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Strategic Applications, Research and Innovation Agenda

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Abstract

This is edited version of all the white papers that identify strategically important applications in smart cities and broadband communication technologies for research and innovation for Europe.

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Background to this Document

This is the results of extensive discussions and brainstorming with more than 50 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 Innovation Union have been the basis of the proposed technologies and applications. The report covers the following chapters:

- Position statement on Europe's Strategy for Research, Development and Innovation
- Smart Cities Applications and Requirements
- Broadband wireless beyond 2020
- Radio over Fibre
- Future Networks and Management

List of Acronyms

3D	Three Dimensional
3GPP	3rd Generation Mobile System
API	Application Programming Interface
CDMA	Code Division Multiple Access
CNM	Cognitive Network Management
CNO	Cognitive Network Operation
CPU	Central Processing Unit
DG	Directorate-General
EC	European Commission
EU	European Union
FCCC	Fast, Cheap, Clean and Cognitive
FIA	Future Internet Assembly
FN	Future Networks
FP7	Framework Program 7
FTTH	Fibre to the Home
FTTH	Fibre To The Home
FW	Framework
Gbps	Giga bits per second
GDP	Gross Domestic Product
IaaS	Infrastructure as a Service
ICT	Information and Communication Technologies
INFO	Information Society
INM	In-bound Network Management
IP	Internet Protocol
IT	Information Technologies
ITS	Intelligent Transportation Systems
LED	Light Emitting Diode
LTE	Long Term Evolution
LTE-A	Long Term Evolution – Advanced
M2M	Machine to Machine communications
MAC	Medium Access Control
NaaS	Network as a Service
NGN	Next Generation Networks
OECD	Organisation for Economic Co-operation and Development
OEO	Optical-Electrical-Optical
PA/D	Photonic A/D
Pbps	Peta bits per second
PC	Personal Computer
PD/A	Photonic D/A
PON	Passive Optical Network

QoS	Quality of Service
R&D	Research & Development
RAT	Reverse Network Address Translators
SAA	Strategic Applications Agenda
SaaS	System as a Service
SARA	Strategic Applications and Research Agenda
SDK	Software Development Kit
SoftN	Software Defined Network
SON	Self-Organizing Networks
Tbps	Tera bits per second
TCP	Transmission Control Protocol
TMN	Telecommunications Management Network
TV	Television
UMTS	Universal Mobile Telecommunications System
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
WDM	Wave Division Multiplexing
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WSN	Wireless Sensor Network

Chapter 1 Europe's Future Networks Research and Innovation Strategy

1.1 Realising 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 infrastructure is the basis of global commerce and communication, included in national critical infrastructure plans - and according to the United Nations, 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 (Telefonica, Deutsche Telekom, Vodafone, Orange, BT, Telecom Italia, Telenor Group), 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 investment made by these manufacturers exceeded €10.1Bn, resulting in global sales of €76.3Bn and the employment of 290,000 people¹. 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 €145Bn in capital expenditure to 2013, creating direct and indirect employment for over 4.7M people².

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)³ "top 1000 UK companies" from 2010 shows the communications and broadcast industries as representing revenues of £129Bn (second only to Oil and Gas) and an R&D spend of £3.7Bn (second only to Pharma and Bio)⁴.

In the current economic climate, investment in telecommunication network infrastructure has already proven to be an effective economic stimulus. An 8% change in telecommunication 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 growth⁵. Currently, the

¹ European Commission: Monitoring industrial research: 2010 EU Industrial R&D investment SCOREBOARD. Joint Research Centre. DG Research 2010. http://iri.jrc.ec.europa.eu/research/docs/2010/SB2010_final_report.pdf

² European Mobile Capex & Employment Impact, Sep 2009, GSMA & AT Kearney. Note: includes 0.352m direct and 4.4m indirect employment gains

³ <http://interactive.bis.gov.uk/digitalbritain/>

⁴ 2009 UK R&D Analysis' published by the Digital Communications KTN, 2010

⁵ <http://www.oecd.org/dataoecd/4/43/42799709.pdf>

ICT sector is directly responsible for 10% of Europe's GDP, with an annual market value of €660Bn, and directly accounts for 3% of employment (6.1M)⁶. 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%⁷.

1.2 Trends and Drivers

The number of mobile users and the scale of mobile traffic are increasing at a staggering exponential rate. Cisco predicts that by 2015, global mobile data traffic will increase 26-folds. It will increase by 1000-fold by 2020, according to Huawei⁸ and DOCOMO's⁹ forecasts. These statistics are all relative to the 2010 traffic levels, implying a doubling of traffic per year. Moreover, CISCO 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 video¹⁰. In this time scale, one second of video traffic uploaded on the network will take one person two years to watch. Additionally, mobile to mobile traffic is expected to reach 295 Petabytes per month in 2015.

The "Worldwide Mobile Industry Handbook 2011-2015"¹¹, (a report published by Generator, an industry insight provider), suggests 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 Agenda¹², 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; the traffic demand is doubling every year whilst capacity is only doubling every ten years. This gap between demand and supply will be continuously increasing unless major technological advancements are made. This unprecedented technical challenge also offers

⁶ European Commission: The 2010 report on R&D in ICT in the European Union. Joint Research Centre, Institute for Prospective Technological Studies, 2010. <http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=3239>

⁷ MEP Roza Grafyn von Thun Und Hohenstein, Future Network and Mobile Summit 15th -17th June 2011, Warsaw, Poland

⁸ Mobile World Congress presentation, MWC 2011

⁹ Dr. Stefan Kaiser, Net!Works Expert Group Workshop, 19th -20th Jan 2011, Alcatel-Lucent, Stuttgart, Germany

¹⁰ http://www.rysay.com/Articles/2010_02_Rysavy_Mobile_Broadband_Capacity_Constraints.pdf

¹¹ <http://www.portioresearch.com/WMIH11-15.html>

¹² http://ec.europa.eu/information_society/digital-agenda/documents/digital-agenda-communication-en.pdf

unique opportunities for Europe, should timely investment in appropriate technologies are made by funding organisation. This is the purpose of this report to create awareness and help in mobilising research community to focus their efforts on strategically important technologies that can lead to greater market and employment opportunities in Europe.

