end user needs, and safety and privacy concerns (enabling users to be aware of what kind of data is being transmitted, and to whom). Following the above, personal data security and location privacy are considered to be some of the most important future challenges. Furthermore, related to challenges within the field of ICT security aspects, one of the main challenges in this key area relies in the trustworthiness of the gathered physiological parameter information. The main challenge in the area of hospital consultation and emergency scenarios is secure delivery of medical quality (multimedia) data over wireless channels, while the enhancement of the main functionalities in terms of speed and data compression are also considered important. The main challenge for assistive technologies is offering independence and autonomy to senior citizens and people with disabilities; legal, ethical and regulatory issues need to be addressed, since there are still uncertainties about the liability of healthcare services providers.

The following questions still need to be answered: Who are the most relevant actors in elderly people's and people with disabilities' independent life? How is the daily life of those actors organised? What are the most relevant interactions between those actors, and how and when in their routine are those interactions placed? What are the emerging needs from those actors? What kind of knowledge and familiarity do elderly people have on the technologies to be used? How is the approval by competent authorities? What are the ethical and privacy policies scenarios? What technologies are available for the pilots, concerning, e.g., tracking technologies and geographical information systems, and visualisation hardware? What are the technologies elderly people are already familiar with?

2.4.4 Technical Requirements

ICT in health is one of the key areas of change in the health and social services sector. Mobile technologies are among those that enable, in particular, new services that could lead to a dramatic change in health organisations and healthcare delivery practices. These could be defined as the emerging mobile communication and network technologies for healthcare systems, including sensors, WLANs, satellite, and current and future cellular mobile systems.

Biosensors and other new medical technologies reduce costs dramatically, and lead to do-it-yourself home care. Recent advances in image and wireless video transmission will enable remote diagnosis also in wireless and mobile scenarios (e.g., ambulances). Furthermore, smart phone devices, tablets,PCs, Web TV sets, and video and audio analysis techniques are currently going through major revolutions, changing the way people are accessing information and communicating. A recent study by Gartner [Gart10] forecasts that worldwide downloads in mobile application stores will pass 21 billion by 2013. Among the technical requirements that are associated to the wide adoption of health related ICT technologies, one can identify data security, devices connectivity and interactivity, power requirements for devices, end-user interface problems, among others.

The key technical requirements to be addressed in this domain are: security (encryption, authentication and authorisation), service discovery, scalability and survivability, persistence, interworking, community-to-community application messaging propagation, auditing and logging, location information sharing, and application service migration.

2.4.5 Roadmaps

The developments for the coming years, focussing on the aforementioned challenges, are the basis for the roadmap for preventive health diagnostics, health care and lifestyle management. The future challenges are usability issues, such as user friendliness, privacy of data, human-computer interaction, unobtrusiveness of systems, practicality of the proposed solutions, systems to secure the independence of the users, and ergonomics to increase the functionality that users need, which are important factors in the design of such systems. In order to enable the ease of use of such systems, there is a need to make wireless diagnostic and disease management systems more intelligent, using trends from the artificial intelligence discipline. Machine learning smart-phone systems using advanced sensors that gather data about the physical world, such as motion, temperature, or visible light, together with machine learning algorithms that analyse sensor data to enhance the healthcare services, are recommended to produce patient predictive computer-based models of diseases integrating medical and environmental data.

To obtain reliable and trustworthy information, the system has to consider both the integrity of the transmitted data between the sensor and the doctor‘s reporting unit via diverse entities (end-to-end integrity protection), and the validation that sensors and reporting unit are executed in a trustworthy and not manipulated state. Those demands can be enforced by hardware and software, e.g., by trusted computing technologies. This challenge does only consider attack or manipulation attempts on the transmission path or the entities itself (sensor and reporting unit). The manipulation of the sensor‘s environment to (intentionally) falsify recorded sensor data has to be tackled by a second challenge that considers plausibility checks on the sensor data.

The challenge related to ICT security aspects has to be ensured by a manageable access control management system, to ensure that only authorised persons (e.g., doctorsand relatives) are allowed to access the data, and ensures that the data is protected to achieve confidentiality. Users should manage authorisation. Dedicated authentication and logging mechanisms have to support the access control enforcement. The challenge in this approach is that access control architecture has to consider both the decentralised storage of data at a medical practice, and the comprehensive access control mechanisms and enforcement that concern all parties that could have access to that data. That means that, even if data is locally stored in a medical practice, the access control system has to approve data usage according the current access permissions.

Wireless transmission of multimedia medical data is a challenging application area, due in particular to the high quality requirements of medical video, the bandwidth limitation/error prone characteristic of the wireless channels, and real-time requirements of most of the services in this area. In order to keep the required quality, lossless compression techniques are usually considered when medical video sequences are involved, resulting in huge amounts of data for transmission. When transmission is over band limited, error prone channels, lossless compression is not possible, and a compromise should be made between compression fidelity and protection, and resilience from channel errors and packet loss. The quality level achieved in a low-bandwidth system is acceptable, in some cases; although due to the high compression ratios and to the effects of the wireless channel, such systems are of interest for a first diagnosis or emergency scenarios, a second diagnosis being usually required.The most recent broadband wireless access technologies, including WiMAX, UMTS, CDMA2000, and LTE, allow a broader bandwidth, which provides the means to make multimedia tele-medical applications reliable, by maintaining good quality levels. The proper exploitation of such novel technologies, and the development of tailored tools for medical video compression and transmission over these systems, is one of the main challenges in the area. The trend towards even more bandwidth demanding 3D medical digital imaging adds interest to such a challenge.

Future developments will also see an increased use of satellites, particularly in situations such as natural disasters and emergencies, and where the existing infrastructure is poor or non-existent. Given the specific properties of satellites, including the ability to oversee and monitor large parts of the continent, they are likely to play an important role in a future unified European eHealth system.

The challenge for offering independence and autonomy to senior citizens and people with disabilities could be addressed by: locating services and guiding people with heterogeneous disabilities at places like museums, airports and shopping malls; developing customised and accurate platforms to exchange homogeneous data among different devices, services and healthcare personnel; developing easy to use, highly reliable, unobtrusive, low power and transparent technologies and devices in order to gain users' confidence. The implementation of stress detectors and face recognition applications utilising emotion recognition techniques is expected to meet the expectations and cognitive capabilities of end users.

Contributions to innovation that will boost wellbeing and personalisation services are expected in several areas, such as intelligent agents, ambient intelligence, smart shirt sensory architecture and wearable sensors for activity monitoring, and in-home and domotic sensors. The challenge now is not to invent new devices, but to make any service adaptive to the conditions of the users and the device there are using. In this way, one should start talking about equality and design for all.

Japan [JaGo10] has a calendar that impacts on the introduction of ICT for healthcare, Figure 8.

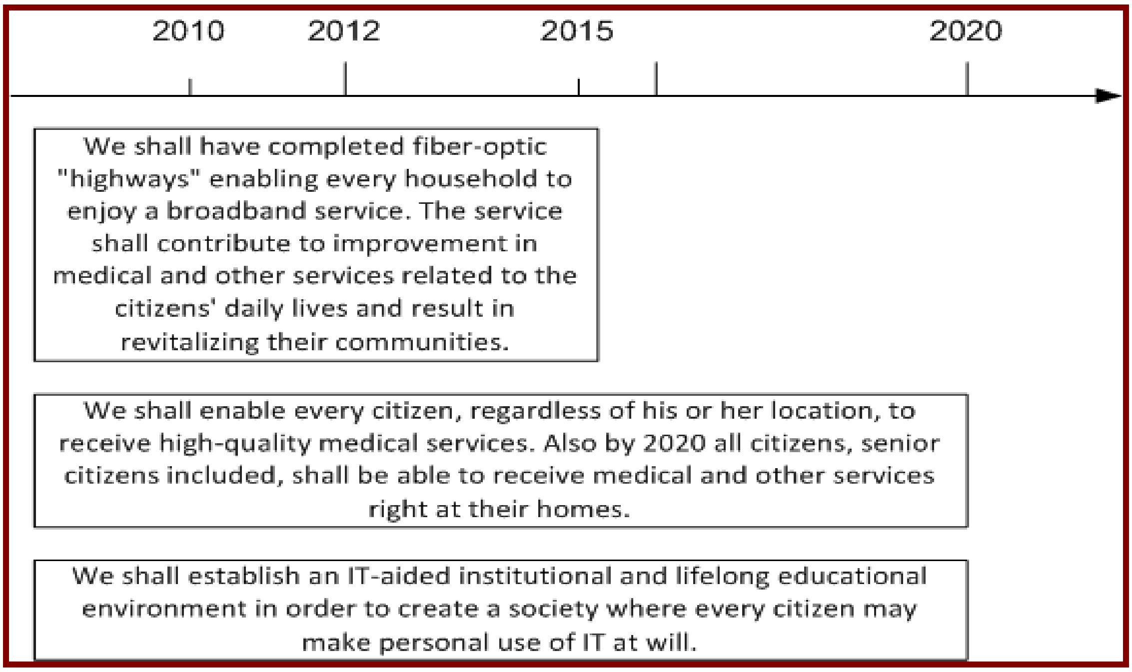

Figure 8 – Roadmap for the introduction of ICT in health care in Japan (extracted from [JaGo10]).

In Europe, an integrated perspective on healthcare solutions for the near- to long-term views has been presented by [EPOS09], Figure 9. Some of the enabling technologies are directly related to communications, bridging thegap between the technological development of communications (radio and network components) and the health area (within Smart Cities) in the years to come.

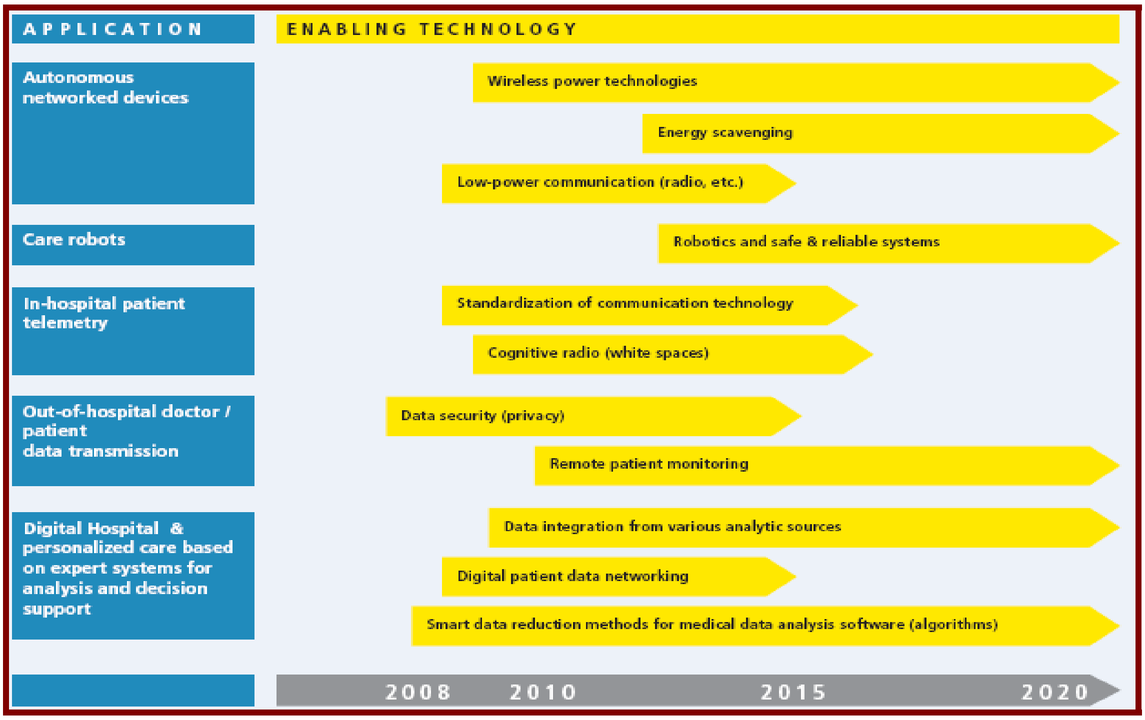

Figure 9 – Integrated healthcare solutions timeline (extracted from [EPOS09]).

2.5 Intelligent Transportation Systems

2.5.1 Application

As previously mentioned, currently, 80% of the European population live in urban areas. Their mobility needs often result into a number of problems, such as traffic congestion, increased pollution levels and/or greenhouse gas emissions, excessive travelling time, and energy consumption. These problems can be largely alleviated by exploiting Intelligent Transportation Systems (ITS) and further adoption of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication networks.

More precisely and from the ICT viewpoint, applications should cover the following requirements in order to guaranty sustainable Smart Cities: reducing the mobility needs for both individuals and goods; optimising trip planning and management, transport mode selection and allowing seamless multimodality; impacting the overall behaviour of the drivers in the long term; improving the vehicle manufacturing process to directly include Smart Cities considerations; increasing the vehicles passenger and goods capacity; and enabling more efficient transport networks.

As an example, public parking spaces could be more efficiently managed, by guiding drivers to nearby free parking places (e.g., they could be displayed on portable or car-mounted devices), which requires accurate location information. By lowering the average time needed to find a public parking place from 15 minutes (estimated time in downtown Barcelona) to 12 minutes, the associated reduction in terms of CO2 emissions would be of 400 tons/day. Besides, the provision of multi-modal travelling support (bus, taxi, train, plane, etc.) to citizens is instrumental to minimise traffic congestion problems. To that aim, platforms allowing transportation system operators, urban districts and passengers to effectively and securely share information are needed in Smart Cities. Distributed Urban Traffic Control systems capable of tracking cars location in real time, and adapting traffic management to current and predicted conditions, are instrumental too, which could be used, for instance, to set up fast lane corridors for emergency services (e.g., ambulances, police or fire brigades). Complementarily, dynamic carpooling systems [CoVi09], or the ones developed in the WiSafeCar project [WiSa12], provide a means to optimise the utilisation of transportation systems for commuters living in nearby places and sharing a common destination. Currently, the challenge is to go beyond static systems where routes are planned in advance, and make them advantageous for occasional travellers too.

2.5.2 Potential

A widespread adoption of ITS in urban areas has a tremendous impact on citizens' quality of life. On the one hand, traffic congestion can be reduced, and on the other, a number of energy-related and environmental problems (e.g., pollution and energy consumption) can be alleviated as well. Interestingly, a more efficient use of energy resources is one of the Grand Societal Challenges identified in the Innovation Union flagship of the European Commission [EuCo10b]. Besides, in DG INFSO's Digital Agenda [EuCo10a], it is acknowledged that R&D and innovation policies should be re-focused "in areas where Europe has a lead market potential, e.g., health, green mobility, smart grids & meters and energy efficiency". Moreover, the EU i2010 Intelligent Car Initiative [InCI10] indicates that intelligent systems embedded in car or in road infrastructure along with V2V and V2I communication systems should primarily target: (i) traffic congestion problems (10% of the road network is affected daily by traffic jams) and their associated costs; (ii) energy efficiency and pollutant emissions (road transportation accounts for 83% of the energy consumed by the whole transport sector and 85% of the total CO2 emissions); and (iii) safety issues (the cost of over 40 000 fatalities and 1.4 million accidents in the EU represent 2% of the EU GDP).

Interestingly, the information being managed by the aforementioned ITS systems and applications could be relevant to other domains. For example, data on traffic congestion patterns could be correlated with the concentration of pollutants, and this, in turn, with the impact of respiratory diseases in a given geographical area.

2.5.3 Challenges

An effective deployment of ITS in urban areas poses a number of technical, sociological, regulatory and economic challenges. At the technical level, it is often necessary to deploy large communication networks (e.g., Wireless Sensor Networks for the management of public parking spaces), which raises some concerns on the scalability of the proposed solutions when it comes to, e.g., conveying information to a central server for further processing. Besides, the adoption of service platforms capable of dealing with heterogeneous devices collecting different types of data, each of them holding individual vendor requirements, constitutes a technical challenge as well.

The availability of accurate location information is also challenging, due to the fact that, in dense cities, urban canyon effects often result into an insufficient number of visible satellites, and/or severe multi-path propagation this leading to poor signal quality. Therefore novel hybrid satellite/terrestrial positioning techniques need to be investigated, where signals from terrestrial communication systems are effectively exploited in scenarios when not enough satellites are visible [FeND10].

Cost-efficient and self-configuring road traffic management systems allowing for reductions of journey times, fuel consumption and pollution can be developed, on the basis of an appropriate combination of V2V and V2I communication technologies. The main technical challenge here is the real-time exchange of data among vehicles and roadside infrastructure.

In order to offer better alternatives to the user, multimodal public transportation information should be integrated within the itinerary results. Guaranteeing security and privacy along with effective user authentication mechanisms is key as well. Also, the system has to be scalable in order to adapt to different business models and interact with other transportation providers, both public and private.

On a more practical side, protocols and algorithms successfully tested in lab conditions often exhibit poor performance in large-scale deployments: lower data throughput, data-link degradation, unstable multi-hop links, etc. Many of these problems can be fixed at the networking layer, but this comes at the cost of reduction in battery lifetime. To avoid that, it is crucial to test technology on large-scale testbeds (as in the SmartSantander project [SmSa12]), and conduct extensive field trials before undertaking commercial deployments. This encompasses measurement campaigns in order to assess the availability of satellite/terrestrial signals in urban areas.

In order to provide city council's staff with corporate network support in streets (e.g., for police patrols) or other generic city services (e.g., lighting, automatic watering, and waste collection) in a more efficient manner, some municipalities are deploying city-owned communication networks (e.g., based on Wi-Fi or WiMAX). Typically, such networks are progressively deployed (e.g., due to budgetary constraints), which impacts, for instance, on the performance of routing schemes and route stability. Hence, additional research is needed on network optimisation methods, experimental characterisation and monitoring of data traffic, and definition of troubleshooting strategies from network edges.

A challenge under the responsibility of the public administrations is to foster, publicise and convey the benefits that such technologies and applications will bring to citizens. Besides, the impact on the public opinion is clearly linked with the selection of applications (e.g., monitoring CO2 emissions) needed to illustrate Smart City concepts. From the citizens' viewpoint, there are also some concerns regarding the handling of personal data by public administrations (i.e., privacy issues) or technology being used mostly to punish driving and parking faults, rather than to improve their quality of life. Hence, it is also a challenge to stimulate technology acceptance since early deployment phases, or to fight the selfishness of the peers to share, gather, and work on collected information.

2.5.4 Technical Requirements

As a summary of the previous section, a non-exhaustive list of technical requirements encompasses: the provisioning of flexible, scalable and self-optimised networks; dealing with heterogeneity (support of different sensor and actuator technologies, radio interfaces, etc.); effectively exploiting location information, guaranteeing real-time exchange of data where needed; and providing security, privacy and authentication mechanisms.

2.5.5 Roadmaps

Nowadays, a number of standardised short-range wireless technologies (e.g., 802.15.4) are already available for deployments in Smart Cities. In addition, the 802.11p standard was finalised in 2010. The on-board installation of cards by car manufacturers is expected to ramp up in coming months.

Besides, a number of EC-funded projects, such as ICT-EXALTED [EXAL12] or ICT-LOLA [LOLA12] are aimed to investigate the adaptation of existing and future cellular systems (LTE, LTE-A) to the requirements associated to machine-to-machine communications arising in such scenarios.

As for the availability of user devices, the number of Smart Phones equipped with GPS, Wi-Fi and cellular connectivity has steadily increased over the last years, and it is expected to continue to grow.

Finally, city regulations regarding in-street installations (e.g., info-panels, sensing devices, and communication equipment) should be carefully monitored, since this has an impact on the corresponding deployment strategies.

Although many technologies not related to ICT are foreseen in the development of the automotive sector [EPOS09], [EESG10], one can see that wireless communications and networks play a major role in this area as well, Figure 10, Figure 11.

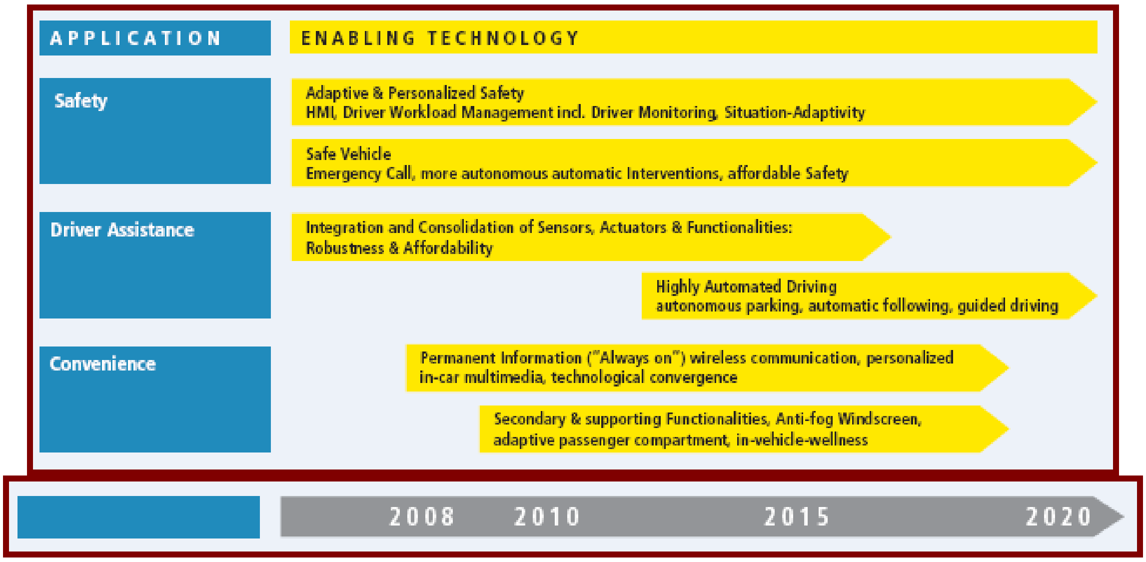

Figure 10 – Developments priorities in the automotive industry (extracted from [EPOS09]).

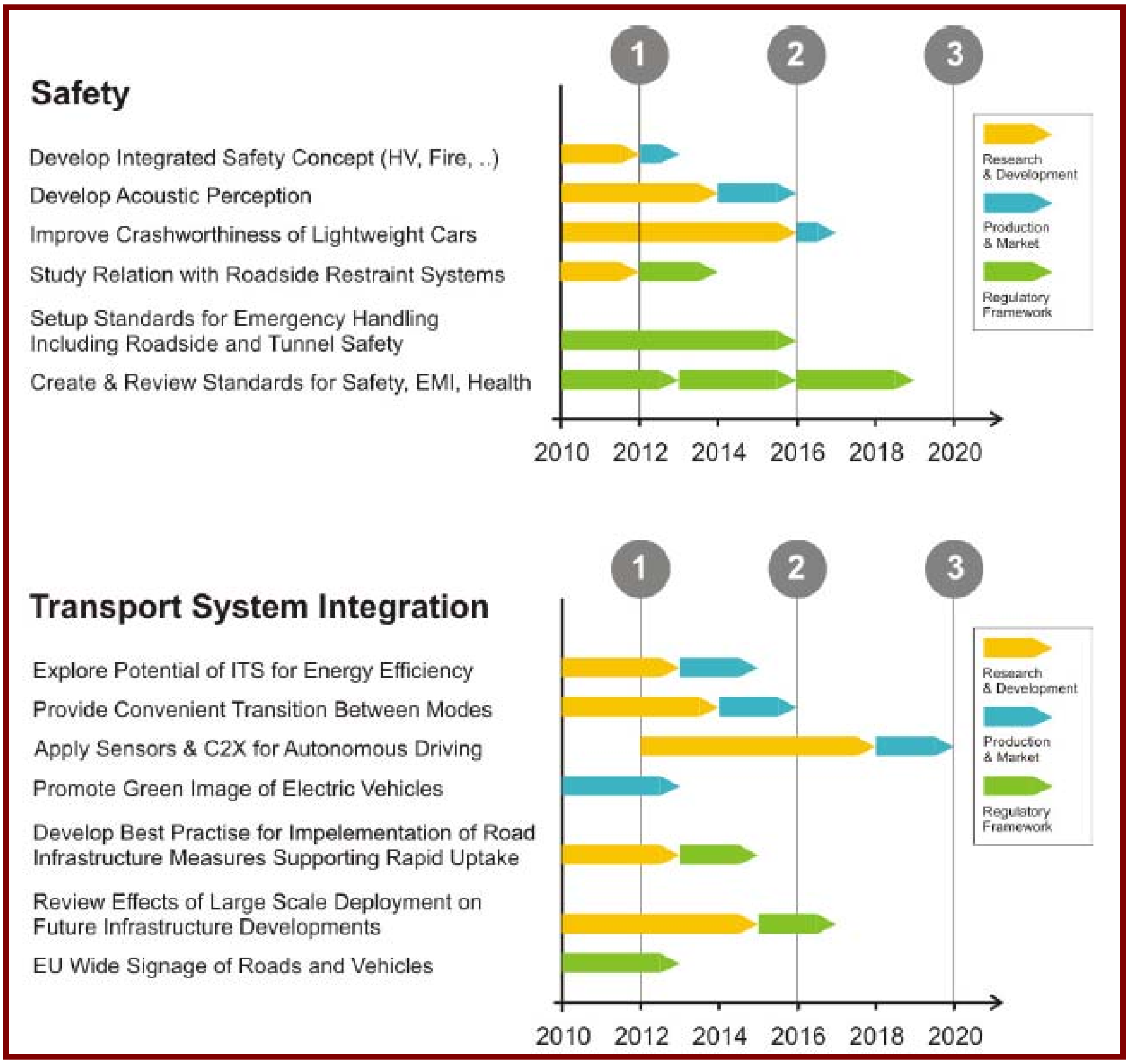

Figure 11 – Goals in safety and transport system integration (extracted from [EESG10]).

2.6 Smart Grids, Energy Efficiency, and Environment

2.6.1 Application

Smart energy grids are the backbone of the Smart City, and will be responsible for the intelligent management and operation of energy networks in cities, by utilising the potential for shift between thermal and electrical loads. Furthermore, the integration of decentralised renewable energy sources into existing energy grids brings up some major technical issues that have to be treated. The interaction between advanced communications infrastructure, mathematical modelling techniques, and numerical simulation environments is a powerful tool in this research area. This also holds for the potential storage capacity for both electrical and thermal energy within energy networks, which can be achieved by intelligent demand side management.

A major requirement in Smart Cities is to leverage energy consumption between the different producers and consumers, which directly translates into reducing the pollution generated by today's cities and the emerging mega cities. To fully understand the complex interaction between the city and its energy management systems with all components at different urban scales (grids, buildings, supply technologies, and consumers), it is crucial to be able to unlock the full potential of smart grids. Therefore, a more holistic approach with a special focus on the interaction of all incorporated system elements is needed.

The successful combination of smart processes (e.g., demand side/response management and real-time consumption management) and smart technologies (e.g., smart meters and intelligent home energy management devices) will enable energy efficiency and savings to be achieved in the residential and business market. In fact, intelligent systems and integrated communication infrastructure are highly demanded, which can assist in the management of the electricity distribution grids in an optimised, controlled, and secure manner.

2.6.2 Potential

According to on-going international discussions, society is facing a worldwide climate change, which calls for an effective low-carbon policy and highly efficient energy technologies in the very near future. Dramatic CO2 reductions have to be achieved, in order to prevent the gradual increase in global average temperature caused by fossil fuel combustion. Consequently, a change of the worldwide energy mix moving towards a smart integration of renewable energy sources (photovoltaic, geothermal, wind, biomass, etc.) into our energy networks is of crucial importance for achieving the ambitious targets for CO2 reduction. Based on this measure, the reliance on imported fossil fuels could be decreased enormously, leading to improved energy reliability in Europe in the long term. However, according to the International Energy Agency, energy efficiency is one of the largest influencing factors for improving the critical situation our environment and society is facing.

As referred in the Digital Agenda for Europe [EuCo10a], smart grids are seen as a major opportunity to merge power and ICT industries and technologies to bring huge changes in people's lives. ICT offers potential for a structural shift to less resource-intensive products and services, for energy savings in buildings and electricity networks, as well as for more efficient and less energy consuming intelligent transport systems.

Energy efficiency offers a powerful and cost-effective tool for building a sustainable energy future based on renewable energy sources. Furthermore, by focusing research on the development of intelligent methods for optimising energy efficiency, the need for investment in new energy infrastructure can be reduced significantly, fuel costs can be cut, competitiveness is increased, and consumer’s welfare is improved. However, in order to realise the full potential of energy efficiency, the current energy policies and technologies have to be further developed.

2.6.3 Challenges

Apart from the global environmental changes, the urbanisation of society is another major factor that has to be considered in the context of energy. According to [UnNa10], the majority of people worldwide will be living in urban areas or cities by the year 2010, which is referred to as the “tipping point”.

From this trend, it is clear that cities around the world will play a crucial role in the future energy system, displaying the large potential of cities for energy savings. The increasing energy demand in cities is without doubt a huge challenge that has to be faced. However, the overall building density of urban areas reflects itself as well as a chance for optimised energy efficiency. From these facts, it can be concluded that future cities will have to address major problems for guaranteeing continuous and efficient energy supply in the long term.

One particular application is to develop new surveillance and control strategies for both buildings and energy networks, allowing for the intelligent and adaptable management of the entire energy system, in the context of the stochastic distribution of energy supply and demand, especially taking the highly volatile nature of renewable energy sources into account. The underlying communication needs include sharing sensor information among consumers, producers, and the grid, with various requirements in terms of reliability, real-time behaviour, and bandwidth. Those strategies include power quality control, as well as interactive feedback to human users, and will increase the energy efficiency of the entire Smart City, requiring all participants (grids, buildings, and consumers) to be connected with appropriate means of communication. Therefore, it is important to build a consensus upon a communications architecture, its underlying communication technologies derived based on ICT requirements, data models that are able to cope with specific services' or applications' needs.

As a main recommendation, the cooperation between the ICT industry, other sectors, and public authorities, should be stimulated to accelerate development and wide-scale roll out of ICT-based solutions for smart grids and meters. The ICT sector should deliver modelling, analysis, monitoring, and visualisation tools to evaluate the energy performance and emissions of cities and regions.

Other challenges include: new communication and networking ICT technologies (improved immunity to environment electromagnetic noise, interferences and network performance; support of large unstructured mesh networks, including self-organisation, self-healing, and fast and reliable routing; open protocols for the development of new products and services, addressing authentication, security mechanisms, profiles, and certification); new affordable devices that gather environment data (e.g., weather sensors, small Doppler radars, and computer vision systems); new intelligent algorithms for smart ubiquitous environments; new light sources (i.e., next-generation-LED); new and fair regulations inside EU that enable the massive implementation of the Intelligent Street Lighting System idea provided by different vendors; new EU products for global markets that enable a steady economic growth; and advanced products and services based on IP created inside EU to foster innovations, and economic growth in the SME sector, based on an open innovation scheme inside the EU.

2.6.4 Technical Requirements

The requirements for the communications infrastructure in this area of energy efficiency and smart grids are: highly reliable, real-time communication for power quality control in the grid; protocol specifications for smart grid components (several candidates exist), including day ahead planning, exchanging load schedules, schedule load shedding, and dynamic adaptation schemes; standardisation of smart meter communications; application level service definitions for distributed renewable energy sources and for accessing buildings and building automation systems from the grid, focusing on standardisation, aiming at interoperability, predictability and reliability; sensor (and actuator) networks for dynamic reconfiguration of open operated city grids to fully meshed topology, dependent on losses, local generation (buildings) and demand peaks; ICT infrastructure and reliability, for adaptive protection based on multi agent systems; and reliable redundant communications.

2.6.5 Roadmaps

The area of energy efficiency and smart grids is being addressed by a few stakeholders, and some related areas have been put into a timeline. The building construction sector has identified some key areas for development in the next years, [REEB10], which include smart meters and Wireless Sensor Networks, Figure 12, while energy efficiency auxiliary technologies are expected to continue to be developed [EPOS09], Figure 13.

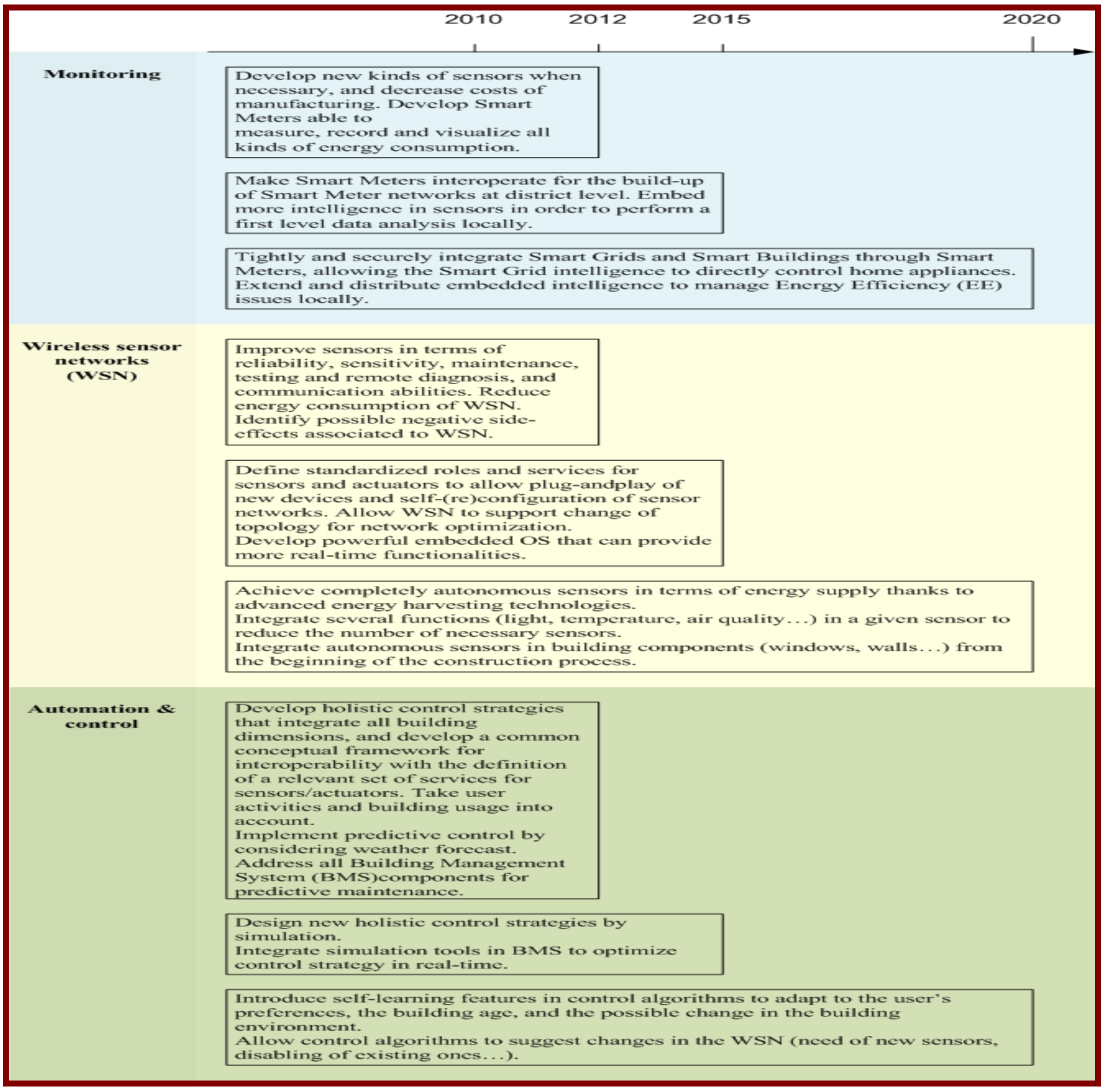

Figure 12 – Roadmap for monitoring and Wireless Sensor Networks in buildings (based on [REEB10]).

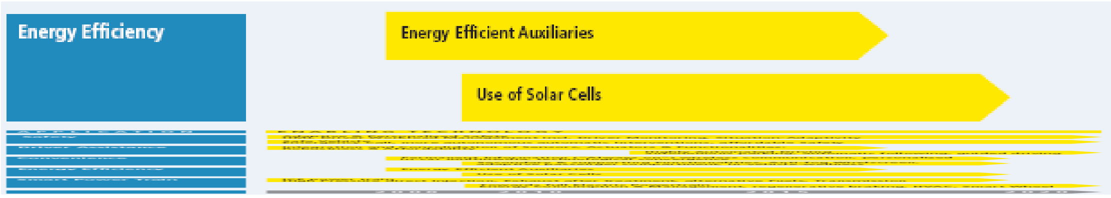

Figure 13 – Energy efficiency timeline (extracted from [EPOS09]).

2.7 Conclusions and Recommendations

The concept of Smart Cities gained importance in the last years, as a means of making ICT enabled services and applications available to the citizens, companies and authorities that are part of a city's system. It aims at increasing citizens' quality of life, and improving the efficiency and quality of the services provided by governing entities and businesses. This perspective requires an integrated vision of a city and of its infrastructures, in all its components: it has to incorporate a number of dimensions that are not related to technology, e.g., the social and political ones. A Smart City can be taken according to six characteristics: Smart Economy, Smart People, Smart Governance, Smart Mobility, Smart Environment and Smart Living.

This chapter identifies major topics of Smart Cities that will influence the ICT environment, as covered by Net!Works. Applications and requirements are grouped into 5 topics:

- Economic, Social & Privacy Implications
- Developing E-Government
- Health, Inclusion and Assisted Living
- Intelligent Transportation Systems
- Smart Grids, Energy Efficiency, and Environment

Each of the topics is put into perspective according to its potential, challenges, technical requirements, and roadmaps.

In order to achieve the goals of a Smart City, there is the need to increase efficiency and efficacy of government, developing environment-friendly applications, increasing mobility, providing better health services, stimulating economic prowess, etc. It is vital that a city clearly outlines these goals in policy making, defining a strategy founded in research to reach them, and which role the city should play.

All the domains discussed in this chapter raise new challenges in security and privacy, and although security is not the main selling point for most applications, users implicitly expect systems to be secure and privacy-preserving. If users deem a system as insecure or threatening their privacy, it will not be able to establish itself successfully in the market. In order to achieve user consent, trust in, and acceptance of Smart Cities, integration of security and privacy-preserving mechanisms must be a key concern of future research. Overall research challenges can be classified into the following aspects: handling of the increasing complexity of distributed systems from the security perspective is required; identity and privacy management, where, e.g., pseudonymisation must be applied throughout the whole system, in order to separate the data collected about a user from the user's real identity; integration into systems of security technologies, e.g., advanced encryption and access control, and intelligent data aggregation techniques. A roadmap in this area foresees that the technological development should be accompanied by legal and communication aspects.

One of the critical elements that will be of ever increasing importance for the Smart Cities of the future is which role(s) the city will take up as an actor within an increasingly complex value network. New players enter the market, actors shift their business strategies, roles change, different types of platforms emerge and vie for market dominance, technological developments create new threats and opportunities, etc. This existing complexity increases exponentially, when considering the involvement of cities as actors in the value network, with all the agencies and domains they entail, and the large differences between cities themselves. Ubiquitous connectivity needs to be facilitated, supported by relevant services and applications (potentially in all the domains in this chapter).

An element related to the trend of platformisation is cloud computing, which is increasingly helping the private sector to reduce cost, increase efficiency, and work smarter. From a business perspective, cloud computing is a key concept to enable a global ecosystem, where organisations are able to be more competitive. In the context of this ever-increasing complexity and platformisation, interoperability between systems will be exceedingly important. Standardisation is clearly an important task, affecting all levels of middleware implementation, assuring transparent and reliable interfaces to the middleware, as well as interoperability between products and services across very different domains. Thus, interoperability and standardised ways of communication between systems is an important research subject, crosscutting all Smart City domains.

One particular challenge in the context of Smart Cities relates to open data business models. As services become pervasive and ubiquitous, the matter of opening up databases will become more important. Transparency towards the end user on how his/her information is being used, with clear opt-in options and secured environments, has to be the starting point when providing services that leverage personal data. The Public Sector Information re-use and utilisation of open data introduces a paradigm shift that will impact on many people working in public administration. Among many activities necessary for Public Sector Information provision and re-use, one can identify achieving most easy comparability and comprehensibility through furthering meta-data and data standardisation, and supporting the publishing of more fine granular data through mechanisms for automatic anonymisation or pseudonymisation of data sets.

The development of efficient and effective e-government is a prerequisite for the development of Smart Cities. The lack of horizontal and vertical integration across the various e-government and urban initiatives in EU states, and the relatively low level of interest shown by many national authorities, limit efforts for the systemic development and implementation of local e-government. The development of transnational authentication systems for citizens and businesses, the development of agreed frameworks for data privacy, and the sharing and collection of individual and business data, are key. Standardisation and interoperability are key requirements for the widespread adoption of technologies and services to provide e-government at the city level. Cities will need to be able to better integrate wireless networks, making provision seamless and transparent. Cities will increasingly move from being service providers to platform ones, providing an infrastructure that enables the development of a broad range of public and private applications and services. Standardised technologies and infrastructures that are necessary to provide personalised and location-based services need to be developed.

The development of Smart Cities requires a pragmatic approach to technological development and deployment that is based on open standards and interoperability, which is vendor neutral and focused on the needs of cities, citizens, and businesses. Technologies need to be deployable, and supported by sound business models. Smart networks and infrastructures need to be developed in order to exchange information from person to person, from people to machines, from machines to people, or from machines to machines. Smart Cities need to be able to integrate themselves into national, regional and international infrastructures. Although implementation aspects depend strongly on national, regional and local authorities, European wide recommendations and directives will definitely contribute to accelerate the deployment of Smart Cities in their e-government perspectives. Roadmaps have been established in Europe, in order to increase of trust in e-government.

Health, inclusion and assisted living will play an essential role in Smart Cities. Many existing and potential technologies under development for the maintenance and/or supervision of health and wellbeing offer a great promise, ranging from health monitoring services to "lifestyle monitoring", encompassing platforms for elderly, support to independent living with social and medical assistance in the home, and helping people with chronic diseases, among others. Inclusion, being concerned with minimising all barriers to learning and participation, whoever experiences them and wherever they are located, has to consider the improvement of quality of life of users by ensuring seamless access to ICT-based services. Furthermore, the needs of people with physical impairments have also to be taken into account. Increased use of ICT among elderly people, the technologies used to be elderly friendly, and encourage elderly people to use the services, are also among the needs in this area; the major hurdle in this domain is the lack of familiarity of elderly people with such new services and technology. Current trends in personal health systems, enabled by the advances in ICT, biomedical engineering, healthcare technologies, and micro- and nano-technologies, can greatly contribute to these goals.

The demand for healthcare and assisted living services is rising, because ageing is changing disease composition. Furthermore, healthcare systems are likely to face substantial challenges in the future, with public expenditure on healthcare likely to grow by 1.5% of GDP across the EU by 2060. In this context, the provision of healthcare services using immediate applicable innovative ICT is seen to be one of the elements helping the containment of healthcare delivery costs.

The challenges in health, inclusion and assisted living can be summarised into three different categories: Social, Market and Business, and Technical. The grand social challenges address access to public and private services, policy and ethics, and safety of people living independently. Market and business opportunities include a Go to Market plan, and economic and financial aspects. The technical challenges encompass geographical localisation and positioning, interoperability and maintenance of connectivity context, and pervasive borderless middleware platforms.

Requirements for ICT in health include biosensors and other new medical technologies (to reduce costs dramatically, and lead to do-it-yourself home care), high definition image and video wireless transmission (to enable remote diagnosis, also in mobile scenarios, e.g., ambulances), data security (encryption, authentication and authorisation), devices connectivity and interactivity, end-user interface problems, service discovery, scalability and survivability, interworking, community-to-community application messaging propagation, location information sharing, and application service migration. In Europe, an integrated perspective on healthcare solutions for the near- to long-term views has been presented, some of the enabling technologies being directly related to communications, bridging a direct gap in between the health area (within Smart Cities) and the technological development of communications (radio and network components) in the years to come.

Given that a vast majority of the European population lives in urban areas, their mobility needs result into a number of problems, such as traffic congestion, increased pollution levels and/or greenhouse gas emissions, or excessive travelling time and energy consumption. These problems can be largely alleviated by exploiting ITS and further adoption of vehicle-to-vehicle and vehicle-to-infrastructure communication networks, in Smart Cities. From the ICT viewpoint, applications should reduce the mobility needs for both individuals and goods, optimise trip planning and management, improve the vehicle manufacturing process, increase vehicles passenger and goods capacity, and enable more efficient transport networks.

A widespread adoption of ITS in urban areas has a tremendous impact on citizens' quality of life. On the one hand, traffic congestion can be reduced, and on the other, a number of energy-related and environmental problems can be alleviated as well. The information being managed by ITS applications could be relevant in other domains, which increases its potential.

An effective deployment of ITS in urban areas poses a number of technical, sociological, regulatory and economic challenges. At the technical level, it is often necessary to deploy large communication networks, which raises some concerns on the scalability of the solutions. Besides, the adoption of service platforms capable of dealing with heterogeneous devices collecting different types of data, each of them holding individual vendor requirements, constitutes a technical challenge as well. The availability of accurate location information is also challenging, therefore novel hybrid satellite/terrestrial positioning techniques need to be investigated. The main technical challenge in vehicle-to-vehicle and vehicle-to-infrastructure communications is the real-time exchange of data among vehicles and roadside infrastructure. The system has to be scalable in order to adapt to different business models and interact with other transportation providers, both public and private. Often, systems exhibit poor performance in large-scale deployments, so it is crucial to test technology on large-scale testbeds, and conduct extensive field trials before undertaking commercial deployments. Additional research is also needed on network optimisation methods, experimental characterisation and monitoring of data traffic, and definition of troubleshooting strategies from network edges. A further challenge, under the responsibility of public administrations, is to foster, publicise and convey the benefits that such technologies and applications will bring to citizens.

Although many technologies not related to ICT are foreseen in the development of the automotive sector, one can see that wireless communications and networks are key in this area. Roadmaps established in this area forecast that wireless communications will play a major role before 2020, that the regulatory framework for emergency communications should be ready by 2016, and that the potential for exploring ITS for energy efficiency should have products on the market by 2015.

Smart energy grids are the backbone of the Smart City, and will be responsible for the intelligent management and operation of energy networks in cities, by utilising the potential for shift between thermal and electrical loads. A major requirement in Smart Cities is to leverage energy consumption between the different producers and consumers, which directly translates to reducing the pollution generated by today's cities and the emerging mega cities. The successful combination of smart processes (e.g., demand side/response management and real-time consumption management) and smart technologies (e.g., smart meters and intelligent home energy management devices) will enable energy efficiency and savings to be achieved in the residential and business market. In fact, intelligent systems and integrated communication infrastructure are highly demanded, which can assist in the management of the electricity distribution grids in an optimised, controlled, and secure manner.

The potential for smart grids is enormous. Smart grids are seen as a major opportunity to merge power and ICT industries and technologies to bring huge changes in people's lives. ICT offers potential for a structural shift to less resource-intensive products and services, for energy savings in buildings and electricity networks, as well as for more efficient and less energy consuming intelligent transport systems.

It is clear that cities around the world will play a crucial role in the future energy system, displaying the large potential of cities for energy savings. One particular application is to develop new surveillance and control strategies for both buildings and energy networks, allowing for the intelligent and adaptable management of the entire energy system, in the context of the stochastic distribution of energy supply and demand, especially taking the highly volatile nature of renewable energy sources into account. The underlying communication needs include sharing sensor information among consumers, producers, and the grid, with various requirements in terms of reliability, real-time behaviour, and bandwidth. It is important to build a consensus upon a communications architecture, its underlying communication technologies derived based on ICT requirements, data models that are able to cope with specific services' or applications' needs.

As a main recommendation, the cooperation between the ICT industry, other sectors, and public authorities, should be stimulated to accelerate development and wide-scale roll out of ICT-based solutions for smart grids and meters. The ICT sector should deliver modelling, analysis, monitoring, and visualisation tools to evaluate the energy performance and emissions of cities and regions.

Other challenges include support of large unstructured mesh networks, including "self-techniques", and new intelligent algorithms for smart ubiquitous environments.

The requirements for the communications infrastructure in this area of energy efficiency and smart grids include highly reliable and real-time communications for power quality control in the grid, protocol specifications for smart grid components, infrastructure and reliability for adaptive protection based on multi agent systems, and reliable redundant communications.

The area of energy efficiency and smart grids is being addressed by a few stakeholders, and some related areas have been put into a timeline. The building construction sector has identified some key areas for development in the next years, which include smart meters and Wireless Sensor Networks, while energy efficiency auxiliary technologies are expected to continue to be developed.

In conclusion, this chapter addresses application areas within Smart Cities, i.e., e-Government, Health, Inclusion and Assisted Living, Intelligent Transportation Systems, and Smart Grids, Energy Efficiency, and Environment. Within these areas, examples are shown, clearly linking the underlying technologies with end-users at a broader view (ranging from individual users to official authorities, and encompassing businesses). In order to achieve the goal of Smart Cities, one has to develop quite a number of technologies in the area of wireless and fixed communications networks, and many research challenges are identified.

Spectrum Crunch

3

3. Spectrum Crunch

3.1 Rationale

Globally, the demand for broadband wireless communications is drastically increasing every year. A major factor contributing to this development is the ever-increasing number of users subscribing to broadband internet services using their mobile devices, which is accelerated by the trend towards flat-rate subscriptions. Moreover, new devices, such as smart-phones and tablets with powerful multimedia capabilities, are entering the market and creating new demands on broadband wireless access. Finally, new data services and applications are emerging, which are key success factors for the mobile broadband experience. All these factors together result in an exponential increase in mobile data traffic in the wireless access system, and such a trend is expected to continue to a similar extent over the next decade.