1.3 Strategic Research and Technologies

This section proposes 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 Electro-Magnetic fields.

Telecom Industry Challenges:

- Capacity crunch and provision of 1000-fold capacity relative to 3GHSPA in 2010;
- In wide-area and long-range; Provision of at least 10 times more throughput than HSPA and substantially more than 50 Mbps throughput per user;
- In 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 (M2M) 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 in turn 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 area for digital inclusion;
- High service integrity, reliability, availability and network robustness;
- Digital single market provisioning;
- Efficient health and tele-care system;
- E-Government;
- Intelligent Transport system;
- Efficient energy systems;
- Carbon-neutral Environment and environment monitoring and alarm;
- Privacy, Safety and security.

Listed below are 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:

- 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 the 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 technology-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-In support of multi-service providers, Multi-RATs, Multi-services, Multi-networks technologies and Multi-Cell topologies with evolution capability towards a universal platform for Future Internet. The network evolution roadmap should enable provision of 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 networking and protocols- A potential solution in overcoming service inter-operability across different and heterogeneous network technologies;
- Hybrid of optical fibre and wireless technologies - Research into radio over fibre (RoF) subsystems and components, Optical network switching/routing and implications on protocol stacks;
- Multi-granular, flexible, scalable transparent and adaptive optical networks, supporting channel rates of Tb/s;
- Visible light communication technologies;
- Co-design of radio access and wireless backhaul particularly for high capacity small cells;
- Energy Efficient Systems – A holistic and end-to-end research theme that comprises of terminals, infrastructure, networking, deployments, and energy-aware system operation;
- Universal and common standard Interface between Service-to-Network:, enabling proliferation of services and applications and services interoperability across different networks;
- Trust, security, and privacy mechanisms and protocols.

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.

Two distinct and complementary tracks of research are proposed. One track should be dedicated to advance research and technologies towards 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, that is; "cognitive, intelligent, flexible and evolvable" in terms of being equipped with appropriate functionalities to capture, 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, network, 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. One good example candidate is different variations of the FBMC (Filter Bank Multi Carrier) techniques. New air-interfaces should target at least 1Gbps for long range and 10Gbps 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 cleanslate solutions into it, and will probably be implemented first in pilot-scale deployments, before being integrated into the mainstream public Future Internet.

1.4 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 strategy and of future healthcare, transport, security, space, energy and environment policy. 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 Information and Communication Technologies 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.

We 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.

We believe the following list of technologies and topics are strategically important and future research programmes should incorporate:

- **New architectures**
 - Intelligent Multi-radio access and multi-network technologies;
 - M2M, UE-to-UE, Peer-to-Peer networking integrated with the wide-area networks;
 - Flexible and universal core network architecture supporting hybrid of optical fibre and wireless technologies and enabling infrastructure sharing comprised of multi-access (wired and wireless) technologies;
 - Service-aware networking architectures;

- **New Networking**
 - SMART communication;
 - Software Defined Networking (SDN);
 - Context-based networking and service provisioning;
 - Information-based (centric) networking and protocols
- **New Technologies**
 - Visible light communication technologies;
 - Small cell technology;
 - New communication waveforms, post-OFDM;
 - Co-design of radio access and wireless backhaul;
 - End-to-end approach to Energy Efficient networks;
 - Technologies for monitoring and lowering of EM fields;
 - Universal interface Service- to-Network;
 - Common and universal platform in support of eHealth, Smart Energy, Intelligent Transportation,...

The need for a more holistic, coordinated and strategic approach spanning the research to business spectrum is clear. We need to develop masterplans 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 the flexibility 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 which could be considered is the process adopted for the FI-PPP.

Current instruments for collaborative research, such as IP 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.

Chapter 2 Smart Cities Applications and Requirements

Cities have 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 (Information and Communication Technologies) 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 citizens’ quality of life and 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 [SmSa11]. A total of 6 dimensions have been identified in [Smar11b], which describe the global perspective that is required in this area: 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 chapter is 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
- Roadmaps

Based on the work of Net!Works, and on the past experience with eMobility’s SAA (Strategic Applications Agenda) [eMob09] and SARA (Strategic Applications and Research Agenda) [eMob10], this chapter on Smart Cities Applications and Requirements groups 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.

2.1 Economic, Social and Privacy Implications

2.1.1 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 (Information Technologies) – 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 1.

SMART ECONOMY (Competitiveness) <ul style="list-style-type: none"> ▪ Innovative spirit ▪ Entrepreneurship ▪ Economic image & trademarks ▪ Productivity ▪ Flexibility of labour market ▪ International embeddedness ▪ <i>Ability to transform</i> 	SMART PEOPLE (Social and Human Capital) <ul style="list-style-type: none"> ▪ Level of qualification ▪ Affinity to life long learning ▪ Social and ethnic plurality ▪ Flexibility ▪ Creativity ▪ Cosmopolitanism/Open-mindedness ▪ Participation in public life 	SMART GOVERNANCE (Participation) <ul style="list-style-type: none"> ▪ Participation in decision-making ▪ Public and social services ▪ Transparent governance ▪ <i>Political strategies & perspectives</i>
SMART MOBILITY (Transport and ICT) <ul style="list-style-type: none"> ▪ Local accessibility ▪ (Inter-)national accessibility ▪ Availability of ICT-infrastructure ▪ Sustainable, innovative and safe transport systems 	SMART ENVIRONMENT (Natural resources) <ul style="list-style-type: none"> ▪ Attractivity of natural conditions ▪ Pollution ▪ Environmental protection ▪ Sustainable resource management 	SMART LIVING (Quality of life) <ul style="list-style-type: none"> ▪ Cultural facilities ▪ Health conditions ▪ Individual safety ▪ Housing quality ▪ Education facilities ▪ Touristic attractiveness ▪ Social cohesion

Figure 1 - 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.