Recent studies and extrapolations from past developments predict a total traffic increase by a factor of 500 to 1 000 within the next decade. These figures assume approximately a 10 times increase in broadband mobile subscribers, and 50-100 times higher traffic per user. Besides the overall traffic, the achievable throughput per user has to be increased significantly. A rough estimation predicts a minimum 10 times increase in average, as well as in peak, data rate. Moreover, essential design criteria, which have to be fulfilled more efficiently than in today's systems, are fairness between users over the whole coverage area, latency to reduce response time, and better support for a multitude of Quality of Service (QoS) requirements originating from different services.

An emerging factor in the overall design of next generation systems is the energy efficiency of the network components and its deployment. The environmental impact by reducing the CO_2 emissions is essential for the ecosystem. Moreover, increased energy efficiency of the network reduces operational expenses, which is reflected in the cost per bit; this metric is important, given the expected traffic and throughput growth until 2020.

It is essential that broadband wireless access systems in 2020 can meet these requirements. Achieving this goal will have a strong impact on the economy of the broadband wireless sector, from the device and component manufacturers up to the network and service providers. Today's wireless systems are far from fulfilling these requirements, and strong efforts in R&D are necessary in this coming decade. Consolidated efforts are necessary from all players in academia and industry to develop innovative technologies and deployment scenarios, which can guarantee to meet the demands on broadband wireless in 2020.

To have a globally-harmonised approach for specifying and developing broadband wireless networks, ITU-R has established a successful framework by setting minimum requirements for next generation systems. This global effort started with the definition of IMT-2000 systems for 3G standardisation, and recently, 4G systems have been specified, which have to fulfil IMT-Advanced requirements. ITU-R is expected to analyse the demands and requirements for the next generation of broadband wireless systems, in order to guide and harmonise future developments towards 5G.

There are expectations from network operators that new spectrum for mobile services will be allocated at the World Radio Conference (WRC) in 2015. However, it can already be forecast that it will not be sufficient to support the predicted traffic demands for 2020 by some distance. Thus, technologies with increased spectral efficiency, as well as new heterogeneous network deployments with distributed cooperation of devices, have to be developed. It is not unconceivable to see yet another new air interface, if significant gains can be obtained by introducing a new access scheme.

3.2 Research priorities

3.2.1 New Wireless Network Topologies

On a network topology level, the main tools to cope with the spectrum crunch are denser and denser node deployments and enhanced coordination. However, these require advancements in several other areas to make this feasible both technologically and economically, which are addressed in what follows.

Multilayer Multi Radio Access Technology Networks

Future networks will need to be deployed much more densely than today's networks and, due to both economic constraints and the availability of sites, will need to become significantly more heterogeneous and use multi Radio Access Technologies (RATs). They will become more heterogeneous in terms of: transmit power, antenna configuration (number, height and radiation pattern), supported frequency bands, transmission bandwidths, and duplex arrangements. Radio-network architectureswill vary from stand-alone base stations to systems with different degrees of centralised processing, depending on the available backhaul technology (e.g., fibre, leased lines with technicallyor commercially-limited bandwidth, DSL-like lines, microwave links, or in-band relaying). Diverse radio access technologies will need to be integrated, such as: LTE, including LTE-Advanced; UMTS, including HSPA; WiFi; future RATs; or any combination thereof. Last, but not least, the overall allocated spectrum will be more fragmented, and may be shared according to new licensing modes.

Therefore, procedures, such as Radio Resource Management (RRM) and optimisations thereof, will need to be revisited in the light of these trends, and new technologies will need to be flexible to support all cases without generating excessive overhead. Smart self-configurability and autonomous self-adaptation are key features to adapt to a variety of design criteria. In this way, the user experience, including availability of required data-rates, latency, and other QoS parameters, should be provided in a consistent and secure way, whilst simultaneously meeting deployment criteria, like energy and cost efficiencies.

Energy Efficiency

Both heterogeneous network topology and network management need to be fundamentally rethought and redesigned for better energy efficiency, dimensioning virtually all quantitative parameters, such as the ratio between large and small cells, form factors, and the number of hops to a node with wire-line backhaul, in a harmonised and holistic way, and not individually. The backhaul organisation deserves particular attention, especially for cloud computing/processing approaches. Moreover, besides solutions that are theoretically ideal, research should also take practical constraints into account, including constraints to reduce electromagnetic radiation in general.

Switching nodes on and off, depending on the actual traffic, has been the most obvious technique to use, but some critical points need to be addressed in the future. For one, keeping nodes alert while they are asleep (standby) still requires a non-negligible amount of energy. In this context, an entirely passive technology that does not consume any energy at all while being idle would be desirable; this would require a technology leap, as opposed to further fine-tuning of existing ones. A complementary aspect is to switch on nodes before they are actually needed, introducing a proactive element in management, which turn requires statistical insight into the network and user behaviour.

Cooperation of Wireless Network Nodes

The conventional cellular structure will be complemented by novel network topologies in the IMT-Advanced compliant networks. Possible extensions include self-organising mesh-type networks, with direct user-to-user communication, and different levels of cooperation or coordination between end-user devices and/or network nodes. The most promising, albeit the most challenging, approach for providing the much-needed capacity and coverage increase, particularly for cell-edge users, is coordination between transmissions, which facilitates multi-user pre-coding techniques across distributed antenna elements, or other network nodes in effectively utilising the interference. This can be used to improve the utilisation of the physical resources (space, time, frequency, and phase) by exploiting the available spatial degrees of freedom in a multi-user Multiple Input Multiple Output (MIMO) channel (e.g., collaborative scheduling in combination with 3D-beamforming). However, these technologies have not yet reached a high-enough level of maturity, thus, further research efforts have to be spent.

Wireless Network Coding

Wireless Network Coding (WNC), also known as Physical Layer Network Coding (PLNC), is a technique that has potential to become a “disruptive” technology for such networks. It has the capability of naturally solving problems related to dense, cloud-like, massively-interacting networks of nodes. It can also be regarded as an example of the more general concept of the “network-aware physical layer”, in which functions (such as routing) conventionally performed at high layers of the protocol are more efficiently carried out at the physical layer, which alone has the capability of processing signals directly, without loss of information.

These networks will nevertheless need to be self-managing to optimise their efficiency, adapting to varying demands and resource availability. This will require new cognitive methods, implemented using distributed artificial intelligence, based on tools such as game theory.

Radio Access Resource Sharing

The densification of wireless networks, i.e., reduced inter-site (antenna cluster) distances, will boost capacity and reduce total radiated power, thus,decreasing energy consumption. Exploitation of cloud technologies, equipment/resource sharing and virtualisation are key enabling technologies to achieve this cost-efficiently, and increase areas and degrees of coordination, a necessary prerequisite for higher traffic at lower cost. These technologies are, however, still in their infancy, needing many breakthroughs and refinements to reach a stable status for deployment, including synchronisation requirements of low-cost base stations and architectures supporting also loose synchronisation, e.g., interference alignment techniques.

Broadband Radio over Fibre

Broadband radio over fibre is a further virtualisation step, where even D/A and A/D converters are centralised, and analogue signals are forwarded as optical carriers (optionally with Wavelength Division Multiple Access (WDMA)) via a Fibre Distribution Network (FDN) to/from antenna heads, which only contain analogue electrical/optical converters and amplifiers. Key challenges for this approach include minimising energy consumption, maintaining or improving link linearity, and reducing signal conversion times. This requires substituting, as much as possible, electronic processing with the corresponding optical one. Such high-speed, photonic-driven (and integrated) signal processing systems may support high bandwidths at high carrier frequencies, from a much larger number of antennas than with conventional network nodes. They still require research on algorithms addressing user mobility, traffic routing and delivering, energy consumption, congestion, and capacity optimisation, to cope with the considerably higher attenuations at higher bands.

New Radio Access Architectures

Current cellular systems are designed with extensive in-band signalling, putting a limit on achievable spectral efficiency. This problem is exacerbated with some trends, e.g., towards smaller and smaller cell topologies, resulting in excessive mobility related signalling. To achieve simultaneously spectral and energy efficiencies, one needs to move away from traditional cellular architectures, and investigate new and alternative architectures where signalling messages and user data can be supported and optimised for capacity and energy efficiencies irrespective of cell size, which calls for a physical separation between control and data planes. For both on-line spectral and energy efficiencies optimisation in network operation, such new architectures must take users' and cells' active and idle states into account, and manage network resources intelligently and dynamically,whilst maintaining the overall system stability. Physical separation between control and data planes brings about new research challenges, notably synchronisation between these planes.

3.2.2 New Air Interface Technologies

The air interface is the foundation on which any wireless-communication infrastructure is based. The properties of the different air-interface protocol layers (physical layer, MAC layer, retransmission protocols, etc.), and how these operate together, are thus critical for QoS, spectral and energy efficiencies, robustness, and flexibility of the entire wireless system. One of the key drivers for the evolution of the air interface is the paradigm shift in network architectures from larger coverage cells to smaller and smaller ones, less and less regularly deployed; hence, this viable change (e.g., in link geometry distribution) has to be carefully studied as an enabler for novel technical solutions to provide the expected services, despite the fact that the available spectrum does not increase in the same proportion.

Basic Transmission Technologies

Orthogonal Frequency Division Multiplexing (OFDM) is the transmission technology used in the most recently developed wireless technologies, such as LTE/LTE-Advanced and WiMAX. Being a kind of multi-carrier transmission scheme, OFDM provides a low-complexity means to handle, and even take advantage of, radio-channel frequency-selectivity, due to the small sub-carrier spacing and the possibility for scheduling in the frequency domain. At the same time, OFDM spectral efficiency, flexibility, and robustness are a compromise with the need for a cyclic prefix and the required guard bands. Different means to further enhance spectral efficiency and flexibility/robustness, e.g., improved spectral containment allowing better coexistence with services in adjacent bands, and thus efficient implementation of Cognitive Radios (CRs), beyond that of conventional OFDM, should thus be pursued. This includes more general multi-carrier transmission schemes, as well as other transmission approaches that may not be based on the multi-carrier principle. An example candidate isthe FBMC (Filter Bank Multi Carrier) technique, and its variations.

Advanced Multi Antenna Transmission/Reception

The use of multiple antennas at the transmitter and/or receiver sides is an important way of greatly enhancing the efficiency and robustness of the air interface. Although today multi-antenna transmission/reception is an established technology component in state-of-the-art mobile-broadband technologies, such as HSPA and LTE, much can still be done to fully exploit all its potential, on both link and system levels. This includes more robust multi-antenna transmission schemes (e.g., in terms of limited channel knowledge), as well as extending their capabilities to provide efficient and flexible multi-user multiplexing.

A more radical technology step is to extend current multi-antenna schemes, typically consisting of just a few antenna ports at each transmitter/receiver node, towards *massive multi-antenna configurations*, in the extreme case consisting of several hundred antenna ports. In theory, this would provide a path towards enormous enhancements in terms of system efficiency. However, the introduction of such massive antenna configurations for wireless communication requires extensive work, in terms of both the antenna technology itself and the transmission and reception algorithms needed to efficiently use the antenna system.

Smart Adaptive Antennas

Antenna systems are crucial for any wireless network. The conventional approach to antenna system research has been to optimise certain antenna parameters in terms of antenna-level properties, such as impedance matching and radiation patterns. Such an approach is no longer adequate to deal with the stricter performance requirements imposed by new technologies, such as multi-antenna systems, mm-wave communications, and cognitive radio.

In this context, future antenna system research will undergo a paradigm shift. Specifically, it will account for various interactions between the antennas and their surroundings to achieve optimal system-level performance, including interactions between the antennas and the user, as well as the antennas and the propagation channel. One important aspect in these interactions is smart adaptability, not only to changes in the surroundings, but also to different application requirements (e.g., flexible bandwidth on demand for cognitive radio). Existing work in these topics is in its infancy, partly limited by the slow but steady development of various enabling/supporting technologies such as new materials and circuit components (e.g., MEMS).

Advanced Interference Handing

Today, link performance in mobile broadband systems is often limited by interference from other nodes of the system. Relatively primitive means to suppress such interference at the receiver side have already been introduced in state-of-the-art wireless-communication systems. However, the ever-increasing ability for computationally-intensive signal processing, even in hand-held terminals, opens up new opportunities for more advanced methods in interference suppression/elimination, or even utilisation. Research is needed to realise such schemes, both on their basic principles and on their integration into wireless networks. A very specific type of interference impacting the receiver of a radio unit is its own transmit signal. Nowadays, in all systems (apart from simple repeaters), such interference is handled by the separation between transmission and reception, either in frequency (Frequency Division Duplex - FDD) or in time (Time Division Duplex - TDD). If the interference of the transmitted signal could be suppressed by other means, such as advanced receiver processing and specific antenna configurations, this could, at least in theory, *double the capacity*. Means to achieve this have been demonstrated, and the scheme becomes of particular interest in small cells scenarios, when transmit and receive signal level differences are smaller than in other settings (e.g., macro-cellular). However, significant work is still needed to make such schemes practically useful.In particular, extending the bandwidth and dynamic range of such systems are a priority. The implications of such schemes extend beyond the physical layer, and could potentially transform, even revolutionise, higher layers of the network, and allow previously intractable problems to be solved.

Disruptive Transmit and Receive Architectures

Concerning hardware, the major challenge will be the size of the components. For reasons of cost and practicality, in the future network nodes will be significantly smaller in size. To date, this goal is pursued by improving existing technologies, but at some point in time, the limits will be reached and a technology leap will be necessary here as well. Outsourcing tedious computations to the network cloud is already a new and promising paradigm, but power amplifiers and other components will also have to be revisited with respect to the energy-saving potential. The future of mobile communications will include a vast variety of communication nodes with various sets of requirements and roles. Some have to be designed with primarily the Quality of Experience (QoE) in mind, some call for the highest energy efficiency, while for others the emphasis will be on robustness and security. This variety in requirements and roles needs major improvements in designs in terms of flexibility, concerning both the network and the architectural design of the nodes.

Visible Light Communications

In the last decade,visible light communications have been a subject of increasing interest and development due to the scarcity of radio spectrum. Such interest can be traced back to the relatively recent development of white Light Emitting Diodes (LEDs), which are expected to replace conventional lighting sources, particularly as the efficiency of these devices is continuously improving. One can expect that solid-state illumination will replace other sources in the near future. Whilst LEDs are a good source of illumination, they can be modulated with high-speed data, resulting in visible light optical links. There is more than 300 THz of bandwidth readily available in such optical channels; moreover, optical transceivers are typically simple, inexpensive and low power. For indoor scenarios (e.g., home and office), optical downlinks are possible where information is confined within the room; furthermore, as no radio waves are used, no interference to other equipment is created. This is of great advantage in sensitive environments, such as hospitals, airplane cabins, among others. There are, however, several challenges that need to be tackled before visible light communications is widely adopted. They include developing techniques that will help to mitigate problems caused by ambient light and shadowing. Visible light communications do not compete with radio communications, rather complementing them. Extremely simple transceivers easily support several tens of Mbps, and more advanced systems have been demonstrated to operate at data rates well above 1 Gbps.

Energy Efficiency

Air-interface and associated technologies are key to energy efficiency, if designed with that goal. Promising approaches include the use of multiple antennas that go beyond existing MIMO schemes in current technologies. Moreover, an inconvenient property of today's technologies is that they require a large overhead for channel estimation and mobility support, which consume a significant part of the system power in low-load situations. Hence, completely new transmission paradigms must be envisaged in the design of new air interfaces and in the enhancement of existing ones.

Additionally low power hardware architectures and energy-efficient signal processing needs to be addressed. Since these goals are close to theoretical limits, it will also require a paradigm shift in wireless system design to dramatically improve efficiency in terms both of power and spectrum. Notably the existing "layered" protocols, with their requirements for retransmissions, multiple acknowledgements, etc., may be highly inefficient, and result in bottlenecks in multihop networks that prevent them scaling, as required both for high capacity density access networks and large scale IoT networks.

User Context

Modern smartphones may allow predicting user behaviour, including user location and data transfers using their sensors, e.g., GPS, gyroscope or accelerometer combined with calendar information and past activities. This allows for several possibilities for RRM optimisation, such as: send or receive emails with large attachments, send or download large files not necessarily immediately but at the ideal time/position for the wireless network (requiring less spectrum and energy), still in time to satisfy user expectations and possibly even before the user request; providing users advice when/where to get the optimum service (e.g., closer to the base station); signalling can be optimised based on user context.

Important research questions to facilitate this approach include: algorithms to determine and predict user context/activity; evaluating the potential of this approach, regarding more efficient spectrum and energy utilisation; defining a generic framework to be introduced in future systems/standards to enable this approach.

This technology can be combined with various other approaches of system optimisation for future wireless systems, by advancing not abstract low level performance figures but focusing on end-to-end context specific user requirements, and directing scarce rescores (e.g., spectrum and energy), as well as optimising the network on all levels towards where most value is created for users in their respective contexts.

Efficiency and Security at the Wireless Terminal Side

Wireless terminals remain an open challenge for the radio communications evolution in the coming decade, and efforts should be taken to make them more efficient and secure. In this sense, the major challenges are to develop terminals able to exploit the full potential of nanoscale hardware and devices in terms of performance and low power, e.g., massive multi-core hardware, which opens the route to novel physical (PHY) and higher layer algorithms. Also terminals should have extra wide band capabilities and mainly digital RF, which will require a major evolution of PHY schemes and design, in order to mitigate the more significant imperfections resulting from these very wide capabilities (in terms of spurious, reduced dynamic range, enhanced interferences, harder linearities to cope with, etc.).

The massive wireless devices deployment with highly variable capabilities will require networks able to recognise and integrate these devices, and compensate for their limited performance through various means. One will need to have much more enhanced security, combining PHY layer security, cryptography and protocols, to ensure the highest confidentiality and integrity of data in the case of wireless connectivity. Extremely simply self-configured, but controllable, connectivity of devices to the various wirelessly accessible environments (BAN, PAN, WLAN, MAN, etc.) has to be addressed, allowing a simple switch to one or another according to user demand. Seamless (but user controllable) integration of the various localisation techniques and location providing systems (GNSS, network based, UWB, and/or any other) for a fully transparent use with extremely limited need for user intervention is also a requirement to be tackled.

Testing adaptive, distributed, cognitive mobile systems

Few people will realise that the mobile phones they might be using daily, are normally 100% tested for software, for radio frequent performance and compatibility, but not for operation under realistic conditions, even 20 after the advent of GSM. Part of this is caused by the fact that the standards do not demand such testing, and that the mandatory testing is already an appreciable overhead. The notion of how much overhead testing under realistic operational conditions may add, seems to work paralysing. First steps are now taken by ETSI 3GPP to reach a standard on this so-called Over-the-Air testing for MIMO devices at the end of 2012.As this first step is already difficult enough, it aims at emulating single device performance over a realistic channel, incorporating the influences of antennas at both ends. But, only the downlink is tested, the device is still under central control and the smart, adaptive features of LTE or LTE Advanced are switched off, precisely those features that were designed into the system for increased performance compared to earlier generations.

However, when (link and antenna) adaptivity will be used to the full, when central control gradually shift towards distributive, and when cognitive functions using dynamic spectrum access are exploited, testing has to assess how devices more or less on their own operate in environments and networks that become increasingly chaotic and crowded. Implementing these types of technology with thorough testing is not an option, but a revolution of test technology itself that is required to cope with such challenges. The conclusion is that the development of operational testing of systems should be concurrent with the evolution of communication systems, and is a serious theme for future research programs.

Self-Organised Networking and Cognitive Radios

Future wireless networks will face diverse challenges, amongst which are efficiencies in cost and resources, including the growing but still scarce spectrum resource. All aspects of mobile networking still can and, more importantly, have to be improved to meet future requirements. Capacity and coverage have been continuously enhanced for many years, but never matched completely the increasing demands. An always important topic is resource efficiency, in terms of both installed/active equipment and shared resources to harvest on statistical multiplexing. Moreover, in the time of climate change and operational cost, energy efficiency has become of greater important.

To continue the process of improvement and innovation with respect to these wireless networking characteristics, many key enabling technologies are available, but there are still many issues unsolved and require in-depth investigation in a holistic manner before they can be deployed.

Inter Layer Network Optimisation

Undoubtedly, future wireless communication networks must provide a large range of services, including voice, data and streamed multimedia, at reasonable cost and QoS, comparable to competing wire-line technologies. This increased demand may lead to a need for employing new network topologies, such as multi-hop wireless networks and mobile ad-hoc networks, and deeper integration of wire-line and wireless networks.

A fundamental problem in designing such complex systems is the derivation of a network control mechanism, comprising flow control, routing, scheduling and physical resources management that can provide QoS guarantees, and ensure network stability under a large set of service demands. Traditionally, these control decisions are optimised independently at different network layers. Every layer controls a subset of the decision variables and observes a subset of parameters and variables from other layers, thus, each layer in the protocol stack hides the complexity of the layers below and provides a set of services to the layer above. While the general principle of layering is widely recognised as one of the key reasons for the enormous success of wire-line data networks, there is now a worldwide recognition that it is no longer efficient, especially in the case of wireless networks. Globally-efficient designs of wireless networks cannot be achieved without crossing the boundaries of the standard Open Systems Interconnection (OSI) layers.

Radio Access Network Operation

The tendency in radio network management is to allow system optimisation at local level as much as possible:the systems are getting more and more decentralised. The long-lasting dilemma has thus been on finding a right balance between centralise control vs. Self-Organised Networks (SONs). As small cells will have a more important role in the future, and optical fibre backhaul is becoming more feasible to deploy, the system architectures based on local centralised clusters of small cells become of interest for global optimisation of the cluster operation(e.g., following the NUM framework). An alternative approach is to allow full flexibility at each small cell, leading to a true SON behaviour.

Energy Efficiency

In an intelligent future wireless network, the connections for delivering services should also be designed from an energy efficiency perspective. This means that the service plane should be intelligent enough to use the least amount of radio resources and energy as possible, and use the maximum allowed latency as much as possible. Hence, instead of offering a more or less uniform bit pipe with varying delivery capabilities, services could be delivered intelligently, taking advantage of the operation environment (e.g., existence of alternative access networks, including infrastructure-based or infrastructure-less, availability of bandwidth, radio propagation environment, and predicted user mobility pattern) and to scale quality according to the available delivery capabilities (e.g., scalable video encoding). This is important from both energy efficiency and QoEviewpoints. Furthermore, the availability of ample spectrum allows transmitting data with lower spectral but higher energy efficiency, e.g., by using lower modulation schemes and less complex receiver algorithms, enabling globally optimal trade-offs.

Cognitive Radio Networks

Wireless networks in the legacy and the Future Internet context will have to satisfy an increasing volume of applications (e.g., various new concepts, like smart infrastructures, various information flows like video and data apart from voice, various end-points, namely, machines and smartphones) and an increasing volume of associated demand and traffic. Moreover, as there is fierce and intense competition in telecommunications, there is a pressing need for cost efficiency in the satisfaction of the application/demand/traffic requirements. Cost-efficiency requires savings in various cost components, e.g., capital and operational expenditures (CAPEX and OPEX). CR networks have the potential to become a main contributor in this direction, deriving from their self-management/awareness/organisation capabilities, as well as from the knowledge they can obtain through inherent machine learning functionalities. In the light of these aspects, CR networks can efficiently complement/extend and add sophistication to a wireless communication ecosystem.

A CR network is based on opportunities regarding the links (e.g., RATs, spectrum, and transmission power), as well as the nodes (e.g., devices, terminals, relays, and access points serving cells of various sizes) that can be used for its formation. They can be created in a particular location and time period, for the efficient application provision and the resolution of capacity and coverage problems, either in the wireless access or in the backhaul. Efficiency will stem from the higher resource utilisation that can be achieved (opportunity exploitation), the lower energy consumption of the infrastructure, the handling of situations through adaptations and without needing to resort to worst-case oriented planning, and the capability for automated and knowledge-based handling of situations. All these have the potential to lead to decreases in CAPEX and OPEX, as well as to a fast and reliable management.

Advanced intelligence should be developed for realising CR networks. The intelligence of a CR network requires research work for yielding capabilities for the perception and reasoning regarding the context of operation, decision-making regarding its creation/maintenance/release, as well as learning regarding the contexts encountered, the decisions taken to handle them, and the alternate ways they could be handled. The context of operation refers to traffic requirements, radio environment conditions, mobility levels, and the status and capabilities of devices and potential links.

The research on CR networks will need the precision and evaluation of scenarios and requirements regarding their role in extending wireless access infrastructures. Next in the agenda can be the development/refinements of functional and system architectures, also taking the integration with the overall wireless world into account. In order to complement the architecture work, there needs to be elaboration, and ultimately specification, of control channels for the cooperation of the cognitive management components. Efficient, stable and scalable algorithmic solutions are needed. Special emphasis needs to be placed on validation, especially by means of experiments, trials and pilots. Concrete links with standardisation and regulation should be evolved and exploited for producing the framework that can lead to exploitation.