2.1.2 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, pseudonymisation 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 and 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 2 shows a roadmap on how the technological development should be accompanied with these other aspects.

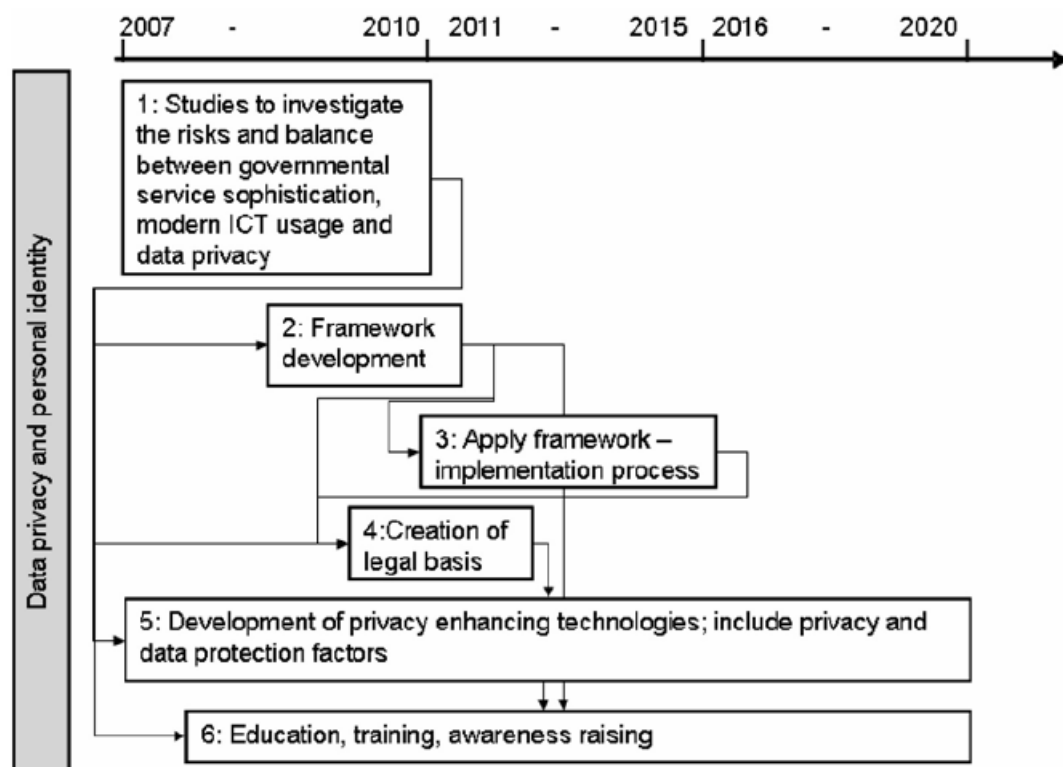


Figure 2 – Phased actions concerning data privacy and personal identity (extracted from [CoWi07]).

2.1.3 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 to 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.

2.2 E-Government

2.2.1 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.

2.2.2 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 the point of view of privacy and integrity is ensured.

2.2.3 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 3, 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 4.

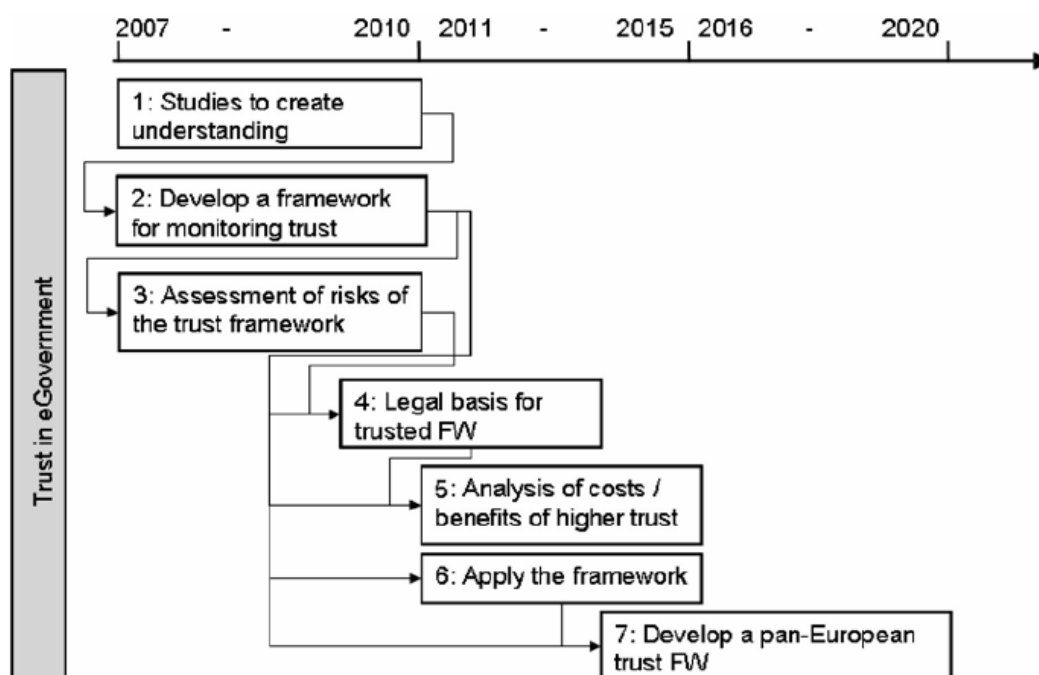


Figure 3 – Roadmap for the increase of trust in e-government in Europe (extracted from [CoWi07]).

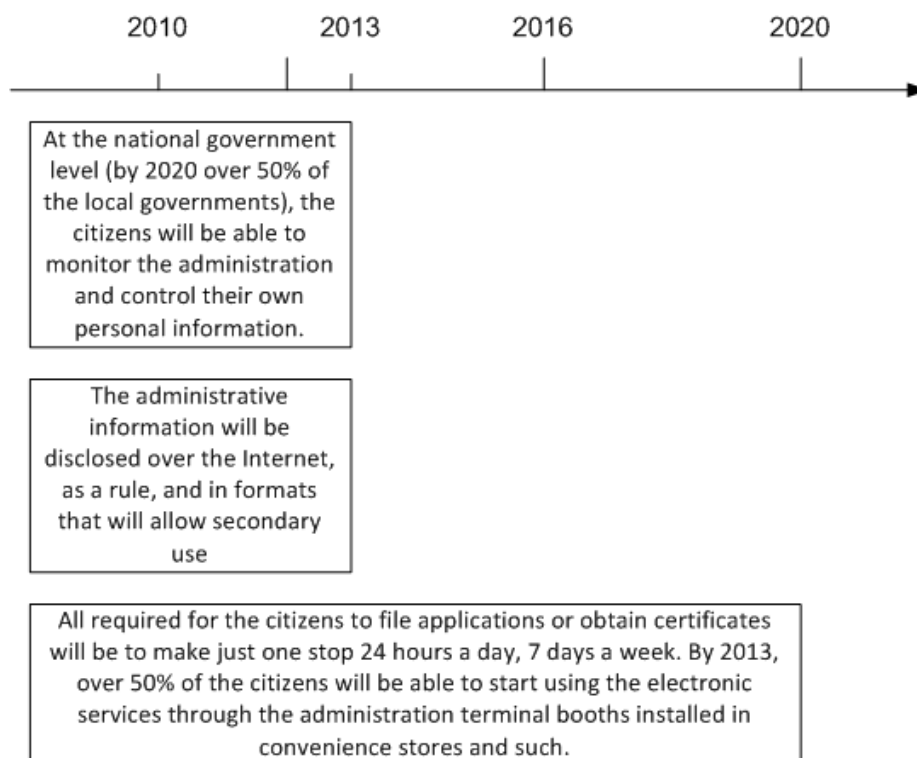


Figure 4 – Roadmap for the introduction of e-government in Japan (extracted from [JaGo10]).

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.

2.3 Health, Inclusion and Assisted Living

2.3.1 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, [Chro11], [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.

2.3.2 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.

2.3.3 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, among others); 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?

2.3.4 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, tablet 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.

2.3.5 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., doctors, relatives, and clinic personnel) 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. Thanks to 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 system of eHealth.

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 they 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 5.

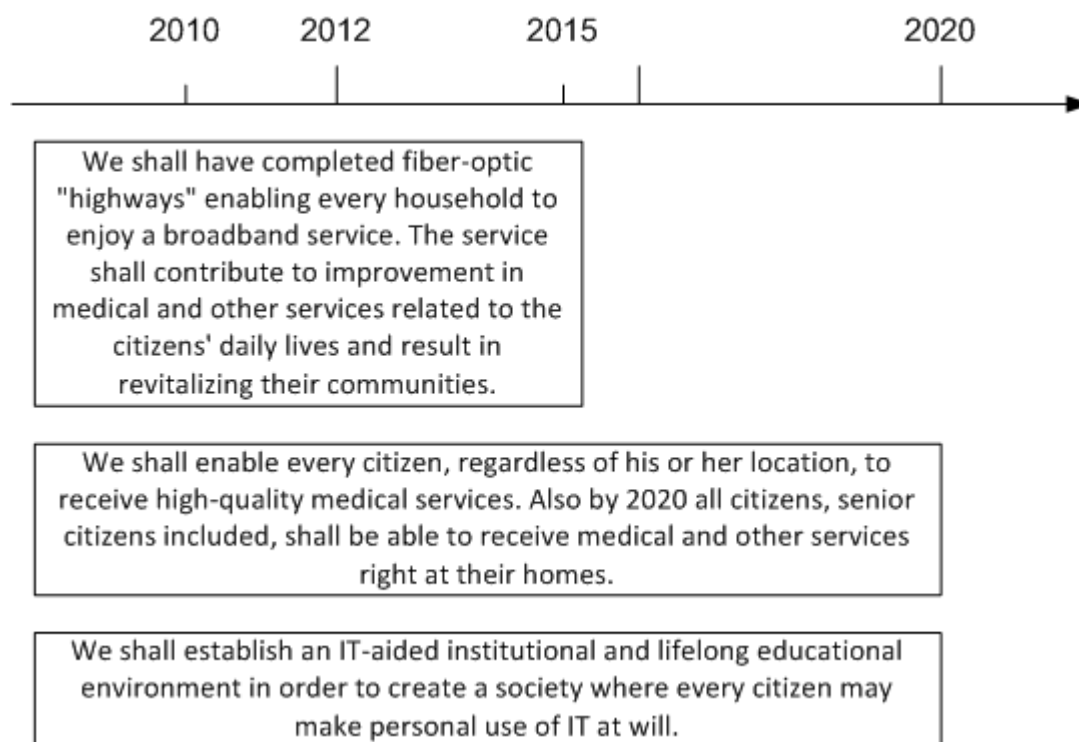


Figure 5 – Roadmap for the introduction of ICT in health care in Japan (extracted from [JaGo10]).