Spectrum Packing

A most prominent component of future mobile traffic increase is expected to be due to video-type services. It makes sense to enhance the existing broadcasting functionality in mobile networks, so that the dense infrastructure of cellular networks can be even better exploited for offering spectrally efficient mass multimedia delivery, thereby also offloading the mobile broadband (unicast) access.

Furthermore, for broadcasting, the introduction of state of the art digital broadcasting technologies, like DVB-T and DVB-T2, enables more dense frequency reuse, thereby leaving less white space between the service areas of a TV channel. With the appropriate dense transmitter network and technology, using, e.g., cellular broadcasting solutions, Single-Frequency-Networks (SFNs) are possible for nation-wide broadcast content; which enables significantly increased "packing" of TV spectrum. This opportunity has been exploited to only a small extent at the ITU Regional Radio Conference Geneva'06 broadcasting frequency re-planning activity. Studies have shown that the secondary use of TV white spaces is possible, however, of limited value for macro cellular networks.Therefore, the prime focus should be on reducing the white space wherever possible, by packing broadcasting channels more densely, so that larger amounts of contiguous spectrum can be re-farmed, and thereby be reused without the burden implied by white space operation.

However, many research challenges remain to be addressed mainly towards making mobile broadcasting more efficient, in terms of spectral and energy efficiencies, by using and optimising as much as possible the advanced techniques developed in mobile broadband cellular systems, such as MIMO, diversity and beamforming, thereby reducing the current gaps between mobile broadcasting and mobile broadband. Research should also be focused on the provision of technologies for multicasting at single- and multi-cell levels, and for energy efficiency develop targeted broadcasting technologies, as opposed to current “anytime and anywhere” broadcasting.

Spectrum Sharing

Research on spectrum has focused or even hyped on the secondary use of the UHF band and TV white spaces, using mainly geo-location database techniques as the most basic way of spectrum sharing. The scope should be extended to opportunistic ways of spectrum sharing to any commercially viable segments of the whole spectrum, under the vision that any portion of spectrum that is not being used at a certain time and location can be used, regardless of the specific frequency range, bandwidth, and contiguity of available frequencies. This vision would significantly drive a breakthrough in the envisaged new paradigms of spectrum usage. ITU-Restimated that the overall spectrum demand for mobile radio in 2020 will be 1 280 to 1 720 MHz. Sharing of the radio spectrum is the most developed and well-known solution for current under-used spectrum bands and future "Spectrum Crunch" problem. This mechanism should encompass different techniques (at both device and network sides) in terms of administrative, technical and policy-based approches, to improve spectrum utilisation in licensed and license-exempt bands. Dynamic Spectrum Access (DSA) is the key functionality of the CR technology that enables cognitive devices to observe radio frequency bands, and adapt their transceiver parameters based on its internal and external knowledge to explore and exploit interim spectrum holes opportunistically. Eventually, CR will pave the way to effectively reaching a less fragmented spectrum allocation, by making larger chunks of spectrum available for communication, if not permanently then at least temporarily, on a secondary basis, but still simplifying the creation of devices.

Self-Organising Systems for Extreme Automation

The management of the mobile network infrastructure plays an important role in achieving the requirements in terms of constant performance optimisation, fast failure recovery, and fast adaptations to changes in network loads, architecture, infrastructure and technology. The increasing network heterogeneity (multiple RATs and multiple layers running in parallel, fully or partially uncontrolled deployment patterns) and dynamicity lead to an increasing complexity and efforts on the Operation, Administration and Maintenance (OAM) of mobile networks. SONs are the first step towards the automation of (mobile) networks OAM tasks, introducing closed control loop functions dedicated to self-configuration, self-optimisation, and self-healing. First generation SON functions need to be individually configured and supervised by a human operator. This manual configuration and tuning is getting less and less practical, due to the increasing complexity of the SON system, since multiple SON functions being operated in parallel may have interdependencies, and lead to network performance degradations due to inconsistent or conflicting configuration.

Extremely automated systems have to follow high-level operator goals regarding network performance and reliability. These systems have to autonomously ensure and control a conflict-free and coordinated operation of multiple SON functions, providing automated control not only at (low-level) SON function level, but also at the high-level network management, network planning and Operations and Support Systems (OSS) level.

CR networks describe a radio network that employs a cognitive process (i.e., involving thinking, reasoning, and remembering) and learning capabilities in order to achieve end-to-end goals. This applies to both the horizontal network (i.e., including all the protocol stack of wireless networks, both radio access and backhaul/transport) and the vertical management views (i.e., abstracting network elements and their configuration towards a holistic high-level view). Control loops need to work not only for single independent functions, but also to be extended for the complete environment to be managed, which may involve several layers of control loops. The control loop diagnosis and decision making processes need to be adapted automatically by learning, e.g., based on the results of previous actions, in order to improve their effectiveness and efficiency, leading to a cognitive processes driven and controlled through high-level operator goals.

Advanced Human Computer Interfaces (HCIs) are required to define and acquire the high-level business and technology driven operator goals, end-user requirements, and network capabilities. The cognitive management of the underlying infrastructure uses the knowledge-based inference and diagnosis of the current network state together with occurring performance issues and failures, as a basis for an autonomous creation and enactment of an optimised network plan, and configuration that reflects the operator's high-level end-to-end goals. Methodologies need to be researched for the acquisition, analysis and improvement of knowledge representing semantics of operational goals and strategies, network properties, and historic and current network status enabling an automated reasoning for the alignment of different CR networks functionality at runtime.

3.3 Technology Roadmap

The foreseen roadmap concerning wireless broadband and spectrum scarcity aspects is presented in

Table 1.

Table 1 – Technology Roadmap for Spectrum Crunch.

Timeline	In 5 Years	In 10 Years	Beyond 10 Years
Radio	• *data rate*: several 100 Mbps • *bandwidth*: up to 40 MHz • *antennas*: roughly 10 layers spatial multiplexing • *first features of user context*	• *data rate*: up to 1 Gbps • *bandwidth*: at least 100 MHz • *antennas*: tens of cooperative antenna elements • *user context aided RRM*	• *data rate*: multi-Gbps • *bandwidth*: GHz range • *antennas*: hundreds of cooperative antenna elements
Energy	• network architectures are adapted to energy efficiency needs • intelligent switching on/off of resources using current technologies is optimised	• novel transmission schemes and novel form factors for equipment are employed	• technology leaps provide further enhancements
Network	• small cells • cloud RAN • local intra-site CoMP • inter-site cooperation • coverage relays • fast inter-RAT load balancing	• smaller cells • baseband cloud • inter-site CoMP • interlayer coordination • capacity relays • mobile and multi-hop relays • network-controlled device-to-device • inter-system load balancing	• ultra small cells • immersed radio (massive multi antenna) • radio virtualisation • complete inter layer/system CoMP • all photonic RF “leaky RF fibre” • cooperative relays • load balancing with multitude of systems, including full device-to-device

SON	• usage in LTE-A, and in multi-layer and multi-RAT, and SON coordination (light)	• usage in heterogeneous networks, and in E2E, including radio, core, backhaul, and transport • fully coordinated SON at network level (operator domain) • cognitive learning mechanisms for SON improvement • high-level operator goal driven network management using multiple-layer control loops	• CR networks with cognitive learning and reasoning capabilities • automated improvement of management mechanisms • fully high-level operator goal driven E2E network management including all network domains
Spectrum	• opening TV white spaces with advanced cooperative cognitive protocols • geo-location cooperating	• licenses shared by co-operating operators • multi-antenna signal processing • dynamic spectrum access location based • any free portion of spectrum usable • advanced spectrum handover, and spectrum mobility mechanisms regarding inherent QoS.	• dynamic spectrum access • dynamic spectrum management (sensing, sharing, and trading) among operators • cooperative spectrum hole prediction mechanisms in multi-standard stochastic systems • visible light communication
Cognitive Radio	• opportunistic spectrum access in femto-cells	• spectrum usage data bases • cognitive engines for access networks • self-reconfigurable multi standard chips in MIMO systems	• secondary spectrum use supported by sensing • licensed user behaviour prediction in multimedia stochastic networks

3.4 Conclusions and Recommendations

Radio access techniques need significant development to meet the predicted capacity requirements for the future. There is no single obvious approach, but the solution will be a combination of several alternatives, and will depend on the time and place. There are several promising approaches to take in networking, and radio access implementation, which are briefly summarised in what follows.

The key drivers in this area are:

- 500-1000 times capacity increase requirements,
- shortage of spectrum,

- energy efficiency requirements,
- wide-scale utilisation of small cells,
- availability of super-broadband optical fibre,
- flexible spectrum use.

The potential technical approaches to address these problems are:

- heterogeneous networking solutions,
- large MIMO constructions,
- more efficient duplexing and modulation techniques,
- co-operative networking technologies,
- all-photonic RF,
- mobile cloud processing techniques,
- inter-layer network optimisation,
- clustered small cells,
- new radio access architectures leading to physical separation between control and data planes,
- spectrum packing of broadcasting services in mobile cellular systems,
- software defined radio
- visible light communications,
- usage of user context and prediction in radio optimisation

The following recommendations for successfully setting up joint research initiatives are put forward:

R1) Significant improvements of the wireless network have to be explored, by strengthening the research efforts towards innovative cooperation and coordination schemes for network nodes, in a flexible heterogeneous network deployment, including wireless network coding systems applied to dense, cloud-like, massively-interacting networks of nodes.

R2) New radio technologies (scale of channel modelling to small and complex scenarios, access, multiple antenna schemes, interference handling, etc.) must have a high priority, in order to meet the high requirements on 5G systems.

R3) Cooperative spectrum-sharing techniques in non-homogeneous bands.

R4) Antenna systems fundamental limits, providing the performance benchmark for smart adaptability, including interactions with the user and the propagation channel, and taking an integrated approach where performance can be effectively optimised by appropriate sensing of the physical environment.

R5) New radio access architectures, logical and physical separation between control and data planes, for achieving both spectrum and energy efficiencies.

R6) Full integration between mobile broadcasting and mobile broadband communications.

R7) Collaboration between wireless and optics experts, towards new network technologies with very high performance at reasonable costs.

R8) Future network deployments have to allow for network/infrastructure/resource sharing on all levels, in order to meet the fast changing demands on network resources and operation.

R9) Cognitive capabilities have to be incorporated into network design on all layers, supporting a flexible network adaptation at low operational costs, towards providing exactly the performance required for the determined user context.

Networks for the Next Generation of Wireless Optics Communications

4

4. Networks for the Next Generation of Wireless Optics Communications

4.1 Rationale

The expected increase in data rate, in access networks, to 50 000 ExaByte per month in 2012 will mean an urgent requirement for a new technology. This consequently will lead tosubstantial increasesin electrical power to cope with such high data rate, in the order of 20 TWh per year,being approximately 8-10% of the total generated power for ICT. Access networks are responsible for about 70% of the overall energy consumption by telecommunication networks. In addition, the cost per bit/Hz is decreasing, which will allow more users. According to [METI07], the amount of electricity consumed by networking equipment in 2025 is predicted to be 13 times greater than in 2006, if no energy-saving measures are taken.

Today, the majority of the network infrastructure uses optical technologies. Mostly invisible to the end user, transmitted data from wireless devices or send from a PC, is modulated onto laser light and transported through optical fibre shortly after it enters the core network. The transition from electrical to optical transports will occur closer and closer to the end user, due to high capacity requirements. For example, Passive Optical Network (PON) technology is used, even today, to move this transition into end users' homes. Hybrid fibre and radio networks will help in bringing the fibre as close as possible to the wireless antenna. All this is motivated by end users demand for higher bandwidth, better quality video on smart phones, IP-based television, smart homes with networked appliances, data-hungry business applications, and 3D-video conferencing. These services need data rates that require efficient network infrastructures, based on a hybrid of both radio and photonic technologies.

Internet traffic growth is strongly impacting on access, metro and core network costs. This growth is expected to continue in the future, due to the widespread availability of smart phones, fixed and mobile broadband access connections (e.g., FTTH and LTE), and the fact that these new access technologies will allow end users to consume new and widely diverse applications, such as social networking, cloud computing, media (high/ultra-high definition, or 3D formats). Some of these applications are high-performance and/or data-intensive network-based ones, with strict network resource requirements (e.g., computing and data repositories), and bandwidth requirements sometimes beyond 1 Gbps.

New architectural solutions are needed, capable of efficient handling this huge expected traffic increase and provide end users. Moreover, novel architectures need to be developed to provide increased network reliability in a number of realistic scenarios. In some cases, the topology of the networks needs to be dynamically changed, in response to a number of changing parameters, such as traffic requirements.

With increasing traffic, concerns about energy consumption become increasingly important. IP Routers have exponentially increased their power consumption as a function of their throughput. The result is that energy consumption and network operational costs of current IP networks strongly depend on traffic growth. Therefore, it is important to address new architectures that replace electrical data planes by optical ones, in performing data aggregation and routing operations.

4.2 Research Priorities

The expected exponential growth of traffic, cost of energy and multi-access technologies of future networks has made the hybrid of fibre and wireless a strategically important area of research. The aim is to minimise the number of Optical-Electrical-Optical (OEO) conversions in the transport network (backhaul, aggregation and core). This way, a huge reduction in energy consumption is expected compared with the traditional OEO approach.

Research should be towards an all-optical networking including optical packet switching used for transporting data generated in packet based Radio Access Networks.

In FP7 research started mainly on the components level, however future research should focus more on a best hybrid of electrical and optical transport architecture supporting multi-access and multi-technology network of networks.

Below is a list of considered strategically important research topics. This comprise of enabling technologies for smooth evolution to the future flexible, energy efficient and universal network.

4.2.1 Physical layer

All-Photonic Signal Conversion and Processing

Regarding the growth rate of demanded end-users traffic to the order of ExaByte per month, the requirement for high-speed transportation networks is essential. The main challenge that next-generation networks will face is congestions in the core, metro and access networks. The congestion in the core network is due to the impact of the 3R signal processing (re-timing, reshaping, and re-amplifying)in the electronic domain. This process inserts the delays of optical to electrical signal conversion, signal processing in the electrical domain (which significantly increases the signal processing time, due to the lower speed in electronic systems compared to the one photonics), and electrical to optical signal conversion delay. The switching and routing process of the traffic in core and metro networks are other challenges that cause congestion in the network. By replacing hybrid optical and electronic switches and routers by only optical switching and routing devices, and optimising hybrid switching with proper protocols, implementation can significantly mitigate the congestion problem.

All-Photonic Digital Radio over Fibre

Digital Radio over Fibre (DRoF) systems are significantly more robust against the impairments of the optical communication link compared to Analogue Radio over Fibre (ARoF). Therefore, in DRoF, by using the free spectrum of the metro and access optical communication network infrastructures, more operations and signal processing centralisation at the central stations will be achievable, in comparison to traditional ARoF, and it can be cost effective in the support of the future broadband RoF access networks deployment.

However, the main challenges in DRoF link implementation are the high-speed analogue to digital conversion, the spectrum limitation for transportation of the generated digital data over dispersive fibre channel, nonlinearity of optoelectronic and optical devices, additive noise, integration of system and devices, and system cost.

4.2.2 Super Broadband

Dispersion and Non-linearity

A main challenge of future super-/ultra-broadband transportation networks will be from fibre chromatic dispersion in addition to the network subsystems nonlinearity impairments, which cause serious disruption and restriction for broadband data transportation, through long fibre length without periodic signal relaying. In spite of the huge potential TeraByte optical fibre bandwidth, the modulation bandwidth limitation on each wavelength prevents the high data rate transportation over a wavelength and fibre length. Therefore, Wavelength Division Multiplexing (WDM) techniques are a necessity, an alternate solution being to compensate dispersion by using either zero dispersion shifted fibre ora fibre Bragg grating dispersion compensator, and still another solution being to use Ultra/very-high Dense Wavelength Division Multiplexing (UDWDM). Furthermore, the implementation of high-speed all-photonic signal equalisation might also be the way forward.

Attenuation

Due to wireless spectrum scarcity, the requirements for switching to higher frequency carriers, such as license-exempt mm-waves, will become inevitable. However, the mm-wave range carriers suffer from high signal attenuation and expensive electronic components. One solution in overcoming the high attenuation is by shrinking the cell size to very small ranges, and replacing the electronic components by photonic components for signal conversion and processing. There is a need for cost-effective integration of such components and systems for all-photonic RF and mm-wave signal processing.

Routing and Handover

Traffic routing and handover in converged wired and wireless networks are an extra concern, because of the bandwidth limitation, requirements for fast signal processing regarding the very high speed data transportation rate, and end-user speed and mobility, because of optical-to-electrical and electrical–to-optical signal conversion insertion delays. Dynamic traffic routing and handover is a main issue in future super/ultra-broadband networks.

Traffic Asymmetry

Access networks must be capable of interconnecting orders of magnitude higher numbers of users with a symmetrical or asymmetrical bandwidth. The challenge is to achieve the requested capacity and QoS performance in the access network by exploiting the vast bandwidth, low loss and dispersion of new types of fibres. Such fibre technology is currently being developed to set up a massive pool of WDM channels at aggregate rates, which can be selected from a range up to 10 Gbps for residential users, and between 40 Gbps and 100 Gbps for business ones. The challenge will be in exploiting the full 400 nm of bandwidth across up to 1 000 WDM channels for creating a hierarchically flat access network. In addition, technical challenges will be concerning with the possibility for ultra-long-reach access performance, i.e., “un-regenerated” transportation of the WDM channel pool over long distances bridging the barrier between access and core networks. Future long reach access networks will result in consolidated metro-access networks, which will reduce the number of central offices that currently subscribers are connected to. The work will identify the ultimate limits of capacity and reach of this technology in providing network solutions.

4.2.3 Cognitive Radio over Fibre Protocol

Dynamic Wavelength Allocation

Dynamic Wavelength Allocation (DWA) is one of the best solutions for the high data rate and high bandwidth that WDM can provide, with up to 160 signals (wavelengths) and data rates up to 2 Tbps. There are different DWA types, according to the assignment schemes (centralised and distributed), each one having different types as well.

Wavelength conversion has been used in DWA with different schemes and types, to develop any network and overcome the following challenges:

- To increase network capacity by developing wavelength reuse.
- To decrease blocking probability in the network by using an improved algorithm.
- To minimise network cost by minimising wavelength conversion usage in the network.

Everything on IP

Progress in VoIP, IPTV and high-definition video streaming has impacted on the access segment of service-provider networks. Moreover, today, many access lines terminate on multiple home devices. This has led to a need for home networks, which are designed for a blend of multi-computer Internet access, entertainment, and voice support. The evolution towards multi-service platforms and the emergence of a range of new IP-based applications are fuelling more demand for bandwidth, being expected that substantial advances can be achieved through the innovative use of new architectures, protocols, and algorithms operating on hardware, which will itself allow significant reductions in energy consumption. This will represent a significant departure from accepted practices, where ICT and networking services are provided to meet the growing demand, without any regard for the energy consequences of the relative location of supply and demand. In addition, wavelength handover should be investigated, as the fibre will be connected to different access points and base station technologies.

4.2.4 Energy Efficient Network Architecture, Operation and Control

Radio over Fibre

Another aspect of RoF networks that could benefit from further research is the architecture of the network. Ideally a high-speed fibre optic backbone connecting hundreds or thousands of remotely placed wireless/optical transceivers could provide the end-user with a nearly unlimited amount of bandwidth and almost seamless connectivity, no matter where they travelled, whether crossing a room in their home or crossing a large metropolitan area in their car. However such a network will inevitably be faced with several practical issues. The first is cost. While a large amount of interconnected transceivers would provide excellent mobile coverage for the end-user, these transceivers would also require power, even in standby mode. Thus, as the number of transceivers increases, so too does the power consumption by the network, and hence its operational cost. Therefore, in the absence of any sort of “green” transceivers, a network architecture that balances bandwidth and mobility, while minimising power consumption, should be investigated. This effort could be made in conjunction with the work done on integration as integrated components should not only be lower in cost, but may also be more energy efficient, and thus have a significant impact on the optimal network architecture.

Installation costs are also an important consideration for RoF networks. One of the prohibiting factors of FTTx installations is the labour cost involved in installing the network. Hence, it would be cost effective to minimise the amount of fibre installed in the network, and instead make as muchas possible of the final connection to the end user using wireless. The drawback of this scenario is that network bandwidth may suffer, as potentially large amounts of users and their devices crowd the wireless link. Thus, the trade-offs between end-user bandwidth, including end-user future needs, and installation costs should be addressed, so that high bandwidth data links can reach as many end-users as possible, at a cost that can be supported by the average telecommunication provider’s business plan.

Another issue that needs to be addressed in a RoF network architecture is reliability. This aspect is especially true as personal health monitoring technologies become the mainstream. If the fibre backbone were to be severed in a RoF network, hundreds or even thousands of end-users could suddenly find themselves isolated from the network. This would be especially problematic for an end-user who required immediate assistance for a sudden health emergency. Thus, some level of redundancy should be built into the network, so that even a minimal amount of communication can be maintained at all times no matter what happens. Wireless mesh networks are a good example of providing redundancy to a network should one (or more) data paths become disrupted. The mesh could be used to reroute data to transceivers that still have a functional fibre connection, thus improving the reliability of the network.

Metro-Core Optical Network Technologies

Metro-core networks should be able to scale to a capacity of several Pbps, and core network node architectures to reach hundreds of Tbps. As a result of the deployment of deep reach access, traffic demands at edge aggregation nodes will add to tens or hundreds of Tbps, which will aggregate into several Pbps traffic load across the backbone network, and into core transit node throughputs at the order of hundreds of Tbps.

Considering these demands, ultra-high bit-rate transmission (0.4 to 1 Tbps) is becoming a central issue for research. The challenge is to leverage on new optical fibre and amplifier technologies, and in particular characteristics such as low loss (or, even better, zero effective loss), low non-linearity, extended band amplification, phase sensitive amplification and regeneration, simultaneous processing (such as wavelength conversion) over a large number of signal carriers in order to optimise transmission bitrates, capacity and distance based on advanced transmission formats.

Overall, a network carrying such capacity should be as power efficient as possible, and therefore strategies for minimising the “cost” of processing in the data path is important. This is likely to entail removing electronic routing for most of the traffic. To make this feasible, dynamics should be provided at the optical layer, in the form of multi-granular optical routers that can transparently and adaptively support port rates of up to 1 Tbps, and can dynamically switch optical timeslot, packets, bursts, wavelengths and wavebands together in one optical switching fabric. It is particularly important to provide flexible and scalable solutions in boththe switching dimensionality and the bit rate and throughput. A main research focus should be the design of modular, flexible and scalable optical routers that can be deployed in the metro-core network in order to guarantee end-to-end transparency and service delivery, and support much higher rates and throughput than electronic routers alone. The work should consider traffic (i.e., where in the network and what traffic dynamics will appear?), energy consumption and QoS requirements. Further advanced functions should include contention management, in order to achieve a virtually lossless end-to-end packet performance, and unicast and multicast functions (using replication at the optical layer). Timing and synchronisation for real time applications (flows) are very important, and the capability to achieve this optically at very high rates should be considered. A fundamental rethinking of what constitutes an optical router and its architectures is now possible, due to a number of enabling technologies.

Additionally further research should address new control plane architectures enabling: scalability for multi-domain and multi-technology scenarios; automated end-to-end service provisioning, and monitoring between different network segments and operators; network resources optimisation, by an integrated control of different network technologies (e.g., wireless and optics); virtualisation of the network infrastructure; convergence of analogue and digital communications, and unification of heterogeneous technologies; unified OAM mechanisms, able to operate in a complex environment (multi-technology, multi-domain and multi-carrier behaviour). A new service plane should be developed for: composition of wireless and optical networks, to create virtual infrastructures as a service; on-demand provisioning services with advance re-planning functionalities; co-advertisement, co-planning and co-provisioning of network connectivity(i.e., connectivity resources at the end-points coordinated in a single, optimal procedure) and an enhanced traffic engineering framework for energy consumption, in support of energy-efficiency.

Topology Control Techniques

Novel solutions call also for developing advanced approaches, allowing dynamic changes in network architectures as a function or in response to a number of measured or estimated parameters. A typical example of this is topology control. At the access network, in particular, novel and reconfigurable architectural concepts for distributed antennas implemented with RoF technology should be investigated. As a large number of RoF branches will be eventually involved, branches could be dynamically switched on and off depending on, e.g., traffic requirements in certain areas. Such a concept would have a positive impact on the overall power consumption of the network. Other requirements besides the energy efficiency maximisation could be diversity and interference management.