In Europe, an integrated perspective on healthcare solutions for the near- to long-term views has been presented by [EPOS09], Figure 6. Some of the enabling technologies are 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.

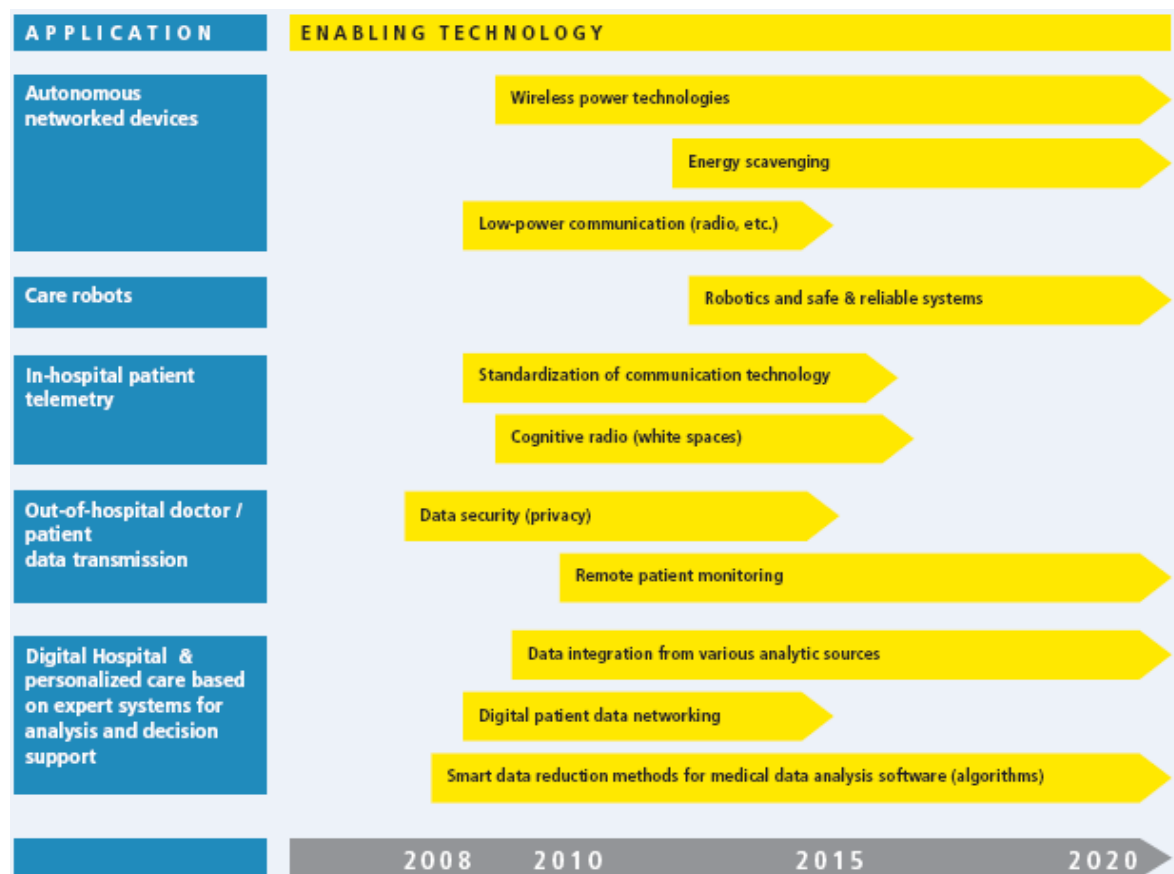


Figure 6 – Integrated healthcare solutions timeline (extracted from [EPOS09]).

2.4 Intelligent Transportation Systems

2.4.1 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, or 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, in Smart Cities.

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 [WiSa11], 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.

2.4.2 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.

2.4.3 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. Besides, 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 [SmSa11]), 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 with respect to the handling of personal data by public administrations (i.e., privacy issues) or about 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.

2.4.4 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.

2.4.5 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 the coming months.

Besides, a number of EC-funded projects, such as ICT-EXALTED [EXAL11] or ICT-LOLA [LOLA11] 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 7, Figure 8.

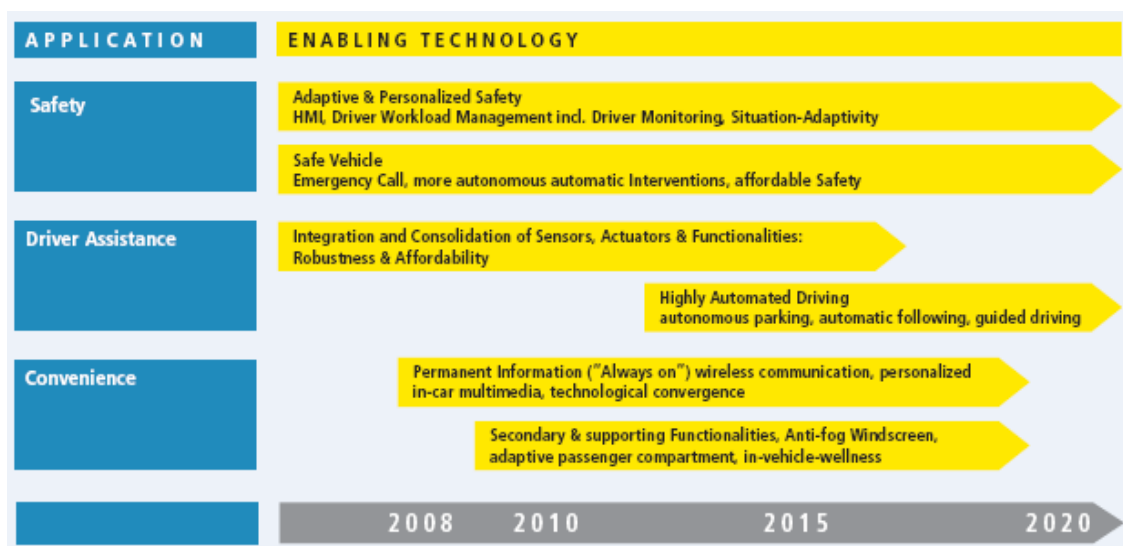


Figure 7 – Developments priorities in the automotive industry (extracted from [EPOS09]).

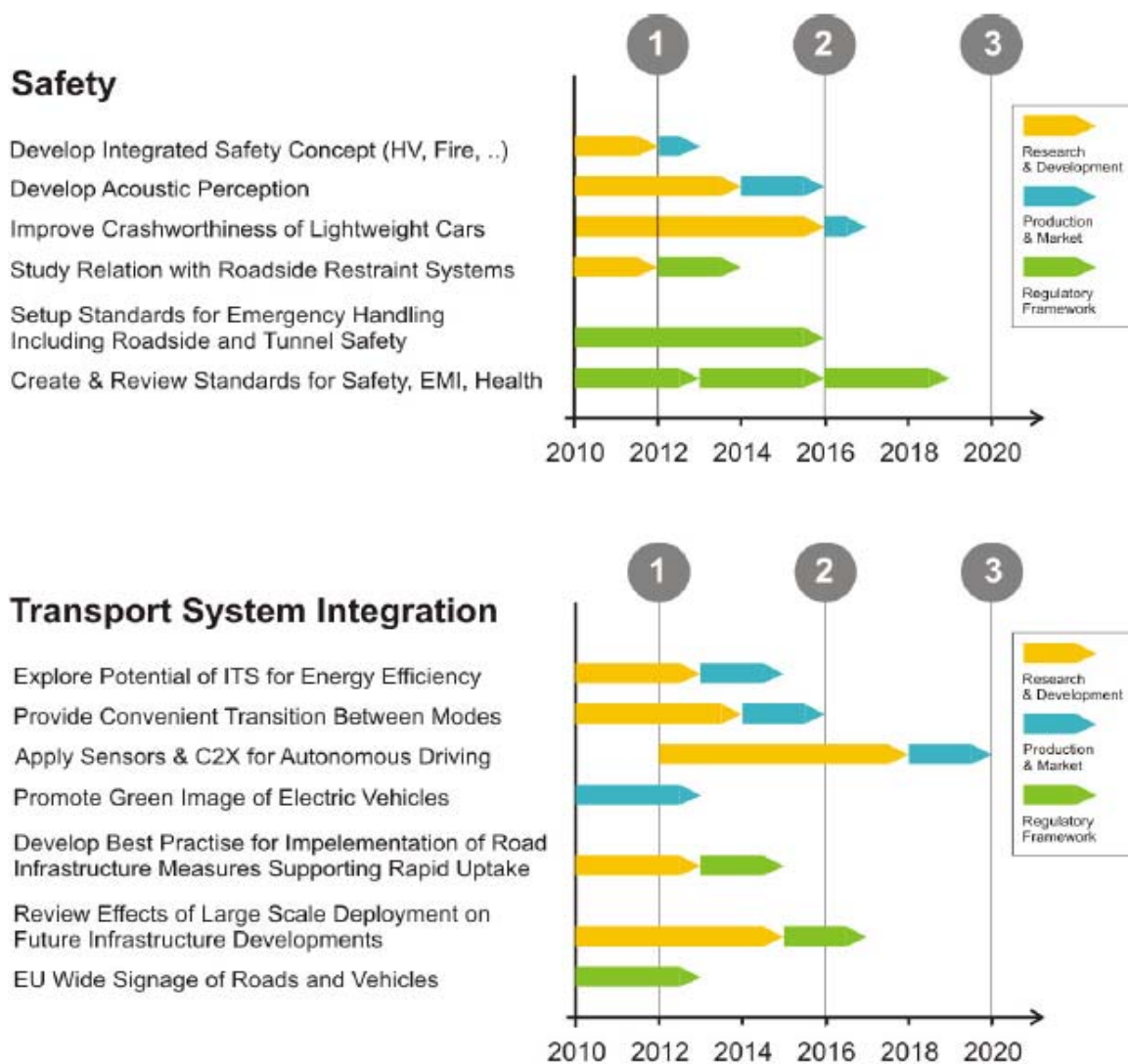


Figure 8 – Goals in safety and transport system integration (extracted from [EESG10])

2.5 Smart Grids, Energy Efficiency, and Environment

2.5.1 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.

2.5.2 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.

2.5.3 Challenges

Apart from the global environmental changes, the urbanization 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.

2.5.4 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.

2.5.5 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 9, while energy efficiency auxiliary technologies are expected to continue to be developed [EPOS09], Figure 10.