Advanced architectures are also needed, in order to provide increased reliability. This can be realised by exploiting redundancy (diversity) in different ways. Redundancy at the network architecture level is one of the most effective approaches to increase reliability. However, redundancy adds to complexity, cost and power consumption; one interesting approach would be to find engineering compromises and trade-offs between them. Rapidly deployable access networks based on RoF is another research area to be considered. Such approaches are highly valuable in situations where natural catastrophes take place. In addition to quick deployability, another desired characteristic is low cost and reliability.

4.2.5 Wireless Optics

Wireless optics is a very rich and diverse area of research, with an increasing role in future communication networks. Roughly speaking, it can be classified into outdoor and indoor wireless optics. Each of these categories has different approaches and techniques, with very particular technical solutions. An example of outdoor optical wireless communications is free-space optical links. Both terrestrial and space applications are currently considered and widely studied. Whenever a cost effective very-high data rate and rapidly deployable point-to-point communication link is needed in an urban environment, free-space optics is one of the best available options.

Indoor wireless optical communications include a large array of possibilities, well-established and standardised techniques in some cases, and new concepts being currently developed. Examples include IrDA, diffuse and directional infrared communications, as well as diffuse visible light communications. Diffuse schemes are very competitive systems for home networking. Particularly, visible light communications is emerging as a very attractive solution. Indeed, the ever important need for improving energy efficiency has led to consider solid-state sources (e.g., LED) for indoor illumination, instead of the traditional light sources. At the same time, it is possible to modulate these semiconductor-based devices with data information that can be broadcasted, or sent in a unicast/multicast manner to users in the room.

In the context of femto-cells, RoF can also be used to improve indoor coverage and capacity. The in-home device acts as a bidirectional wireless-to-cable adapter that guarantees the femto-cell RF signals to be transferred to/from antennas from/to the remote macro-cell base stations, exploiting telephone wires or optical fibres connectivity in place of the digital link as for xDSL. In the long term, the FTTH paradigm would provide the ideal cabling situation for femto-cells. The concept of distributed antennas can be also implemented within femto-cells, to extend coverage, improve QoS, or create a particularly-shaped service area, among others. In that sense, RoF is perhaps one of the most cost-effective solutions that can be applied for these approaches.

4.3 Technology Roadmap

The roadmap of developments in the area of networks for wireless-optics communications is presented in Table 2.

Table 2 – Technology Roadmap for Networks for the Next Generation of Wireless-Optics Communications.

Timeline	In 5 Years	In 10 Years	Beyond 10 Years
Super Broadband	• 1 Gbps • 20 % FTTH	• 10 Gbps • 50% FTTH	• 100 Gbps • 80% FTTH

Physical layer	• photonic A/D and D/A	• 60% of electronic components converted to optical	• 80-90% of electronic components converted to optical
Cognitive RoF Protocol	• transparency • power efficient	• optical cognitive • partial optical handover	• fully optical handover
Energy Consumption	• small percentage of electrical components with optical one • sleep mode implementation	• replacing electrical switches and routers with optical • new power optimisation techniques	• replacement of more electrical devices and components with optical ones
Wireless Optics and new air interface (including femto-cells and home networks)	• new wireless air interface • POF utilisation	• new wireless and optical wireless air interfaces • improvement in POF utilisation	• fully use of POF • integration of wireless and optical wireless

4.4 Conclusions and Recommendations

The implementation of the roadmap requires a few important steps, i.e.:

- Standardisation: a key aspect, in particular in the field of network control plane, and encompassing the implementation of network prototypes, comprising the innovative data and control plane solutions, in particular pre-commercial software (control plane, network-service interworking, etc.), and hardware prototypes (sub wavelength switching, multi granular nodes, etc.).
- Industrial exploitation: accelerated uptake of the next generation of network and service infrastructures, enabling increased access capacity and flexibility, as well as cost and power consumption minimisation for intensive bandwidth consuming applications and cloud services.
- Definition of next generation business models, and consolidation of a generic reference model under a bottom-up approach.

The following recommendations for successfully setting up joint research initiatives are put forward:

R10) Convergence of wireless and optical networks, such as the physical layer RoF, fully-optical signal processing, cognitive RoF protocols for dynamic traffic routing, channel and spectrum allocations, solutions to reduce energy consumption, and power saving should be investigated to allow the optimal useof the network.

R11) Converged access networks capable of interconnecting orders of magnitude higher number of users with a symmetrical or asymmetrical bandwidth over long distances bridging the barrier between access and core. Identification of the ultimate limits of capacity and reach of wireless-wired technologies in providing network solutions.

R12) A fundamental rethinking of what constitutes an optical router and its architectures: optical routers providing flexible multi-granular and scalable solutions in switching dimensionality, as well as in bit rate and throughput, and transparently and adaptively support port rates of up to 1 Tbps. By using the corresponding photonic system, the power consumption of the network will decrease remarkably, while the processing speed and allocated channels bandwidth will significantly increase.

R13) Dynamically wavelength and channel allocation throughout the network, increasingnetwork throughput and decreasing service cost, as well as providing better spectral efficiency and lower power consumption.

R14) Development of new wireless air interface and optical wireless, to cope with the high data rate at home and in building applications.

Architectures and Management of Future Networks

5

5. Architectures and Management of Future Networks

5.1 Rationale

The continuous and fast evolution of technologies, as well as user requirements, drive the research community to revisit new concepts and paradigms that need to be addressed in the following 5 to 10 years. The final aim is to come with a flexible, scalable and robust end-to-end smart integrated network, which is able to cope with the requirements imposed by both fixed and wireless accesses infrastructures. A non-exhaustive list of such requirements as well as its rationale in terms of market, social and technology drivers is described below.

Concerning new architectures capable of evolution and support for integrated services; there are several aspects to take into account regarding Future Networks (FNs):

- *Interworking*: FNs are represented by the interconnection and interoperations of several heterogeneous and dynamic networks sharing their virtualised resources. Resources, such as processing, storage and all communication resources of multiple domains and networks, are available to all networks for aggregation and combining to support the provision of any service in a simple and pervasive manner. FNs encompass all levels of provisioning, operation, interoperability and interfaces for enhanced manageability, for diverse services and for optimal access and usage of shared resources.
- *Service Access:* FNs should offer unrestrictive access to different service providers. FNs should provide to service providers qualified access mechanisms to a set of network embedded resource-facing services, providing scalable, self-managed inexpensive networking infrastructures on demand.
- *Service Provisioning:* FNs can provide services of any complexity. FNs should support the complete lifecycle of services that can be primarily constructed by recombining existing elements in new and creative ways.
- *Network Empowerment:* Distinguishing characteristics of FNs are the existence of cognisance in several domains: service, content, knowledge, environment, energy, economic, and social.
- *Software Defined Networking:* FNs should support the following design goals as software defined and driven objectives, which are differentiating

FNs from existing networks: functional programmability and elasticity; integrated virtualisation of connectivity, storage, processing and smart objects resources; and in-network management.

The fundamental difference between FNs and Next Generation Networks (NGNs) is the switch from a packet-based approach, such as those using Internet Protocol (IP) with a separate transport and service strata in NGNs, to a service- and management-aware packet network, which is based on shared virtualised resources in form of processing, storage, smart objects and communication resources. These features of FNs are shown in Figure 14.

Upcoming mobile networks are characterised by the convergence between fixed and mobile networks, and the convergence of heterogeneous wireless access technologies (multi-RATs). Furthermore, in the future, networks will be extended and complemented by users themselves. Multi-RAT networks will inexpensively provide user-centric communications, catering a multitude of services to end-users (and machines) with seamless mobility, application and session management, guaranteed QoS and throughput at an order of magnitude higher than current standardised technologies, in order to address the anticipated growth in the number of terminals and traffic capable of handling 1 000 times more traffic than today. Network complexity will thus increase, and so will the complexity and costs of network management. In order to cope with this challenge, future networks need a unified network operation and management of heterogeneous networks (network of networks). Operation costs can be further reduced by enabling remote configuration of network capabilities.

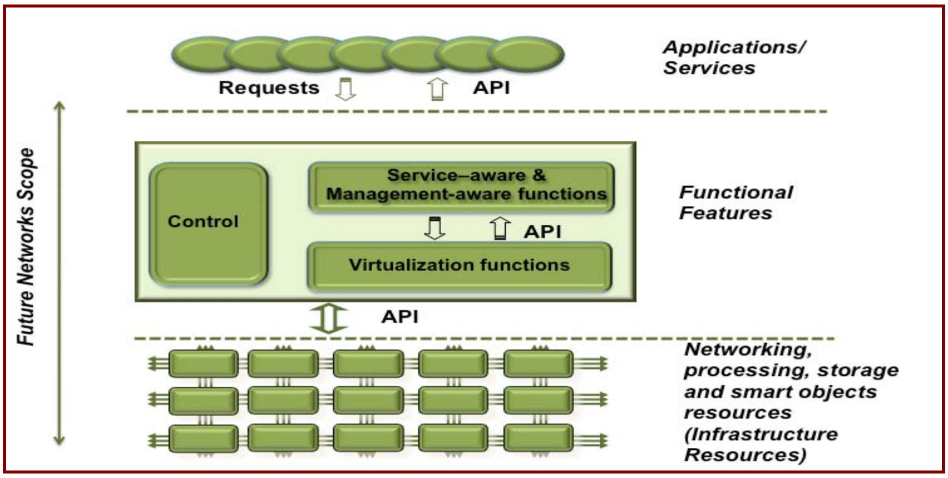

Figure 14 – Key Features in Future Networks.

However, despite the on-going extension and convergence of networks, it can be expected that network resources will not be sufficient to support the expected number of users' increase with broadband services and traffic. Network resources need to be used more intelligently and efficiently. Also, the need to increase energy efficiency calls for an economical usage of network resources, and for new techniques with learning capability in how to dynamically apply available resources in an optimal way. Already on the radio interface, where resources have always been scarce, the benefits of using radio and service context that reflects user's communications needs have been catered through software radio technology. The same idea should be extended to network resources, leading to the requirement for a cognitive (smart) network operation.

Key drivers in this area are: new network architectures capable of evolution and support for integrated services; unified in-bound network management of heterogeneous networks; context-aware and content-aware networking; extensibility, flexibility, scalability, efficiency and robustness; efficient support of large number of M2M communications; effective and optimised support for large number of complex services; and energy efficiency and green considerations.

5.2 Research Priorities

Based on the identified requirements and key drivers described above, the following is the description of several strategically important research topics for the realisation of Future Networks.

5.2.1 Cognitive Network Operation towards a SMART System Paradigm

Traditional network management is generally statically configured, e.g., a network is dimensioned for peak load, and a fixed set of parameters is being monitored. Decisions on changing the network configuration are typically made by a human administrator. More recent developments, such as SONs in 3GPP, have paved the way for a more local and autonomous management paradigm. CR applies the idea of self-organising to air-interface and generally aims at enabling spectrum sharing. Cognitive Network Operation (CNO)is extending the self-organisation techniques used for radio access sub-system to include the entire network with knowledge representation, automated reasoning and learning.CNO encompasses adaptive mapping of a user's requirements, preferences, context, and situation, onto an offered service considering the service provider's resource assignment, and other strategies and policies. This requires techniques for real-time monitoring and control of situation and context of the network, and its resource status. The autonomous decision-making aims at optimising network performance, based on a pre-defined objective function, and allocation of resources is carried out considering current and short-term resource usage and assignment policies. The overall aim is continuous and dynamic optimisation of system performance, and efficient use of all resources. The CNO evaluates the effect of the taken decision and learns how to improve its future actions, thereby realising self-adaptive operations and control.

Knowledge modelling and management is seen as one cornerstone solution to support operating the network from a single point of administration, since it will be necessary to bring together business and service requirements with the operational experience in network and resource management. From an operators' perspective, a service- and business-driven management will be transparent and independent regarding the underlying network infrastructure, domains, and resources, to hide the network complexity from the operators' perspective. However, it will be necessary to address requirements coming from the network and the users (e.g., on the required performance), and to map these requirements onto the available resources within the network domains (e.g., used access technology, and core/transport capacity). For this purpose, an intelligent end-to-end traffic steering that spans all network parts required by dedicated service and user will be necessary, providing a single interface towards the network operator, for defining rules and policies that autonomously set up and control the requested network services.

The benefits of CNO include a more cost-efficient network operation, and an increase of resource usage efficiency. In addition, CNO has the potential of creating a new market, e.g., based on "cognitive services", that can be added to network management in real-time, or on-demand, with automatic extension and shrinking of network resources.

As CNO reduces the overall costs associated with network capital, operation and administration, it makes provision of broadband services to remote areas, such as rural ones, an economic viability. Thus, it fosters the participation of all Europeans in the digital market/economy, and addresses one of the challenges identified in the EU Digital Agenda [EuCo10a].

The technology addresses the following requirements:

- Unified network management of heterogeneous networks, and managing complexity. As network complexity increases, so do complexity and costs of network management and service provision. Static configuration is increasingly sub-optimal and manual operation is too difficult and prone to human errors. CNO reduces the need for human configuration and intervention, by delegating certain tasks to be solved intelligently by the network.

- Flexibility, scalability, efficiency and robustness (intelligent and controllable). As an autonomously working system, a CNO is able to satisfy these requirements more easily than traditional static/human management. Recent studies on cognitive systems have proved their scalability. Furthermore, the system is able to evaluate and adapt its decisions, thereby improving its resource efficiency and robustness during operation. It also providesnecessary hooks for control and intervention by a human administrator.
- Context-aware networking. The monitoring and reassignment of resources in CNO is situation-driven and having additional precise information about the service and its user could bring further advantages for both the network operator as well as the end user. Adjusting and optimising the network operation according to the characteristics and demands of the service, while taking user profile information and preferences into account opens up new possibilities fornetwork management or even the introduction of new services.
- The basis for any SMART system, especially in the case of CNO, is a situation- and real-time monitoring and reporting solution, which provides the decision entities with up-to-date information about the status of the network and its associated resources. Consequently, an advanced monitoring and information processing system is the natural starting point for the technology roadmap.
- Having available a sufficiently accurate view of a network situation provides the necessary capabilities for autonomous decision-making and optimisation process. In general, the increase of resource usage efficiency is under focus, but a huge variety of possibilities to achieve this exists.
- Considering the heterogeneity of future networks and emerging business driven strategies, such as infrastructure sharing, network virtualisation isan important enabling technology. It also facilitates flexibility in new services introduction and deployment, whilst helps inhiding technical complexity and inter-operability between heterogeneous networks.

In parallel, the focus of CNO can shift from optimising resource usage efficiency towards a context aware networking, where the traffic is steered primarily according to service and user demands. The monitoring system evolves to a context-aware knowledge system able to draw conclusions, by combining various networks, service and user related information.

5.2.2 Store-forwarding, Push and Pull

The proliferation of affordable mobile devices, along with an explosion in the creation of mobile content and delivery services, has pushed mobile computing to the forefront of thinking when it comes to the future of networks. The dramatic increase in mobile traffic seen in the last few years has highlighted the known concerns facing the existing Internet protocols, such as TCP/IP. The inefficiencies of said protocols lie in their design and the requirements for networks that the designers had in mind during the 1970s when developing them, in terms of usage and technological constraints.

The ways in which people use networks are changing, from being fixed and rigid routines to flexible and diverse in nature. Expectations are changing, as more devices, such as smart phones, make it easier to access networks from places never envisaged. This has created a new paradigm shift away from source-to-destination fixed structure networking, based on the “end-to-end principle”, towards mobile devices switching from one network to another, in order to always stay best connected. A prime example of the latter is the TCP model, which has served networks well for the last 30 years. However, due to the recent advances in mobile communications, severe limitations of the technology when dealing with intermittent and unreliable wireless connections are now becoming apparent. The pitfalls of TCP are further personified when considering the current content distribution model of TCP, being point-to-point, where the dominating trend from content providers is in providing content suitable for dissemination in a more point-to-multipoint fashion.

The cost of computing devices and their components, such as memory (dropped by 6-7 orders of magnitude since initial Internet design), along with the increase in power of CPUs and the increasing link capacity of networks, argue for a clean-slate approach when considering the redesign of the traditional end-to-end networking model. Such a model should take the factors mentioned above into consideration, such as requirements for large-scale mobile networks and content dissemination, along with the increasing power and capabilities of networking devices and end users.

The requirements call for a new network architecture, possibly based on the concept of store-and-forward, and exploiting push and pull models for services and applications where applicable, in order to increase the reliability and efficiency of the network. Such network architectures can exploit the rapid increase in storage and computing power seen in today’s devices, to specifically target the mobile content delivery problem when faced with large-scale mobile networks and the increasing demands of mobile users.

One of the key enablers in these architectures is to facilitate opportunistic transport on a hop-by-hop basis, rather than focusing on a single end-to-end data stream as in TCP/IP. An architecture like this requires the storage of large amounts of content in-network as it is transmitted through the network, which enables the use of content caching throughout the network, increasing efficiency and speed. Content caching itself can be seen as an additional service of the network, which can be searched, archived, and updated in real-time. Another feature facilitated by using such architecture is context aware routing, whereby data is routed based on the availability of storage opportunities in the case where end-to-end connectivity is temporarily unavailable. Traditionally services, such as the aforementioned, would require overlays operating on the upper layers; however, in future networks these services could be considered as basic network capabilities.

Transactions on networks today can mostly be considered as "pull"; by this, in the majority of the cases, the party that initiates the transaction is the one seeking the data to be consumed. A new architecture based on both push and pull transactions would be able to transmit content, even to an offline user when connectivity is unavailable. When the user regains connectivity, the content would then be pushed to the device, enabling seamless handovers regardless of the underlying protocols.

5.2.3 Network Virtualisation

Current physical infrastructures are constrained by the amount of resources that they have to deal with; however, this cannot be a constraint anymore. They have to be composed of heterogeneous set of resources that allow the delivery of any type of services between different nodes. Resources like network elements, connectivity, storage and computation are those that take part as core elements of the physical substrate. The challenge however, is on the level of flexibility, optimisation and transparency to deliver the service. No matter what the infrastructure is, it would be homogeneously controlled and managed to deliver any requested service. Virtualisation would overcome the multilayer and current network segmentation, bringing the envisaged flexibility and transparency for the network infrastructures.

Although many virtualisation technologies exist for storage and computational resources, an optimum virtualisation framework for the network infrastructure and for the integrated computation, storage and network infrastructure is not yet available. This framework should provide the capability to virtualise the physical network infrastructure, federate resources from different parties, and provide the needed open interfaces, APIs and SDKs, to allow that control and management planes deliver any type of service, independently of whether the physical substrate is analogue (fix and radio) or digital based. Virtualisation may provide the full capabilities to partition the physical substrate into virtual resources, or create a virtual resource from the aggregation of physical and virtual resources too. In fact, partitioning is the lowest level of virtualisation, since aggregation would be realised by composing already partitioned or virtual resources. The main feature behind virtualisation is isolation: all the virtual resources must be isolated from each other, because they will be concurrently managed and operated, and will share the same physical substrate. In that sense, virtual infrastructures will consist of a dynamic composition, interconnection and allocation of these virtual or physical resources. Additionally, these virtual infrastructures will offer their infrastructure capabilities as a service to third entities or control/management planes.

Actually, virtualisation will have a larger impact in networking, which is not restricted to the physical substrate. Its flexibility will allow and facilitate the deployment of new services at the control and management planes (higher layers), with new type of open interfaces, business models and relationships between entities. Moreover, the dynamically deployment of virtual infrastructures will allow creating customised virtual infrastructures for new cloud applications.

5.2.4 In-bound Cognitive Network Management

Network operators running different kinds of access, core, transport and service technologies, and networks, experience a considerable effort in applying their service and business requirements to the network and element management systems of the different network domains.

In-bound management or in-network management approach supports management operations by the means of a highly distributed architecture, where the management functions are located inor close to the managed network and service elements, in most of the cases co-located on the same nodes. The benefit of the resulting distributed network architecture is the inherent support for self-management features, integral automation and autonomic capabilities, easier use of management tools, and empowering the network with inbuilt cognition and intelligence. Additional benefits include reduction in the amount of external management interactions, which is key to the minimisation of manual interaction and the sustaining of manageability of large networked systems, and moving from a managed object paradigm to one of management by objective.

The out-of-bound management operations, the current network management approach, is based on management functions typically residing outside the network in management stations and servers, which interact with network elements and devices via network protocols, in order to execute management tasks. Most of these tasks are performed on a per-device basis. During network operation, for instance, a management station periodically polls individual devices in its domain for the values of local variables, such as devices counters or performance parameters. These variables are then processed on the management station to compute an estimate of a network-wide state, which is analysed and acted upon by management applications. This paradigm of interaction between the management system and managed system underlies traditional management frameworks and protocols.

The development of in-bound management operations should be realised along a number of dimensions, as follows:

- *Degree of embedment*: Management functions and operation are realised as external, separated, integrated, or inherent management capabilities of the networks or services. External management operations include traditional network management paradigms widely used today. Separated management operations are those that are more decoupled from the service, and include, e.g., weakly distributed management approaches. Integrated operation designates visible and modular management capabilities, but that are closely related to and integrated with specific services. Inherent management functionality is located with the managed functionality in the same network nodes.
- *Degree of automation from manual to fully automatic processes and operations*: Manual management operations refer to the direct manual manipulation of management parameters, such as manual routing configurations. Automated management operations can be typically found in the application of management scripts.
- *Degree of autonomicity*: It includes levels of intelligence and cognition that allow the system to govern its own behaviour, in terms of network and service management.
- *Degree of orchestration*: It allows cooperation and interworking of closed control loops specific to different management functions and operations.
- *Degree of extensibility*: It refers to the ability to extend a system and the level of effort and complexity required to realise an extension. Extensions can be thought as the addition of new functionalities, new characteristics, or modification of existing functionalities and characteristics, while minimisingthe impact to existing system functions; the degree of extensibility covers Plug_and_Play/Unplug_and_Play approaches, on demand deployment of management functionality, and dynamic programmability of management functions.

- *Degree of abstraction*:This could include different levels of management according to the Telecommunications Management Network (TMN) functional hierarchy and/or logical networks. Logical networks abstract the complexity of the underlying infrastructure, where multiple logical networks can co-exist above the same physical substrate infrastructure. They can take the form of virtual private networks, active and programmable networks, overlay networks, virtual networks, and service computing clouds.

5.3 Technology Roadmap

The roadmap of developments in the area of architectures and management of future networks is presented in Table 3.

Table 3 – Technology Roadmap for Architectures and Management of Future Networks.

Timeline	In 5 Years	In 10 Years	Beyond 10 Years
Software Defined Networks	• Separate resource virtualisation layers operations and optimisation (connectivity, storage, computation, control resources) • Partial network empowerment (i.e., service -, content-, knowledge-, environmental-, energy-, economic-, and social-cognisance).	• Combined approach of CNO with in-network management. • On-demand network provision and operation. • Integrated virtualisation of all resources – operations, optimisation and usage. • Further network empowerment. • Separate in-bound manageability in all dimensions (embeddiness, automation, autonomicity, extensibility).	• SMART software-defined system services of any complexity and any composition • Full network empowerment integrated in-bound manageability • Combined approach of CNO with in-network management and content centric • Dynamic service aggregation from different providers to
Cognitive network operation	• Monitoring for multi-access and multi-path. • Decision in autonomic and near-real optimisation (centralised vs. distributed).	• Monitoring in knowledge management. • Decision in cognitive, self-learning real time optimisation. • Autonomic adjustment based on application requirements.	

Resource sharing across administrative boundaries: modularisation and network virtualisation	• Optimised infrastructure sharing. • Virtualisation of network functionality as well as of computational, communication, and storage resources in order to deliver cost-efficient operation especially in multi-administrative domain environments.	• Modularisation through the separation of functionality into generic self-contained building blocks to support a variety of business models and regional specifics. • Knowledge based virtualisation of network functionalities as well as of computational, communication, and storage resources in order to deliver cost- and energy-efficient operation especially in multi-administrative domain environments.	create new complex services
Content centric networks	• Content centric optimisation in order to deliver cost- efficient operation especially in multi-administrative domain environments.	• Cognitive content centric optimisation in order to deliver cost- and energy-efficient operation especially in multi-administrative domain environments	

Figure 15portrays an evolution roadmap of fixed and mobile networks, started in 2009 and expected to continue, as a combined effect of new advanced technologies highlighted above, and expected changes in current business models and interfaces.

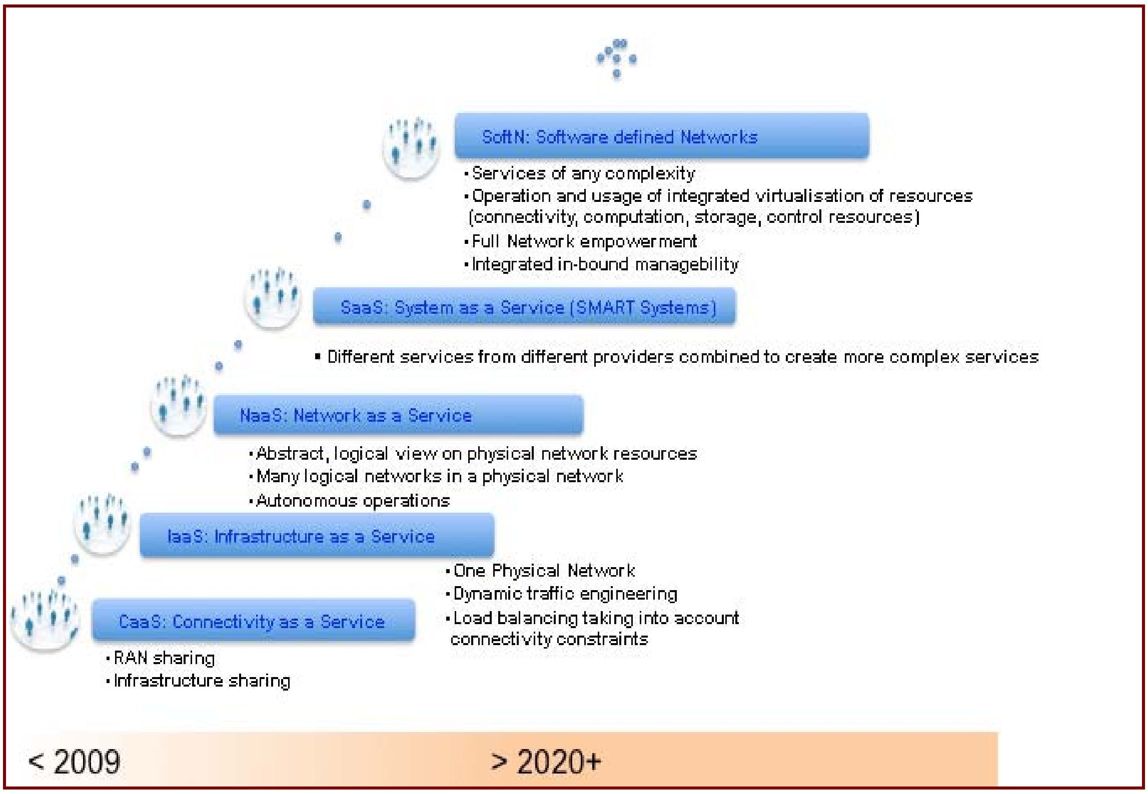

Figure 15 – Networks Evolution Roadmap.

5.4 Conclusions and Recommendations

Future networks architectures and management will be developed according to certain key drivers:

- New network architecture capable of evolution and support for integrated services.
- Unified in-bound network management of heterogeneous networks.
- Context-aware and content-aware networking.
- Extensibility, flexibility, scalability, efficiency and robustness.
- Efficient support of large number of M2M communications.
- Effective and optimised support for large number of complex services.
- Energy efficiency and green considerations.

The following are recommendations for research based on current trends in services/applications and key drivers in the evolution of networks towards future smart software-defined networks.

R15) Definition and design goals of future networks, supporting both clean slates and evolutionary approaches. The latter should aim at sharing and optimising current infrastructure to provide IaaS, NaaS and SaaS, towards a smart software defined network. The core must be universal in terms of efficient support of all access technologies with sufficient intelligence and cognitive features for autonomous yet stable and controllable operation. Energy efficiency should be a design parameter together with flexibility and robustness.

R16) Design of future network architectures, based on software defined architectures, which should address connectivity together with: unification and a higher degree of virtualisation for all infrastructures; software defined and driven objectives; integration concepts enabling better usage of the multi-centric approaches; unification and integration of connectivity, computation, storage and control resources; in-bound manageability; cognitive network operations; full network empowerment, with a multi-cognisance perspective; consideration of large-scale systems integration and deployment.

R17) Future network programmability and elasticity should support the stakeholders' triggered dynamic deployment of new resource-facing and/or new end-used facing services, keeping pace with their rapid growth and change. The architectures should optimise capacity of network equipment, based on service requirement and user demand, taking the various physical limitations of network equipment into account.

R18) Integrated virtualisation of connectivity, storage, processing and control, supporting the dynamical partitioning of physical resources, the management of virtual and physical resources through open interfaces, the dynamic movement of logical network elements (e.g. virtual machines representing service components or virtual routers or virtual objects), and the creation of different networks on top of such integrated virtualisation layer without interfering with the operation of each other. The validation should be done in terms of on-the-fly creation, deployment, management and run of new services on shared physical infrastructures.

R19) In-bound cognitive management should be addressed as well, so that future network will be able to process massive amounts of management information efficiently and effectively transform such data into relevant knowledge for business. In addition all network functionality needs to be managed with ever increased automation and autonomicity, allowing for the network operator input as far the business and governance goals are concerns.Priority should be given to management systems covering multifaceted integration of embedness, automation, autonomicity, cognition, control orchestration and extensibility, empowering the network with inbuilt cognition and intelligence and manageability by objectives.

Networks as National Critical Infrastructures

6

6. Networks as National Critical Infrastructures

6.1 Rationale

"Critical infrastructure" is a term used by governments to describe assets and functions that are fundamental for the society and economy to operate. The assets and functions that compose the critical infrastructures [EoCo10e], [EuCo06],Figure 16, are: energy and electricity generation and networks; water (drinking water, waste water/sewage, stemming of surface water); food production and distribution; transportation systems (fuel supply, railway network, airports, harbours, inland shipping); health (hospitals, ambulances); telecommunications and Information and Communication Technologies (ICT); government, financial and security services.

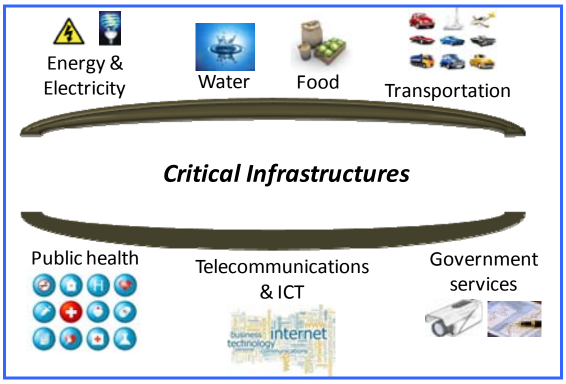

Figure 16 –Critical infrastructures as currently identified (extracted from [EuCo06]).

The global Internet has more than 2.25 billion users globally (as of Dec. 2011) [InWS12], Figure 17.

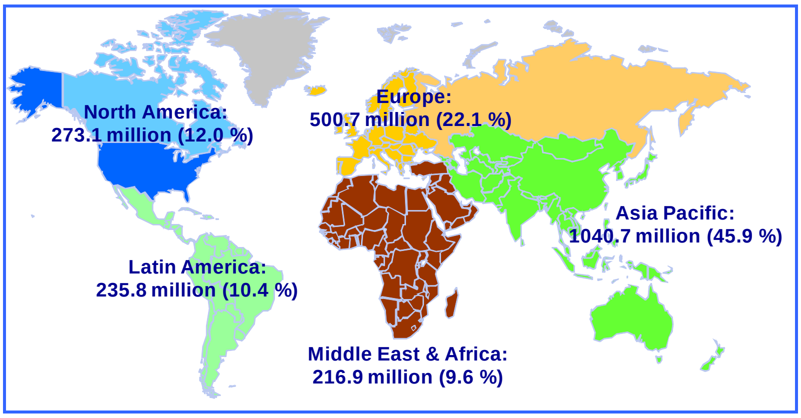

Figure 17 – Worldwide Internet audience (extracted from [InWS12]).

Each of the infrastructures mentioned above plays an important role in preserving a balanced operation of a country. ICT is now part of any country's National Critical Infrastructure, and its importance is growing even more as it is the transformative technology in the modernisation of other national critical infrastructures. ICT is the pillar for other national critical infrastructures in the form of acting as control and transport planes for the aging energy networks, transportation systems, health services, and greener environments. In the environment, it is widely reported that ICT is responsible for 3% of CO2 footprint; however, ICT can help in minimising the other 97% generated by other industries. These are only a few societal challenges amongst many others that Europe is facing.

ICT, in addition to providing quality of life to citizens, will continue to be a key driver to the future economy growth in Europe. According to Bitkom [Bitk12], the worldwide ICT market volume increased in 2010 by nearly 5% to about € 2 500 Billion. The biggest ICT market is the USA one, with a market share of 28.7%, Figure 18; for example, Germany, with a 5.1% global market share, is number four after the USA, Japan and China.

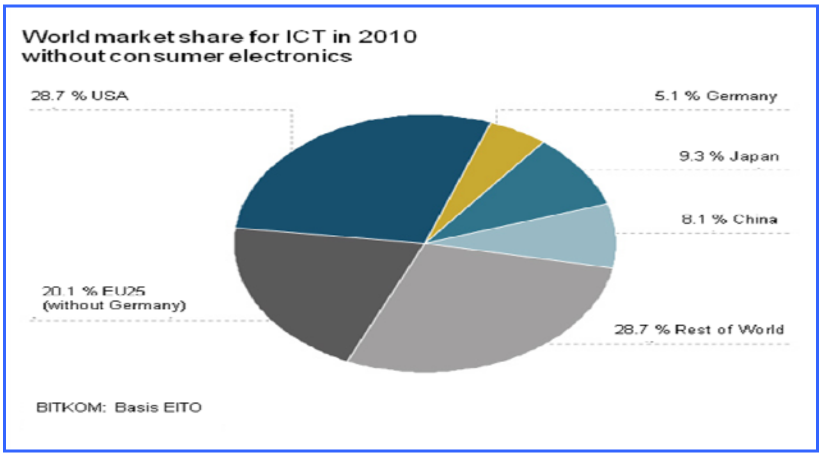

Figure 18 – World market share for ICT in 2010, without consumer electronics (extracted from [Bitk12]).

However, ICT, and in particular broadband mobile networks, is facing new challenges,which if not addressed sufficiently soon enough can have major implications on both our society's quality of life and businesses. It is widely believed that the mobile traffic is doubling every year, and that by 2020 mobile data traffic alone will be 1 000 times the one in 2010; if traffic growth continues at the same pace, in 2030 mobile data traffic will be 1 000 000 times the one in 2010. Such unprecedented increase in mobile data traffic is strongly supported by many in industry, and in particular by Cisco's study [Cisc12], Figure 19.

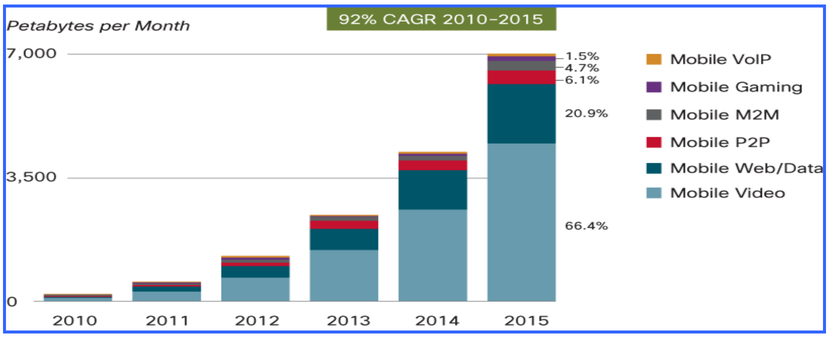

Figure 19 – Increase of mobile data traffic for different applications (extracted from [Cisc12]).

This rate of growth clearly indicates the tremendous increase in mobile communications usage, and therefore it will be a major stimulus in the socio-economy growth dynamics in the upcoming years. Moreover, the extensions of service variety, diverse service mix, user density, and data security, are also important drivers that must be considered for future broadband network research, in order to meet the continuously evolving needs of users, and requirements from other national critical infrastructures. Furthermore, Figure 20, laptops and net-books will continue to generate a disproportionate amount of traffic, and new device categories, such as tablets and Machine-to-Machine (M2M) nodes, will begin to account for a more significant portion of the traffic by 2016 [Cisc12].

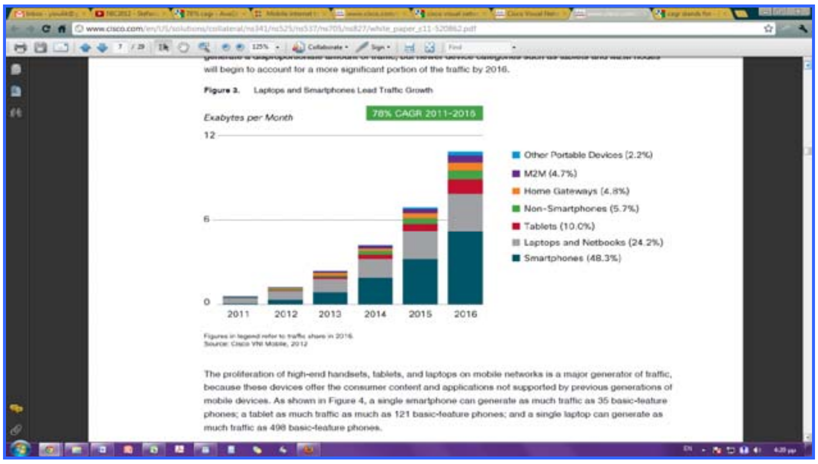

Figure 20 – Updated data traffic for different devices, percentage of sharing referring to 2016 (extracted from [Cisc12]).

It is clear that the demands placed on communications networks are constantly increasing. The growth in the number of new applications running on the networks shows no sign of slowing and, on the contrary, it is accelerating as ever more mobile devices become the preferred device for Internet access for both people and machines. The use of networks to connect machines to the Internet is still in its infancy. Projections suggest that expected rapid growth in the generation of network traffic will be driven by the increasing use of video for communications and the use of networks for M2M communications. New applications are placing new technical demands on the network. Whereas in the past increasing the transmission capacity of the networks was the focus of research, new applications mean that reducing the latency of networks, increasing their energy efficiency, improving utilisation of spectrum, and the scalability and stability of networks, are the requirements that future research and innovation must address. ICT networks will be the control and transport plane of other National Critical Infrastructures, such as: health and tele-care systems, eGovernment, transport systems, energy systems, and environmental monitoring systems.

All these matters present many new challenges to the entire business chain in the communications and networking industry.

6.2 Research priorities

LE3S Concept for Future Networks

All the research priorities can be captured in **LE3S concept** that promotes low **L**atency, **E**nergy efficiency, **S**pectral efficiency, **S**calability and **S**tability in future network research.

- The most important requirement from other National Critical Infrastructures is high availability and robustness, much higher than that normally required in communication network designs of usually 99.9% (three 9s). New networking technologies must be developed to ensure high information integrity, network and service **reliability and availability** of more than five 9s, and resilience to potential cyber security threats.
- Optical network technologies will need further development, as fibre-optic systems now also start approaching Shannon’s limit. New research is needed to increase fibre capacity to more than 100 Tbps in the core, 10 Tbps in the metro, and 1 Tbps in the **access/backhaul** network, and to provide a dynamic software and control environment around this. A flexible optical spectrum approach, programmable transceivers and switching nodes, and the use of multiple wavelength bands will be prerequisites for these targets, whilst still leaving them challenging to achieve. With increasing wireless capacities and smaller cell sites, a close **wireless-optical** integration and operation will be crucial to adaptively optimise end-user experience over a fibre-constrained backhaul-infrastructure.
- **Data and content delivery** need further research in order to ensure that they meet the needs of users. Research on the issues of intelligent

data handling and delivery based on user preferences, and user, device, radio and network contexts offers potential solutions to the challenges.

- There has been many research work worldwide reported on definition and classification of context. However, there is no or little evidence on mechanisms to capture, classify and utilise such information, and how it can be implemented and used in improving a network performance, or in efficient delivery of personalised services. With the increasing deployment of Machine-to-Machine (M2M), and generally Internet of Things (IoT), it is time to start a research on technologies and mechanisms for capturing various **context** information, whether it is user's, device's, environment's, network's or so on, and demonstrate their utilisation effectiveness in intelligent service provisioning, and overall performance improvements in network assets management. Research is required on scalable and efficient networking between IoT nodes, and how such infrastructure-less networks can work with a communication network, Internet and a user device, in a secure, reliable and seamless manner. Another important area of network research is use of context information and their integration technologies for dynamic network resources virtualisation and fast/autonomous network management of resources, service quality and management of self-recovery and healing.
- ICT networks, telecoms and content delivery have still to consider important challenges as **trust and privacy**. As more and more means, like electronic signature and digital identity, will or are already a basic service to be offered to citizens, reinforcing business dynamicity and growth, trust and related technologies are essential to support such growth of services and traffic.
- The convergence between different National Critical Infrastructures is also a need that requires attention.

Emergency Network

Current communication architectures are highly vulnerable to major man-made and natural disasters. For instance, Public Protection Disaster Relief (PPDR) or emergency communications are considered part of ICT critical national infrastructures. Discussions about emergency communications usually diverge into discussions about most prominent catastrophes and terrorist attacks, and emergency services personnel (i.e., police, hospitals, fire brigades, etc.). So far, private citizens are not addressed in such situations, which is often a major issue when commercial networks are no longer available due to collapse of the infrastructure (e.g., electricity cuts or broken mobile network). For this, it is important to define an appropriate crisis handling management system for both public and private users. In such situations, private handheld devices can be effectively used to form rapidly an ad-hoc network infrastructure during such incidents, to create connectivity between people, as well as help in improving the coverage of public authorities' network. Although the target is to provide a system concept for crisis management, as well as critical infrastructure control, the same concepts and solutions may lend themself to other usages and applications. For example, in providing normal communication needs cost effectively to the areas where the basic network infrastructure is non-existent, such as remote locations and areas with low-dense population, and/or in emerging markets where telecom infrastructures do not exist.

This future rapid-deployable network needs to have the capability to support basic communication services (e.g., telephony and narrow band data services), mechanisms to prevent or reduce the impact of disasters (early warning systems), aid in rescue operations, and finally ease the recovery from disasters.

6.3 Conclusions and Recommendations

There is justification for consideration of the Information and Communication Technologies and Networks as the most important critical infrastructure and asset of a nation. Dependency of other national critical infrastructures on ICT infrastructures and technologies will increase over time. ICT is considered as the main enabling technology in helping to modernise, achieve higher efficiencies and provide connectivity in other critical infrastructure in addressing the societal challenges. It is also regarded as the main stimulus of ailing economy in Europe through creating a fully connected digital economy and society. Following this logic, a number of research areas are identified in tackling the challenges that ICT and more specifically broadband mobile communication networks are facing. Addressing these important research areas will ensure sustainability and growth of mobile broadband networks beyond 2020. Furthermore, some research areas are based on common and dominant requirements of other critical infrastructures.

Additionally, it is proposed for Europe to start activity on specification and research into a highly robust, resilient and rapidly deployable emergency network.

The following are recommendations for research concerning ICT networks as national critical infrastructures.

R20) Initiate activity on definition, specification and development of emergency networks.

R21) Develop technologies in capturing of context information in general sense, and demonstrate the effectiveness of context information in autonomous management of network resources, self-healing/optimisation and intelligent delivery of personalised services.

R22) Prioritise network research based on L3S concept.

R23) One should not be complacent that "connectivity is just there". One should ensure that appropriate fund is set aside for collaborative research on the huge challenges that mobile broadband Internet is facing.

Networks for Cloud Computing and Service Platforms

7

7. Network for Cloud Computing and Service Platform

7.1 Rationale

Cloud Computing (CC) is the technological revolution of this decade, similar to, and on equal level with, previous technology disruptions like the personal computer, the Internet, the Web, mobile communications, social networks, and many other phenomena in the digital era.

Meanwhile, pioneering companies like Amazon, IBM, HP, Intel, Rackspace, and Microsoft, but also SAP, T-Systems, Alcatel-Lucent, CloudSigma, RightScale, RedHat, and many others across the whole ICT domain, maintain sizable ventures on top of the CC promise, which is more based on flexible and cost efficient resources (software and hardware) availability and consumption, based on the “service orientation” paradigm.

Commonly abbreviated as “X-as-a-Service” (“Everything as a Service”), the classical IT-oriented CC model promotes usage of resources as a service, on-demand, case-by-case, on top of abstracted, typically virtualised physical resources, supported by (theoretically) infinite scalability, and commercially exploited by means of usage-based pricing. Amazon’s cloud computing services for instance, one if not *the* pioneering CC product, is providing infrastructure plus platform services precisely along these frontiers and fundamental tenets.

The term “cloud” is to reflect the principle of abstraction. Cloud users are offered reliable and trustworthy services that transparently run somewhere, on top of something, and by someone, and thus relieve the user from any involvement into the required infrastructure, platform, or application services, up to levels deliberately chosen by the consumer itself. Given these principles, the National Institute of Standards and Technology (NIST) in the USA defines CC as “*Cloud Computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.*”, [MeGr11].

Meanwhile CC unfolds such an impact on the entire ICT eco-system that the original IT-oriented definition may not hold for much longer. Instead, the term “Cloud” is taken way beyond resources and services provisioned somewhere in data-centres, but includes potentially any resource accessible via the Internet.

This vision in turn implies far reaching consequences on the entire Internet, especially if the on-demand and elasticity capability of CC is to be applied.

Despite the enormous debates around CC, many companies beyond those pioneers and IT incumbents are still struggling with understanding of its implication on business, or hesitant about adopting it, as it is considered to be too disruptive and daring. A good example, among many, is the telco industry, where there is no clear-cut strategy in regards to CC. All these stem from the fact that CC technology is not well understood.

In this chapter, one looks at CC from the networking and telco angles. It identifies some issues and potential directions, and based on these, it provides a set of recommendations for strategic research initiatives that, if put in place, will support Europe in seizing and sustain a leading position in the future multi-billion Euro CC business.

7.2 Research priorities

Given the regular blur associated with Cloud definitions (see [VRCL09] for an excellent overview), and thus to better clarify the scope in here, Figure 21**Error! Reference source not found.** illustrates the general space that is considered here. From a horizontal perspective, this ranges from devices, over access and aggregation networks, to vertical CC stacks somewhere located in large and distributed data centres.

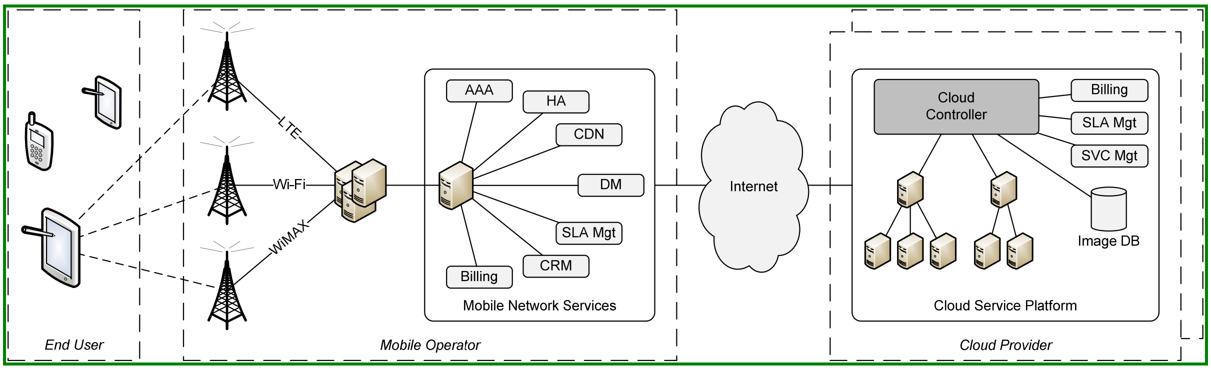

Figure 21 – End-to-end view on current CC with some example RATs (extracted from [VRCL09]).

At this point, the reader should note that albeit the focal point is set on the established notion of CC and networking architectures and technologies, the chapter intentionally leaves additional room for some more futuristic scenarios, where Clouds could morph into something beyond on-demand data centre resources. For example, novel forms of Clouds can be created in different combinations; by proper combination of mobile access networks plus devices to form a distributed ad hoc Cloud of resources offered by accesses, consumers, and devices. Another example could be a combination of mobile networks with one or many data centres, within mobile operator domains. The concept of some kind of ad hoc Cloud, that dynamically associates a set of mobile or sensor devices on-demand and context driven, is discussed and research issues identified hereafter.

Cloud-based Intelligence for Fixed and Mobile Connected Objects

Systems based on so-called Internet Connected Objects will produce very large quantities of information by sensing real world events. This information needs to be stored, processed, analysed, enriched and acted upon. Also, applications need to make sense of it, and privacy of information and trust from end-to-end has to be guaranteed. To that end, communication infrastructures beyond such Clouds have to facilitate the virtualisation and provisioning of applications, platforms and infrastructures as on-demand services over the wide range of Internet domains scale. This will require the enablement of infrastructures and platforms outsourcing/hosting (infrastructure as a service, platform as a service). Furthermore, by sharing virtualised resources, the common Cloud illusion of infinite capacity and high availability need to be properly reflected by the underlying infrastructure, like mobile networks for instance. In contrast to this, resources on small objects, like sensors or even active tags, are very scarce, making both processing and communication tasks expensive and thus efficient, reliable, and service-guaranteed communication with a Cloud could help to load-balance between on-device and Cloud processing.