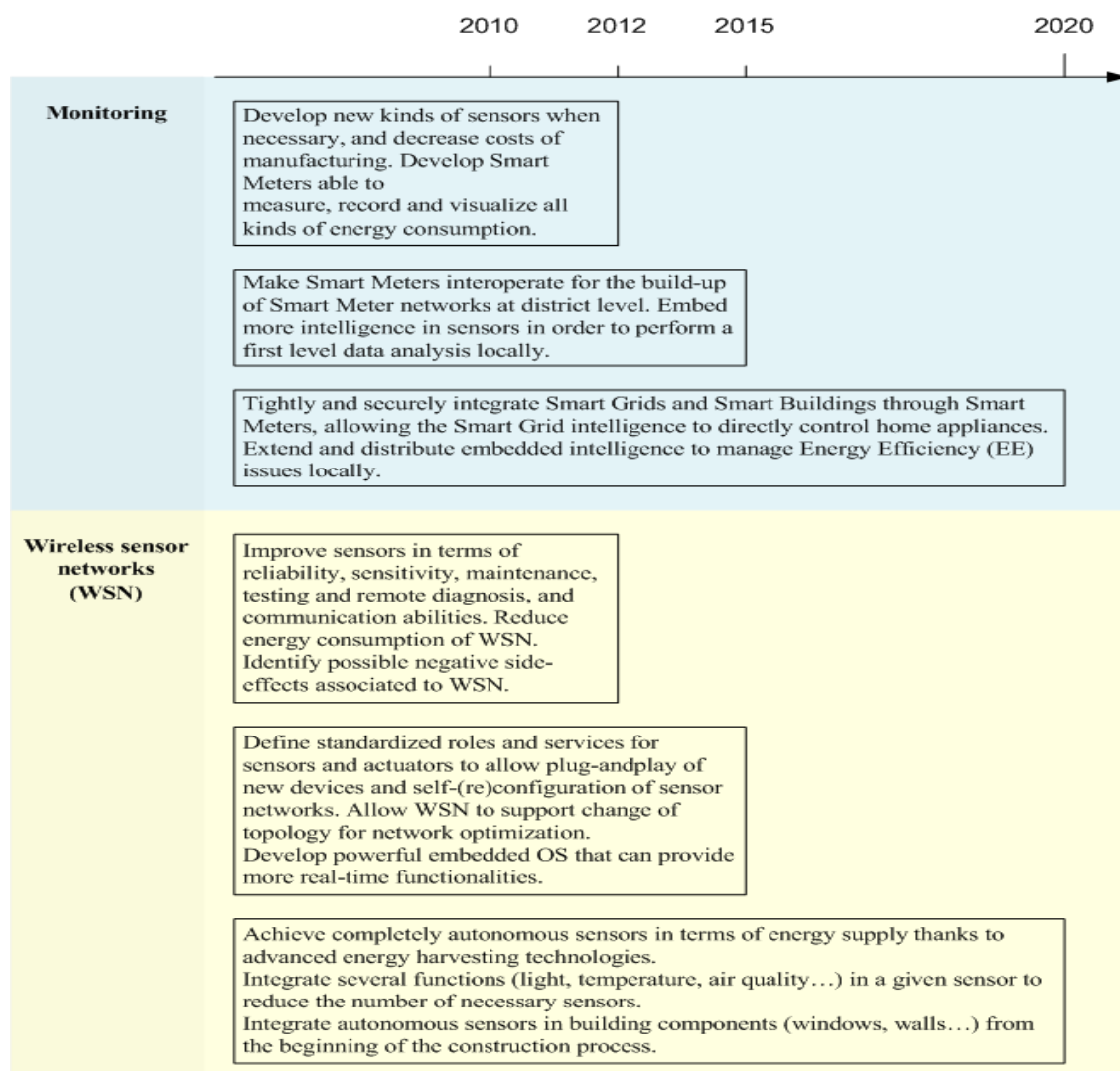


Figure 9 – Roadmap for monitoring and Wireless Sensor Networks in buildings (based on [REEB10]).

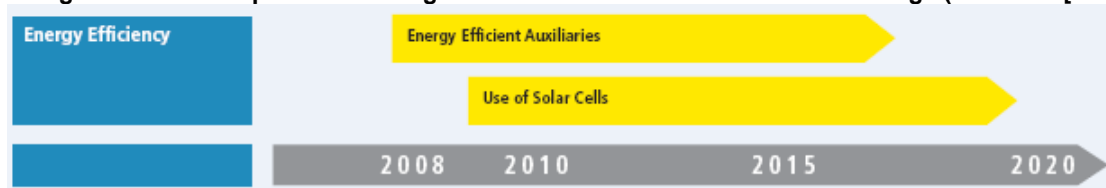


Figure 10 – Energy efficiency timeline (extracted from [EPOS09]).

2.6 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 identified 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 Intelligent Transportation Systems (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, one has addressed 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 have been 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 have been identified.

Chapter 3 Broadband Wireless Beyond 2020

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 packages. This 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 are 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 data traffic in the wireless access system. This 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 1000 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 CO₂ 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 measure 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 will have strong impact on the economy in 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 research and development 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-harmonized approach for specifying and developing broadband wireless networks, the 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 standardization. Recently, 4G systems have been specified which have to fulfil the IMT-Advanced requirements. The ITU-R is expected to analyse the demands and requirements for the next generation of broadband wireless systems to guide and harmonize the future developments towards 5G.

There are expectations from the network operators that new spectrum will become available at the World Radio Conference (WRC) in 2016. However, it can already be forecast today that, even if new spectrum will be allocated for mobile radio applications, it will not 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

Heterogeneous 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 than today. They will become more heterogeneous in terms of: transmit power, antenna configuration (number, height and pattern of antennas), supported frequency bands, transmission bandwidths, and duplex arrangements. The radio-network architectures of the nodes will vary from stand-alone base stations to systems with different degrees of centralized processing, depending on the available backhaul technology (e.g., fibre, leased lines with technically- or 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; Wi-Fi; future radio-access technologies; or any combination thereof. Last, but not least, the allocated spectrum will be more fragmented and may be shared according to new license modes.

Procedures, such as radio resource management and optimizations thereof, will, therefore, 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, latencies and other QoS parameters, should be provided in a consistent and secure way, whilst simultaneously meeting deployment criteria like energy and cost efficiency.