While these aspects are currently raising awareness of a larger community, and pioneering solutions are under investigation, more research is clearly needed to enable a seamless interaction of established CC frameworks with small-scale computing objects, in other words IoT. One aspect of this is also to bring cloud-style on-demand, scaling, and pay-as-you-go concepts to the edges of the Internet, which in turn will require new communication paradigms, interfaces, management and control protocols. So far there is agreement that Clouds and IoT are a natural combination and clearly justifies the case for the Cloud infrastructure and Cloud Data towards computing objects. Research on new interfaces to intelligently distribute processing tasks and information to and from the cloud in a resource efficient way is a key element in order to achieve this vision. The specific challenge here again stems from the architectural differences of the two domains, taking into account the specific requirements of inter-connected objects, Cloud style architectures, and the requirements on a communication infrastructure in between is important.

Sensors and Sensor Networks as Part of a Cloud Environment

Sensors are particularly important for gathering information from the physical environment as well as enabling a plethora of many applications. With the emergence of the Cloud concept, whether Public, Private or Hybrid infrastructures, the vast amount of data acquired by sensor sources, can now be processed and exploited, and thereby more complex applications can be developed. One particular research challenge inherent to this is consistent addressing. Potentials of 6Lowpan to interconnect sensors to the Internet using IPv6 should be investigated. As the very last IPv4 addresses were assigned in the recent past, migration to IPv6 in the context of IoT and Clouds is important. Besides, although many sensors do not run native IP protocols, IP protocols optimised for resource constrained sensor nodes and networks are important as well as their interconnection using gateways (sometimes called sinks). Gateways are nodes that are deployed at the border between the Internet and sensor networks (or sensor clouds).

Sensors can be represented by appropriate software objects for their integration with each other in a service platform. A standardised software representation is needed for the integration of many proprietary domain models and technologies. Discovery, search, dynamic integration, intelligent re-distribution, replication, and similar problems associated with software objects maintained in distributed service platforms hosted by Cloud environments are still important research challenges. Along these lines, more recently, the concept of virtual sensors was introduced. A virtual sensor can consist of multiple physical sensors, and aggregate the various sensor data received from single physical sensors. Virtual sensors and Cloud style platforms are a natural match, but accepted architectural designs as well as appropriate control and management frameworks are to be specified.

The combination of these aspects requires research in the domain of architectural integration of IoT domains into Cloud environments, or in the case of large autonomous IoT domains the on-demand and potentially ad-hoc creation of IoT-Clouds. Such ad-hoc Clouds are characterised by resource and functional oriented ad-hoc cooperation on communication, compute, and storage level and their autonomous self-management features. Altogether, these trends bring up entirely new research questions in individual technical domains, arbitrary combination, but also on the operations, deployment, and provisioning domain especially related to the business models of telco operators that head towards adopting M2M and IoT as future business cases.

Clouds Services and Proxies for End-Customers

Service management (i.e., controlling and guaranteeing quality of user experience) has been identified by ISPs as the number one problem. It is important enough to motivate a Cloud approach, as such management by a user at home is not a realistic assumption. Monitoring user experience and some network level information can only be effectively carried out at the edges of a network, which requires some intelligence, ideally located in the home gateway (the home gateway can see the home and the Internet). Although monitoring information can be exported to the Cloud, it cannot be measured in the Cloud.

One novel concept, considered to be a crowd approach, is a flexible and managed model to deploy services at homes, where a physical box will combine the functions of the home gateway with the capability of hosting and managing an open portfolio of services. Such a Service Hosting Gateway terminates the network connectivity at home and acts as a Cloud Proxy. The main argument in favour of Cloud-based services is that services can be deployed easily (in data centres), and that there is no need for management or complexity at home. This is true only if the user is accessing all services through a unique device (e.g., TVor monitor) and if it is connected to a single cloud. As soon as the user accesses services on multiple home devices - a PC, a tablet, several TV displays, and home automation and energy control services - the Cloud approach becomes significantly more complex, both at home (where additional complexity is required to manage the different devices) and within the Cloud itself (in order to aggregate home information and direct streams toward the user selected device). The service hosting gateway also helps to control the over-dimensioning factor of the data centres.

For all reasons described above, research should be towards a pure Cloud-based model investigating the concept of service hosting gateway as an essential element in any future scenario of networked-services that terminate in the home. Such research should in particular evaluate the two major roles: aggregate and return monitoring information to the Cloud, in order to control the quality of the services delivered to the user, and host local services that cannot be easily provided from the Cloud, such as home automation and energy management. Aggregating home sensor information from the Cloud is indeed quite difficult (as each sensor needs to be directly addressable from the cloud).

Network-Cloud Interfaces and Infrastructure-as-a-Service Provisioning

With the technologies currently deployed, setting up optical paths is a manual and time consuming procedure. During recent years, various telecom providers started experimenting with on-demand optical network provisioning, as a means of handling dynamic loads as well as strict isolation for differential QoS that modern applications and computing paradigms like CC may require. However, these attempts have not taken consumer requirements (and thus acceptance) into account, and strictly controlled and complex interfaces for relatively simple services prevented commercial success at large.

Now, in the era of CC, where almost everything is offered on demand, state-of-the-art network provisioning is lagging behind. Requiring complex and time consuming negotiations between providers and consumers for inflexible and expensive case-by-case solutions, the static and long-term oriented nature of network setup and provisioning is counter-intuitive/productive, and effectively prevents uptake of true end-to-end Cloud services composed of on-demand storage, computing, networks, and software – also known as Everything-as-a-Service.

Research should address end-to-end user-network-storage-computing interfaces for setting up on-demand optical networks, in accordance to the requirements of Cloud services, Cloud infrastructures, and distributed applications that may run on top of cloud-style systems. Especially in enterprise, data-centre, or similar high-capacity settings, these interfaces should be combined with unified solutions for "Network+IT" (storage, computing, network) resource provisioning and management in order to provide the desired, Cloud-style on-demand, elastic, metered, one-service experience.

However, such interfaces and provisioning approaches require significant extensions to standard networking protocols and intelligence, such as GMPLS, PCE, OSPF-TE, RSVP-TE, traffic engineering, etc., along with a new software stack for integrating network services with the IT virtualisation technologies currently used. Research done in several EU FP7 project,like GEYSERS[GEYS12], 4WARD[4WAR12], SAIL[SAIL12], OFELIA [OFEL12], is already investigating some of these issues, but there are many open research questions left unaddressed, including new Cloud-based communication paradigms, unified service descriptions, Network+IT aware service-level specifications and agreements (SLA/SLS), automatic/autonomous SLA negotiations, QoS translation (from high level application requirements to virtual network and IT resources). Furthermore, authentication, authorisation and accounting in multi-domain, especially vertical and horizontal, scenarios still poses significant challenges.

Network Input-Output Challenges in Virtualised Execution Environments

Different forms of networking virtualisations (VLAN, IPSec, VPN, MPLS, etc.) have been available for years, and are now paralleled by host virtualisation

(Virtual Machines (VMs)). According to Gartner, there will be 58 million VMs deployed in 2012 [Gart09]. As a consequence, operations like packet switching, packet routing, scheduling and admission control, load-balancing, network security, packet inspection, intrusion prevention, and so forth, are no longer carried out in dedicated hardware but move into virtual systems that share a physical host. This change requires control-plane functions, processing, networking and security functions previously tuned to x86 platforms to be handle inside virtualised multi-core platforms. These software pieces are commonly not optimised for network functions like fast packet classification, scheduling, and so forth. Research is needed for networking-and workload-optimised software environments that can bridge the missing link between host/server and network I/O, by fully exploiting virtualisation in order to support data centre grade hosting at rates of 20 Gbps and more per VM.

Network and Traffic Engineering Related to Cloud Computing and Data Centres

The design of existing network architectures in data centres dates back to the mid-1980s, and even earlier. The common approach is to adopt a hierarchical design that scales down from a metro access link, connecting a data centre with one with many more Internet POPs, over first level consolidation and aggregation, to cluster aggregation level, and finally per-rack server aggregation.

This simple top-down design poses many challenges in several scenarios on the network, and thus Cloud platforms closely linked with datacentres. First and foremost, from a traffic load perspective, datacentres suffer from a sizeable bottleneck at cluster aggregation level and given the empirically found 100-400% annual increase in load, 100 G - 1 T optical transport technology is urgently required, [LeeD09].

A second aspect relates to the traffic engineering and logical separation of physical and virtual machines. A common approach to both, but in particular to CC frameworks like Eucalyptus[EuOC11], OpenNebula [ONeb11], OpenStack [OSCF11], and similar, is to segregate networks by means of VPN technology and derivatives. However, this approachmostly provides connectivity isolation only, instead of resource isolation, and one service that dominates a shared link degrades the performance of all other services in the same sub-tree, [GHMP09]. A relevant research topic is therefore a standardised datacentre network virtualisation with full traffic engineering support, which can be seamlessly integrated in existing and future CC control and management frameworks.

VPN-based approaches do not support true on-demand elasticity. While CC provides resources on computing and storage level per-request, the network beneath continues to operate in a pre-provisioned and static manner, which is not in line with the fundamental concept of CC. Another important issue with current networking design is data centre interconnection via the public Internet. CC is characterised by high levels of redundancy and continued data replication across datacentres. This implies that, even for regular and periodic maintenance tasks, huge amounts of data are continuously exchanged between datacentres over the public Internet, and thus datacentres access links. Considering typical Cloud services like MapReduce/Hadoop clusters for massive distributed computing, it becomes apparent that the current configuration results in heavy burdens at particular spots in carrier networks that suffer heavily from uncoordinated interdependencies between traffic engineering at network level, and data replication and computation algorithms at CC service level. Research is thus necessary to establish automated coordination mechanisms among the network, datacentre, and service domains.

Quality of Service and Clouds

One future challenge will be to guarantee and continuously improve customer experience offered by cloud-based services. Such experience relies on the End-to-End QoS, and more generally on respective SLAs in place for a given service. This includes well-known characteristics, such as latency, throughput, availability, and security, but by adopting the principles of Clouds, also elasticity, on-demand availability, lead- and disposal times, multi-tenancy, resilience, recovery, and similar characteristics important especially in case of cloud-based services. However, in order to guarantee this kind of service level, network-based service qualities may not be enough, but need to be aligned with platform-level and Cloud specific tenets, like dynamic discovery, replication, and on-demand sizing of VMs, since previous over-provisioning best-practices inherent to hosted and managed execution environments are no longer applicable.

Different services have different requirements in terms of QoS, and there will be no single Cloud architecture and/or deployment that can meet all these different requirements. In the future, there will be many Cloud-derivatives offering different approaches and levels of QoS support. Moreover, public, private and hybrid clouds and respective infrastructure, platform, and software services are frequently compositions of many components (services) spread across many horizontal and vertical domains (e.g., different provider, network, datacentre, and service-platform domains). This will inevitably result in complex multi-domain scenarios, in which logical Clouds are formed by federating different infrastructure or platform clouds and complex service compositions at application level. Obviously, such a highly-distributed environment requires reliable and capable connectivity and the ultimate customer experience depends on the performance of the overall (composite) service.

In order to meet these multi-faceted and interconnected challenges, future research should address network support for accessing and inter-connecting complex multi-domain Cloud services. In particular the nature of on-demand, distributed, service-oriented, applications run on top of clouds need to be better understood and respective metrics must be defined. Some initial directions would be the autonomous self-optimisation of service orchestrations, based on the traffic matrixes of such multi-service composite applications, and information about the capabilities and status of the underlying connectivity infrastructure. Such research should be supported by exploration of network traffic characteristics generated by multi-service compositions. Especially the aforementioned IoT-Cloud combination may pose novel requirements and high demands on networks by firstly, massive amounts of information exchanged between the IoT domain and one-or many Clouds and secondly, the huge networks that may be very dynamic in nature in particular in the IoT space.

Resource Control in Clouds

Future Cloud architectures in the most general sense need to provide resource management mechanisms and protocols that are flexible, dependable and scalable in order to deal with novel dynamics and characteristics. These dynamics of such Clouds are frequently based on virtual resources that can be heterogeneous, distributed overlarge areas/locations (locally in access networks or overall in the Internet, fixed or mobile, transient) with a very large in number of resources.

The expectations are such that clouds of (virtual) resources will be dynamically composed and instantiated similar to the nature of service-oriented infrastructures and applications. Underlying resource allocations are thus assigned and released on-demand, and therefore require autonomic management and control. This in turn requires mapping of resources to composed Cloud-based services and vice versa, covering virtualisation of all types of physical resources and including hard and software services, using a unified methodology.

Since any virtual set of resources can be aggregated, mapped and assigned to a certain service in a dependable and scalable way across the device, network, compute, and storage domain in arbitrary combinations, resource management and control needs to support different types of resources, such as storage, computing, processing power in grid and utility computing type of setups, network and connectivity resources in access, core, and data centre networks, but also resources on devices ranging from sensors, over (smart)phones, tablets, portables and notebooks, up to PCs and appliances in datacentres. Particular challenges will thus be optimisation (cost versus quality) of resource compounds, support of dependable and scalable means to collect and apply customer profiles, resource characteristic profiling, and tracking of resource utilisation versus expense in order to optimise the resource management process.

Communication Services and Applications on Cloud Platforms

One particular aspect of Cloud Computing from a network and telecom perspective is diverse and rich communication services deployed and operated on top of cloud-based execution environments. This requires to understand the boundaries of communication services/telecommunication applications in virtualised execution environments, and to map the frequently comprehensive requirements onto high availability, high performance, and real-time behaviour of such services. To run a SIP Application Server on an elastic Cloud platform, for instance, may have many advantages in particular concerning infrastructure sizing to accommodate multi-media session handling in busy-hours. However, the migration of applications into CC platforms is not trivial. Features like virtualised memory and data persistency in different variations for different purposes by Cloud platforms, frequently providing very specific performances for certain needs, require good understanding of the application and service characteristics. Furthermore, many CC application platforms (PaaS) are optimised for certain application types, like for instance Web-applications based on Java or Phyton in the case of Google App Engine,[GoAE11], and thereby limit the capabilities in aspects like protocols, interfaces, authentication, and others. The immediate requirements in terms of research cover all aspects of understanding telecommunication core services, their adaptation to, migration onto, and operation on top of CC platforms.

On top of that, assuming that these issues could be resolved, there is still the question of locality. If, for instance, a media transcoder (for instance part of IMS) is moved into a CC platform, that is essentially a set of datacentres, locality may become an issue since datacentres may not be that many and not necessarily close to the customers. To address this aspect, there is need for research that addresses the migration of telecom specific applications and services into established, datacentre-centric CC platforms, combined with seeking for novel approaches to tackle the inherent locality issue of datacentres. One possible approach, for instance, would be to investigate ways to distribute part of the virtualised, Cloud-based execution environment into aggregation and access networks, and by that make the network part of the platform.

Network Embedded Platform

The novel concept introduced in the previous topic is the so-called network-enabled Cloud platform, also known as the network-as-platform. The central motivation is to exploit the many resources distributed across the different network domains, in order to raise efficiency, exploit locality, and to support the trend towards more and more consumer mobility. Supporting this trend, however, assumes the evolution of network elements and equipment from tailor-made single (or few) service providing hard and software platforms, towards off-the-shelf multi-purpose equipment that supports dynamic and on-demand resource provisioning for applications of whatever sort. While isolation, advertisement, dynamic provisioning and disposal, and other resource-related issues may be largely solved by state-of-the art virtualisation technologies, there are numerous issues unsolved starting with intelligent distribution of resources close to customers, admission control and other policy control functions, security risks associated with running applications on elements within the networks, or novel complexities in terms of infrastructure planning and operation if potentially any computing and storage element could be exploited.

Management of Execution Environments for Network and Cloud Services

As soon as several services are running on the same networked cloud platform, a number of additional network services are needed on all layers (not only IP as today). Examples are firewall functionality on service layer, load balancing features for distributed services, service-aware routing to get the nearest service available, and many others. Those execution environments require low footprint and a different programming interface than VMs do when used in a network context. Since CC and networking means multi-tenant operations, the management of the diverse set of resources (connectivity, computing, storage, number crunching, support services, authentication, and so forth) at all different layers and domains is naturally of major importance. Customers, as well as operators of any Cloud service, and of course especially end-to-end Cloud services, need context specific insight into state and operation together with the ability to act upon any sort of issue in an integrated fashion.

Management of the Cloud services as a whole is thus of increasing importance and remains to be still open for integrated Network-Storage-Computing-

Execution-Environment configurations. While, there are solutions for individual domains, like management frameworks for networks or virtual machines, their integration supported by standard interfaces is still missing. In turn, measurement, monitoring, reporting, (re)configuration, etc., is to be handled separately, adding heavily to the already very complex operational support landscapes within telecom systems. Research should thus investigate novel OSS and BSS architectures for Cloud infrastructures, platforms, services, and their product specific combinations. These support systems should support service the entire life-cycle of incident management for composite Cloud services, whereas services are compositions of diverse resources of all kinds in the device, network, compute, and storage domain. Such research should also address the necessary concepts for allowing customers to manage their (virtualised) infrastructures, platforms, and applications on top, which again may require entirely new security features and authorisation processes associated with a different management action on a resources and services.

Cloud-based Adaptive Service-Oriented Applications

Service-oriented applications provide their functionality in a rather dynamic way using a number of possibly independent services in a loosely coupled way. Such an application typically operates on different layers to implement its functionality. Especially, those services may run at a third party service provider and might be deployed in a Cloud environment. In both cases, the platform and proper environment for the execution have to be prepared and maintained for service executions.

As studies reveal, [ZhZL10], distributed applications are extremely fragile, due to the execution of uncontrollable external services. Unexpected changes of third party services or unpredicted network latencies, for example, can cause failures avoiding the timely execution of the applications. To prevent such failures, adaptation capabilities are needed and it is central to consider all layers for such an adaptation, as they might impact on each other or might even be conflicting. As an example, if an adaptation on the Cloud layer leads to the migration of a service from one Cloud to another, this could be conflicting with the decision on the service composition layer to choose a third party service instead of the own service implementation deployed in the Cloud.

The need for scrutinising cross-layer adaptations is therefore a top research priority, in particular in an end-to-end cloud environment. A recent survey amongst professionals from the Future Internet community, which has been performed at FIA 2011 in Budapest by the SCUBE project, [SCUB12][SCUB12], confirmed this statement (in fact, cross-layer adaptation has been deemed most important, right behind context-aware and human-in-the-loop adaptation). Such research is supposed to advance systemic understanding of relationships and quality properties across layers. As those quality properties are strongly dependent on the application domain in which a service-oriented application is employed, those dependencies need to be examined for concrete application-domain use cases and on top of the envisioned cross-domain, end-to-end Cloud scenarios.

Further, novel solutions are needed to predict how changes and adaptations occurring on one layer will impact on the other layers. This will lead to service-oriented applications that are capable of proactive adaptations, thus preventing failures and problems before they are observed by the users, a topic in particular relevant for Cloud scenarios that involve mobile devices and networks. Proactive adaptation will become especially challenging due to the strongly distributed nature of virtualised infrastructures in Cloud environments, and especially if Cloud services and/or consumers are mobile.

Context Awareness and Clouds

Context-awareness is seen today as one of the most important drivers for a new generation of personalised and intelligent services. There is a great expectation that not only end-users but also energy and mobility operators will benefit from intelligent environments that react in a sensitive and adaptive way to their needs, while guaranteeing a high level of anonymity, privacy and usability.

The concept of Context-Awareness has been around for several years, [DeAb00]. It is the opportunity offered by CC, through the availability of not only computational resources but provision of its huge storage facility, enabling deployment of context-aware applications and services. There is an important research opportunity, which is to create context-aware Cloud infrastructures and platforms that can adapt to environments conditions, economic incentives and other yet unforeseen context sources. Such infrastructures and platforms would have the potential to re-organise themselves saving resources, fostering competitions amongst CC users, and eventually leading to the development of new paradigms and services. It is therefore necessary to further research into context-aware architectures, covering aspects related to context gathering from multiple sources, processing of context information through evolved data-mining techniques, enrichment of context information through semantic extraction and cross dissemination of context information.

Programming Paradigm for Clouds

Until very recently, the IT industry has successfully relied on Moore's Law to improve the performance of its applications. High Performance Computing

(HPC) and more recently Grid Computing (GC) have been the exceptions to this law through advances in Concurrent, Parallel and Distributed Computing applied to very specific areas and applications. CC presents a new challenge: to harness the computing power of hundreds of machines that are based in mass-market components through the creation of a broad set of new applications and platforms. It furthermore introduces the concept of elasticity that determines that the computational environment, on which platforms and applications are executed, is dynamic, and that platforms and applications must adapt to changes in the underlying fabric.

Albeit the several differences between CC, HPC, and/or GC, they do share several common characteristics, such as the scale of computing power and the need for custom made applications and platforms. CC industry leaders have only recently unlocked the true power of CC through computation platforms, such as Google's Map/Reduce or Apache's Hadoop. Such platforms rely nonetheless on relatively simple algorithms, thereby providing a very large window of opportunity for more advanced algorithms. Much of the research that has gone into Concurrent Algorithms and Parallelisation Techniques used in HPC and GC should now be refocused on applying such already acquired knowledge to an increasing number of applications and services beyond the areas traditionally associated with HPC and GC and that should be made available to a broader CC community that can apply existing and new algorithms, and techniques, to new fields.

Creating platforms and applications for CC is very challenging for today's programmers, as they have been trained to work under a single processor/single environment model with which CC breaks all such ties. If CC is ever to truly become the core of all services and applications, it is necessary that either new service execution platforms or programming models and languages be created. New service execution platforms could quickly become the necessary middleware that can map today's programming models and languages to CC environments. But, nonetheless, it can only be through the creation of new computing models and languages that the full power of CC can be unleashed. Research should therefore focus in creating tools that can further abstract the cloud infrastructure from programmers, and on the creation of new models and computer languages that can in the future be used to create new and more efficient Cloud based applications and services.

Model-driven Cloud Management Platforms

One of the promises touted by the advent of CC is the efficient use of resources in the delivery of software-based services. In this context, "resources" should go beyond its traditional meaning of "network" and "computing elements", to include also other aspects, from the energy expenditure, to the time consumed by all stakeholders (service developers, service providers, infrastructure providers, and users) in the provision and consumption of a service.

Reaching a large degree of resource efficiency requires that the service execution be carried out by a platform capable of reasoning about essential aspects of the service operation at all times. In order to pass such information to the platform executing a service, authors of services must build them according to a parameterisable model, understood by the platform targeted to execute the service. The platform can use the supplied model-based description of the service to determine which operational magnitudes of the service to monitor, and to automatically make decisions affecting the service's operation based on the result of such monitoring.

A model suitable for this task must necessarily include a structural description of the Service Application implementing the Service, capturing the set of components within the service, the relationship among them, and the dependencies with other services.

For each component, a description of its SLA must be provided, and relations with the resources it consumes established within a framework, which can direct the platform to make the right scaling decisions (e.g., increasing/decreasing the number of replicas of each component) when monitoring by the platform so indicates. The service itself must describe its SLA, and the model must allow the SLA, combined with the performance characteristics of the components, to lead to automatic scaling and configuration decisions on the part of the platform.

The software behind a Cloud service, like any other software, will be buggy, requiring patches to fix its problems, and will be subject to improvements. In addition, the service definition itself will change in time, requiring changes in the underlying software to reflect the changed functionality. All this leads to point out the fact that software upgrades will happen, moreover, they will happen often. To avoid an unfavourable impact on the SLA of the service, the model should integrate a working model for upgrades, so that these can be driven by the platform, while maintaining SLA.

One has mentioned earlier that the Cloud is not a forgiving environment for software developers. At best, a Cloud application structure contains just one stateless element. At worst, the service keeps state within, and depends on other services to accomplish its function. Failures occur, and can take down components of a service at unexpected times. Moreover, automatic actions by the platform in the form of taking down component replicas, or taking up new such replicas, add to the haphazard nature of the environment in which these applications must execute.

At the end of the day, a Cloud application is just a distributed application, potentially with several components, designed to be elastically replicated for scale-out. Furthermore, each one of those replicas will present failure modes potentially independent from the rest. Programming for such an environment is not easy and will need support from a programming environment well integrated with the platform model. This will give the platform a fair chance at automating as much as possible the details of taking care of some of the events mentioned before, allowing developers to concentrate on the business logic the service needs to deliver.

There have been some timid attempts from some of the pioneers in this space to offer such a model-based platform. A case in point is that of Microsoft's Azure, whose current model, however, falls short of what one presents in here, capturing only some minimal structural information, and offering some services to cope with failures of service's components.

There will be the tendency for each vendor to offer its own model, with the goal of attaining some sort of lock-in for the services they on-board. However, it is our contention that the concepts that need to be taken into account are going to be very similar, and such lock-in will be short lived. In any case, savvy service developers would do well in abstracting the high level aspects of whatever platform models they are considering, in order to guarantee easy portability between platforms.

The End-to-End Cloud Interoperability Challenge

There are many challenges to CC, but an important one is the removal of lock-in and the enablement of interoperability between Cloud services. This issue is at present a major inhibitor for the adoption of Clouds, and if the notion of Clouds is to be extended to true End-to-End services covering devices, networks, and datacentres, this challenge will become even more relevant in the future.

Interoperability at IaaS (device, network, compute and storage) should firstly target interoperability capabilities offered to the upper layer of PaaS, where lock-in is even more prevalent. To achieve this goal, appropriate standard specifications need to be agreed upon by both research and industrial sectors. In essence this means, in the context of IaaS, to agree upon cross-domain architectures that allow to import and export customer deployments, interface with those deployments in a common way during their lifecycle and runtime, and to have access to the data supplied and generated and in creating that deployment.

Current research and standardisation is addressing such issues for the classical CC that is the datacentre centric. If the concept of Clouds is to range beyond, one has to rethink architectures at large. In terms of standardisation, this requires cooperation and integration beyond the sector as there is no one SDO that can capture the entire research and industry interests. In terms of the IaaS domain, this specifically means: standardised specifications for the import and export of virtualised infrastructure service instances across the device, network, compute, and storage domain (e.g., OVF); standardised runtime specification to allow the run-time and lifecycle management of virtualised infrastructure service instances (e.g., OCCI); standardised data access, import and export capabilities to the data that created and was generated by the virtualised service instances (e.g., CDMI). Any of these domains is currently work in progress and research is an important tool to assure progress.

Interoperability is not only a challenge for those in research initiatives, but also for standards development organisations that solicit input. It is also a challenge that increases in complexity, as one moves up in the commonly accepted CC stack (IaaS --> PaaS --> SaaS). There will be many technical challenges in Cloud interoperability below the level of standard specifications, but the most obvious are: data migration - Cloud service instances can retrieve, consume and process data in ranges greater than TeraBytes, since if one has a cloud service and its related data set is of such an order, present network technologies are not sufficient to transfer the data in any reasonable time; service instance migration - a challenge in a similar vein to the previous one, which is of particular interest is how to maintain and enable the capability of live migration between Cloud providers where paths between two can span many subnets; capability advertisement/negotiation - before any migration of service instances can be accomplished, it is necessary that each Cloud service provider advertises its service capabilities, so that customers wishing to migrate can verify that their current set of capabilities will be satisfied by the target cloud provider. This verification mechanism can also be seen as a negotiation of capabilities, which would lend well to the idea of automated SLAs.

As of today, there are movements under way to tackle the challenge of Cloud interoperability. These initiatives are still at early stages and need continuous refinement in accordance with the dynamics of the CC domain. Research is thus required to not only follow what is conceived elsewhere – but to support ideas and their evaluation, which, if properly instrumented, will allow one to take the lead, and drive this important topic for the future.

Transformation of Current Business and Strategy

All the technological challenges in CC should not neglect the far reaching business and process transformations impacts brought about by CC with moving from on-premise solutions to on-demand and service-based approaches.

Especially looking from a telecom angle, it is far from clear how these new opportunities can be exploited and embedded into future strategies. The asset of existing communication infrastructures enables operators and providers to differentiate from existing and very established CC providers yet the how is not very clear. There are many open questions and an important one in particular is“How the integration of telecom and Cloud Computing and their offering as one-service on-demand experience can provide a market differentiator?”.

Challenges that remain and call for more research are global operations of a converged (Telco+IT) infrastructure, in overcoming the mismatch between geographically limited networks and the globally available CC, as well as meeting increasing customers’ expectations with sophisticated services. Another aspect is the reduction of OPEX, which requires new strategies covering both the networks and CC infrastructures. Further research is thus recommended that addresses methods and tools for analysing and quantifying the Cloud Computing business models, transformations, and strategies. Such research should also provide frameworks for business as well technology strategies to provide established providers, market entrants, and consumers with sound and proven means for investment protection and revenue generation.

7.3 Conclusions and Recommendations

The foremost conclusion in this chapter is that the relation between Cloud Computing, Networking, and Telecommunications is multi-faceted, and for a deeper understanding there is a need for a continued and extensive dialog between the two, currently separated, Networking and IT domains.

First, Cloud Computing is turning into a buzz word and related term like “Whatever-as-a-Service” is being used very loosely for concepts and “wannabe innovators” that strictly speaking have nothing to do with the Cloud Computing concepts of “elasticity, on-demand, pay-as-you-go”.

The second reason is that Cloud Computing is commonly agreed by many to be "simply working". It runs "Over-the-Top" and can help in sharp increases in revenues. However, there is little desire by established Cloud Computing providers to engage with the telecom sector. While this may appear as a disadvantage at the first place, it could be *the* opportunity for telecom operators to engage in addressing the long lasting networking problems. Recent service outages due to poor network operations within datacentres and problems of taking on end-to-end responsibilities, as documented in Cloud Computing SLAs, are examples of such networking problems. This requires cooperation and dialogue between the two sectors by appreciating the overriding technical and business issues, and jointly develop appropriate solutions.

For this to come true, more research is needed. Too different are the visions and positions from the business and technological angles. To believe that Cloud Computing will eventually bring the long awaited solution to Quality of Service problem, for instance, is short-sighted. This is not to say that this may not be the case, in fact there is evidence for the opposite, but before this becomes a reality far-reaching transformations have to take place. Technology, obviously, has to play a key role here, but it has to be accompanied by political and strategic policy transformations.

There is huge potential and demand to converge between the domains of devices, networks, and datacentres. A seamless integration of the Internet of Things and Cloud Computing, for instance, could have a huge impact on the landscape and provide a strong business case for both. Another aspect that stands out is that a convergence of devices, networks, and datacentres is little understood, from an integration, operation, and management perspective. Too many are the concepts, standards, and sector best-practices, and while most of them are developed within a narrow space and for specific applications, there is a considerable gap to be bridged if consolidation for increased efficiency is the goal.

Yet despite these hurdles, which are certainly interesting research areas, there is no doubt in what regards the economic potential and technological significance underneath a converged device-network-cloud landscape. Indeed, this vision of a harmonised platform that consolidates and exploits assets of the three domains, jointly and for the sake of providing the long-awaited one-service on-demand user experience, may eventually pose a sound definition of another, much blurred term – The Future Internet.

The following are recommendations for research topics on networks for cloud computing and service platforms.

R24) Architectural integration of IoT domains into Cloud environments, or in the case of large autonomous IoT domains, the on-demand and potentially ad-hoc creation of IoT-Clouds.

R25) Concept of service hosting gateway as an essential element in any future scenario of networked-services that terminate in the home, evaluating aggregate and return monitoring information to the Cloud, and host local services that cannot be provided from the Cloud-

R26) End-to-end user-network-storage-computing interfaces for setting up on-demand optical networks, in accordance to the requirements of Cloud services, Cloud infrastructures, and distributed applications that may run on top of cloud-style systems.

R27) Networking- and workload-optimised software environments that can bridge the missing link between host/server and network I/O, by fully exploiting virtualisation in order to support data centre grade hosting at rates of 20 Gbps and more per VM.

R28) Establishment of automated coordination mechanisms among the network, datacentre, and service domains.

R29) Network support for accessing and inter-connecting complex multi-domain Cloud services, addressing the nature of on-demand, distributed, service-oriented, applications run on top of clouds, and respective metrics.

R30) Migration of telecom specific applications and services into established, datacentre-centric Cloud Computing platforms, combined with seeking for novel approaches to tackle the inherent locality issue of datacentres.

R31) Novel OSS and BSS architectures for Cloud infrastructures, platforms, services, and their product specific combinations, allowing customers to manage their (virtualised) infrastructures, platforms, and applications on top.

R32) Context-aware architectures, covering aspects related to context gathering from multiple sources, processing of context information through evolved data-mining techniques, enrichment of context information through semantic extraction, and cross dissemination of context information.

R33) Methods and tools for analysing and quantifying the Cloud Computing business models, transformations, and strategies, leading to frameworks for business as well technology strategies to provide established providers, market entrants, and consumers with sound and proven means for investment protection and revenue generation.

Conclusions and Recommendations

8

8. Conclusions and Recommendations

8.1 Strategic Research and Technologies

Two distinct and complementary tracks of research are proposed. One track should be dedicated to advance research and technologies towards a ubiquitous and efficient broadband system, whilst the second track should focus on technologies for efficient support of applications and industries identified in the EU Digital Agenda as Grand Societal Challenges. In the Grand Societal Challenges, the applications are diverse in their characteristics, with extreme requirements from different domains demanding new approaches to networking protocols and network architecture designs. The research approach, however, should be towards a *common and universal platform,* thus minimising the potential problems of interoperability, heterogeneity, scalability, security, privacy, robustness and trustworthiness. The design of separate platforms, for different applications and domains, such as health, transportation and so on, would lead to interoperability problems and they would, individually, be costly to maintain. Mobile and wireless networks are a good starting point for a common platform, offering economies of scale and scope. The research on such a common platform should be complemented, in parallel, with standardisation activities to establish a common standard, thereby enabling innovation and fast market take-up.

Future communication systems will have to be smart, i.e., "cognitive, intelligent, flexible and evolvable" in terms of being equipped with appropriate functionalities to capture and analyse all different context information, and adapt themselves autonomously to local conditions, whilst achieving global optimisation in a stable and robust manner. Full network resource virtualisation, coupled with intelligence and cognition mechanisms are essential features of a fully smart system. Amongst the many information sources, needed for self-managing, self-healing and self-optimisation, are user profile, environment, radio, networks, devices, and services context information.Networks with an evolution capability are essential in the light of highly dynamic business interfaces and emerging new business models, as well as for efficient support of, as yet, unforeseen services.

Ubiquitous personal mobile broadband services will require cost-effective and resource-efficient technologies, such as self-organisation, cooperative and collaborative advanced techniques to form a smart system. New cell deployment strategies and intelligent interactions between them(with special emphasis on small cell technologies and advanced signal processing techniques, which make use of interference and convert it into useful signals) are considered to be potential enabling techniques in addressing spectrum shortage and energy efficiencies in the expected high capacity demands. Small cell technologies with self-organising and managing capabilities, coupled with efficient hybrid systems of fibre optics and wireless links, should be considered as a set of techniques capable of delivering high capacity and energy-efficient broadband mobile communications. New high capacity and flexible wireless backhaul infrastructures are needed to support advanced radio access techniques and, in particular, for very small and high-capacity cells. This demands co-design of wireless backhaul and radio access.

The high-capacity requirements coupled with shortage of suitable radio spectrum, call for more research effort than ever on system-level advanced techniques. The system level research should be biased strongly towards multi-cell, multi-user and multi-network cooperative techniques enabling collaborative and cognitive operation. On the physical layer, there should not be any complacency that OFDM is the end of the road physical layer scheme. Research must continue for post-OFDM schemes that require less signalling overheads and can operate efficiently in multi-user and multi-cell environment, particularly in UE-to-UE communications scenarios. New air-interfaces should target at least 1 Gbps for long range and 10 Gbps for short range communication. Cognitive radio and cognitive networking, together with network resource virtualisation and information-centric networking, are some of salient features of the next generation smart mobile and wireless systems. The planned development of such communication systems, considered together with already deployed extensive worldwide connectivity, purpose-designed quality-of-service mechanisms, efficient mobility management, robust security schemes and efficient support of other domains, mean that mobile and wireless networks can be considered as the important basic building blocks of the Future Internet. The Future Internet will evolve from the current Internet, integrate new clean slate solutions into it, and will probably be implemented first in pilot-scale deployments, before being integrated into the mainstream public Future Internet.

A number of strategically essential technologies that offer great potentials in addressing the mismatch between rates of increase in the demand and that of capacity. The list of technologies is influenced by Europe's telecommunication needs, as well as the societal and telecommunications industry challenges. They are considered strategic in the sense that, if developed, they will lead to greater economic and social impact as the result. Investment in these technologies, in the form of funding of research, is expected to contribute to enhancing Europe’s leadership and competitiveness in the global market.

Users' Requirements for Communications in 2020:

- Ubiquitous broadband Internet services, on-the-move, particularly video-based services.
- Simplicity in accessing device(s), and services irrespective of network technologies and media (wireless and wired).
- Long time between re-charging and new and ubiquitous mechanisms for charging of devices.
- Near zero latency in service access and service continuity.
- Dependable and reliable networks.
- Trusted services and networks.
- Trust in level of exposure to electromagnetic fields.

Telecom Industry Challenges:

- Capacity crunch and provision of 1 000-fold capacity relative to 3G UMTS/HSPA in 2010.
- In the wide-area and long-range, provision of at least 10 time more throughput than UMTS/HSPA and substantially more than 50 Mbps throughput per user.
- In the short-range, provision of 10 times higher throughput than in the wide-area.
- Scarcity and high fragmentation of suitable spectrum and lack of global harmonisation.
- Wireless backhaul spectrum shortage and capacity limitations.
- Need for faster service creation, test and deployment.
- Need for multi-service and evolvable networks.
- Inter-operability between different standards and technologies.
- Support of machine to machine traffic and cost of associated signalling.
- Increasing demand in processing power and storage.
- Ever-increasing complexity in management of systems, number of networks and increasing traffic, leading to escalation of costs associated with system operation, maintenance, and particularly, overall energy requirements.
- Cost-effective solutions for migration of legacy services and networking to new networking solutions.
- Increasing investment cost in long-term research and competition from the rest of the world (China, South Korea, Taiwan, USA and Canada).

Grand Societal and Economic Challenges towards a Sustainable Future and Digital Single Market:

- Sustainable ICT as part of national critical infrastructures, and its economical extension to remote and less populated areas for digital inclusion.
- High service integrity, reliability, availability and network robustness.
- Digital single market provisioning.
- Efficient health and tele-care systems.
- E-Government.
- Intelligent transport systems.
- Efficient energy systems.
- Carbon-neutral environment, and environment monitoring and alarm.
- Privacy, safety and security.

The strategic technologies and research areas that are deemed to collectively address all of the above challenges and market requirements, thus offering the promise of greater economic and societal impacts for Europe are:

- Smart communication systems - defined as self-organising/planning and cognitive communications and operation at radio access, fixed network and service layers and enabling of software-defined networking.
- Context-based networking - including user context, device context, radio environment context and network context, requiring research into technologies for capturing of all the above context information and suitable mechanisms for their combined use for efficient operation of smart communication systems.
- User profiling mechanisms and technologies - for user-centric services, thereby minimising complexity in services and networks access for a user.
- Machine-to-machine communications - Internet of Things, including UE-to-UE (User Equipment), requiring research into protocols and techniques for autonomous and self-organising operation, ubiquitous connectivity, interoperability, context awareness.
- Small cell technologies- enabling very high area capacity, energy and spectrum and cost per bit efficiencies.
- Infrastructure sharing - mechanisms and technologies for a flexible universal core network with network virtualisation.
- Support of a fully multi-dimensional approach – research into multi-service providers, multi-RATs, multi-services, multi-networks technologies and multi-cell topologies, with evolution capabilities towards a universal platform for Future Internet, providing IaaS

(Infrastructure as a Service), NaaS (Network as a Service), and ultimately, SaaS (Service as a Service) in support of different business models, interfaces and sizes.
- Information centric networks –new architectures and protocols for overcoming service inter-operability across different and heterogeneous network technologies.
- Hybrid of optical fibre and wireless technologies - radio over fibre (RoF) subsystems and components, optical network switching/routing and implications on protocol stacks.
- Optical networks - multi-granular, flexible, scalable transparent and adaptive optical networks, supporting channel rates of Tbps.
- New communication technologies – new approaches should be explored, namely visible light communications, and new communication waveforms, post-OFDM.
- Systems co-design – different levels of systems should be taken into a co-design approach, in particular, radio access and wireless backhaul, for high capacity small cells.
- Energy efficient systems – a holistic and end-to-end area that comprises of terminals, infrastructure, networking, deployments, and energy-aware system operation.
- Standard interfaces - universal and common standard Interface between services to networks, enabling proliferation of services and applications, and services interoperability across different networks.
- Trust, security, and privacy - mechanisms and protocols for trust, security and privacy, taking a holistic approach, and encompassing the various stakeholders, hence, encompassing technologies for monitoring and lowering of electromagnetic fields.

The above mentioned technologies and research areas are not listed in any particular order of priority. They are all considered to be strategically important and their realisation should pave the way for a progressive transition to the Future Internet.

8.2 Recommendations for Research and Innovation in Europe

The international market for ICT and mobile communications, as demonstrated, is vast and growing, and there is clearly an opportunity for Europe to exploit it. As already mentioned, ICT is an enabler to other key areas at the heart of EU's strategy, and of future healthcare, transport, security, space, energy and environment policies. Therefore, the EU Framework

Programme on ICT could be a key link to more application-oriented programmes that would form a pathway to other business sectors.

Accordingly, multibillion world markets are available for ICT. Europe is home to the world-leading industries, a vibrant SME sector with a range of inward investors and a world-class academic sector. Furthermore, major international ICT companies have an R&D presence in Europe. Global companies are now being attracted to Europe to gain access to the academic sector, the critical mass of industry, European markets, and European innovation in all the important standards bodies. European and National R&D programmes are available, and should continue to fund advanced research and innovation in ICT.

While the explosion of demand and the transformational power of ICT are clear, serious challenges must be addressed to ensure sustainable solutions, and to harness the investment and effort for increased innovation and exploitation impact. The Net!Works European Technology Platform has identified the strategic technologies that Europe ought to invest in for the next 10 years, in order to generate a high European impact on global Future Internet solutions and standardisation.

It is also recommended that research should be supported and conducted in a multidisciplinary fashion, within communication and networking technologies as well as together with other disciplines, such as health, energy, environment monitoring and control to mention just a few. Examples of multidisciplinary research within communications are any combinations between RF, signal processing, networking, security, transport, services, IT, and so on, with more focus on system-level engineering.

The topics to be addressed in an R&D programme should include:

R1) Significant improvements of the wireless network have to be explored, by strengthening the research efforts towards innovative cooperation and coordination schemes for network nodes, in a flexible heterogeneous network deployment, including wireless network coding systems applied to dense, cloud-like, massively-interacting networks of nodes.

R2) New radio technologies (scale of channel modelling to small and complex scenarios, access, multiple antenna schemes, interference handling, etc.) must have a high priority, in order to meet the high requirements on 5G systems.

R3) Cooperative spectrum-sharing techniques in non-homogeneous bands.

R4) Antenna systems fundamental limits, providing the performance benchmark for smart adaptability, including interactions with the user and the propagation channel, and taking an integrated approach where performance can be effectively optimised by appropriate sensing of the physical environment.

R5) New radio access architectures, logical and physical separation between control and data planes, for achieving both spectrum and energy efficiencies.

R6) Full integration between mobile broadcasting and mobile broadband communications.

R7) Collaboration between wireless and optics experts, towards new network technologies with very high performance at reasonable costs.

R8) Future network deployments have to allow for network/infrastructure/resource sharing on all levels, in order to meet the fast changing demands on network resources and operation.

R9) Cognitive capabilities have to be incorporated into network design on all layers, supporting a flexible network adaptation at low operational costs, towards providing exactly the performance required for the determined user context.

R10) Convergence of wireless and optical networks, such as the physical layer RoF, fully-optical signal processing, cognitive RoF protocols for dynamic traffic routing, channel and spectrum allocations, solutions to reduce energy consumption, and power saving should be investigated to allow the optimal use of the network.

R11) Converged access networks capable of interconnecting orders of magnitude higher number of users with a symmetrical or asymmetrical bandwidth over long distances bridging the barrier between access and core. Identification of the ultimate limits of capacity and reach of wireless-wired technologies in providing network solutions.

R12) A fundamental rethinking of what constitutes an optical router and its architectures: optical routers providing flexible multi-granular and scalable solutions in switching dimensionality, as well as in bit rate and throughput, and transparently and adaptively support port rates of up to 1 Tbps. By using the corresponding photonic system, the power consumption of the network will decrease remarkably, while the processing speed and allocated channels bandwidth will significantly increase.

R13) Dynamically wavelength and channel allocation throughout the network, increasing network throughput and decreasing service cost, as well as providing better spectral efficiency and lower power consumption.

R14) Development of new wireless air interface and optical wireless, to cope with the high data rate at home and in building applications.

R15) Definition and design goals of future networks, supporting both clean slates and evolutionary approaches. The latter should aim at sharing and optimising current infrastructure to provide IaaS, NaaS and SaaS, towards a smart software defined network. The core must be universal in terms of efficient support of all access technologies with sufficient intelligence and cognitive features for autonomous yet stable and controllable operation. Energy efficiency should be a design parameter together with flexibility and robustness.

R16) Design of future network architectures, based on software defined architectures, which should address connectivity together with: unification and a higher degree of virtualisation for all infrastructures; software defined and driven objectives; integration concepts enabling better usage of the multi-centric approaches; unification and integration of connectivity, computation, storage and control resources; in-bound manageability; cognitive network operations; full network empowerment, with a multi-cognisance perspective; consideration of large-scale systems integration and deployment.

R17) Future network programmability and elasticity should support the stakeholders' triggered dynamic deployment of new resource-facing and/or new end-used facing services, keeping pace with their rapid growth and change. The architectures should optimise capacity of network equipment, based on service requirement and user demand, taking the various physical limitations of network equipment into account.

R18) Integrated virtualisation of connectivity, storage, processing and control, supporting the dynamical partitioning of physical resources, the management of virtual and physical resources through open interfaces, the dynamic movement of logical network elements (e.g. virtual machines representing service components or virtual routers or virtual objects), and the creation of different networks on top of such integrated virtualisation layer without interfering with the operation of each other. The validation should be done in terms of on-the-fly creation, deployment, management and run of new services on shared physical infrastructures.

R19) In-bound cognitive management should be addressed as well, so that future network will be able to process massive amounts of management information efficiently and effectively transform such data into relevant knowledge for business. In addition all network functionality needs to be managed with ever increased automation and autonomicity, allowing for the network operator input as far the business and governance goals are concerns. Priority should be given to management systems covering multifaceted integration of embedness, automation, autonomicity, cognition, control orchestration and extensibility, empowering the network with inbuilt cognition and intelligence and manageability by objectives.

R20) Initiate activity on definition, specification and development of emergency networks.

R21) Develop technologies in capturing of context information in general sense, and demonstrate the effectiveness of context information in autonomous management of network resources, self-healing/optimisation and intelligent delivery of personalised services.

R22) Prioritise network research based on L3S concept.

R23) One should not be complacent that "connectivity is just there". One should ensure that appropriate fund is set aside for collaborative research on the huge challenges that mobile broadband Internet is facing.

R24) Architectural integration of IoT domains into Cloud environments, or in the case of large autonomous IoT domains, the on-demand and potentially ad-hoc creation of IoT-Clouds.

R25) Concept of service hosting gateway as an essential element in any future scenario of networked-services that terminate in the home, evaluating aggregate and return monitoring information to the Cloud, and host local services that cannot be provided from the Cloud-

R26) End-to-end user-network-storage-computing interfaces for setting up on-demand optical networks, in accordance to the requirements of Cloud services, Cloud infrastructures, and distributed applications that may run on top of cloud-style systems.

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R33) Methods and tools for analysing and quantifying the Cloud Computing business models, transformations, and strategies, leading to frameworks for business as well technology strategies to provide established providers, market entrants, and consumers with sound and proven means for investment protection and revenue generation.

The need for a more holistic, coordinated and strategic approach spanning the research to business spectrum is clear. One needs to develop master plans to address the opportunities, avoiding fragmentation of efforts and optimising the chances of success in the market. The formation of an ICT research and innovation programme has the potential to make a significant difference to the EU economy more than any other sector.

The rate of innovation in ICT, and particularly in communications, is high and priorities are constantly changing in the sector. A seven-year Framework Programme should provide theflexibility to incorporate and capture these dynamics, hence maintaining relevancy over the period.

Currently, there is a lengthy delay between formulating an idea, writing up the proposal, and the actual start of the project; sometimes this can take up to 2.5 years. This process is clearly too long for industry to commit resources, as the relevance of topics will have changed before the project could start. Efforts should be made to shorten the process from proposal submission to contract signature to less than 6 months. This would encourage more participation from industry in projects. A good example that could be considered is the process adopted for the FI-PPP.

Current instruments for collaborative research, such as IPs and STREPs, are effective and should be maintained.

Another recommendation is on co-financing of projects in the current Joint Technology Initiatives in the area of ICT, in which the EC and member states jointly provide funding for projects. Such co-financing, with unequal availability of funding in different member states and a long and unpredictable evaluation of projects, in which some partners receive funding while others do not, is inefficient and should be avoided. It is recommended to adhere to one single source funding, accessible by organisations from all member states on the same basis, as is currently used in FP7.

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