Energy Efficiency

Both the 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, the form factors, and the number of hops to a node with wire-line backhaul, in a harmonized way and not individually. The backhaul organization deserves particular attention, especially for cloud computing approaches. Moreover, besides solutions that are theoretically ideal, research should also take into account real constraints including desires to reduce electromagnetic radiation in general.

Switching nodes on and off, depending on the actual traffic, has been the most obvious technique to do, 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 would be desirable that does not require any energy at all while being idle. This would require a technology leap, as opposed to further fine-tuning of existing technologies. A complementary aspect is to switch on nodes before they are actually needed, introducing a proactive element in the management. This in turn requires some statistical insight in 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, especially for cell-edge users, is coordinated multi-point (CoMP) transmission, which facilitates multi-user pre-coding techniques across distributed antenna elements or other network nodes. This can be used to improve the utilization of the physical resources (space, time, frequency) by exploiting the available spatial degrees of freedom in a multi-user 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.

In the coherent multi-point MIMO channel, the user data is conveyed from multiple network nodes antenna heads over a large virtual MIMO channel. Assuming linear transceiver processing, a virtual MIMO system with N antennas is ideally able to accommodate up to N streams without becoming interference-limited. Both the inter-user and inter-cell interference can be controlled, or even completely eliminated, by a proper pre-coder selection. The coherent multi-point transmission, however, has high requirements in terms of signalling and measurements. In addition to the global channel knowledge of all jointly processed links, a tight synchronization is required across the transmitting nodes and centralized entities performing scheduling and computation of joint pre-coding weights, in order to avoid carrier phase drifting at different transmit nodes. A large amount of data needs to be exchanged between the network nodes. Thus, high speed links, such as optical fibres or dedicated radio links are needed.

The network nodes may still need to coordinate their transmissions (pre-coder design, scheduling) in order to minimize the inter-cell interference. Carrier phase coherence between the transmit nodes is not required, since each data stream is transmitted from a single base station. Thus, the non-coherent coordinated multi-cell transmission approaches have somewhat looser requirements on the coordination and the backhaul.

Optimal interference management requires global channel knowledge between all pairs of users and base stations; hence, they require centralized resource management mechanisms. Decentralized approaches are particularly attractive in scenarios where the wired or wireless backhaul signalling capability is limited. In such scenarios, the transmission is locally designed based on local channel state information (CSI) measured separately at each base station, relying potentially also on some limited wired or wireless (backhaul) information exchange between adjacent base stations.

It is fair to assume that each base station can measure at least the channels of all cell edge users, independent of which base station they are identified with (for example, during the uplink transmission phase of the time division duplex [TDD] frame). In such a case, each base station could simply form nulls (zero forcing) towards a set of users served by other base station(s) while optimising the transmission for the set of served users. In a more general form of operation, each base station can employ less restrictive interference balancing criteria allowing some controlled interference, and take that interference into account when designing the pre-coders in the adjacent base stations. This obviously requires some extra signalling across the wired or wireless backhaul links but results in clearly improved performance in certain scenarios.

Radio Access Resource Sharing

Exploitation of cloud technologies, equipment/resource sharing and virtualisation are key enabling technologies to cost-efficiently reduce inter-site (antenna cluster) distances and increase areas and degrees of coordination, a necessary prerequisite for higher traffic at

lower cost. These technologies are, unfortunately, still in their infancy, needing many breakthroughs and refinements to reach a stable status for deployment.

Broadband Radio over Fibre

This is a further virtualization step, where even the D/A and A/D converters are centralized and analogue signals are forwarded as optical carriers (optionally with WDMA) via a Fibre Distribution Network (FDN) to/from the antenna heads, which only contain analogue electrical/optical converters and amplifiers. Key challenges for this approach include minimising the 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 processing. Such high-speed, photonic-driven (and integrated) signal processing systems may support high bandwidth at high carrier frequencies from a much larger number of antennas than with conventional network nodes. They still require research regarding algorithms addressing user mobility, traffic routing and delivering, energy consumption, congestion, and capacity optimization, to cope with the considerably higher attenuations at higher bands.

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 the quality-of-service, spectral and energy efficiency, robustness, and flexibility of the entire wireless system. One of the key drivers for the evolution of the air interface is the paradigm shift from larger coverage cells to small cells dominating network architectures; hence, this viable change (for example, in link geometry) has to be carefully studied as an enabler for novel technical solutions.

Basic Transmission Technologies

OFDM (Orthogonal Frequency Division Multiplexing) 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, 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.

Advanced Multi Antenna Transmission/Reception

The use of multiple antennas at the transmission and/or receiver side is an important way of greatly enhancing the efficiency and robustness of the air interface. Although multi-antenna transmission/reception is today 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, both on link and system level. This includes more robust multi-antenna transmission (e.g., in terms of limited channel knowledge), as well as extending the capabilities of the multi-antenna transmission schemes 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, both in terms of the antenna technology itself and in terms of transmission and reception algorithms needed to efficiently utilize the antenna system.

Advanced Interference Handling

The link performance in mobile broadband systems is today 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. Research is needed to realize 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. In all systems of today (apart from simple repeaters), such interference is handled by separation of transmission and reception either in frequency (frequency division duplex) or in time (time division duplex). 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, lead to a significant improvement in overall spectral efficiency. Means to achieve this have been demonstrated in academia and the scheme becomes of particular interest in small cells scenarios, when transmit and receive signal level difference is 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, network nodes will be significantly smaller in size in the future. 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 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 in mind; some call for highest energy efficiency; for others, the emphasis would be on robustness and security. This variety in requirements and roles necessitates major improvements in designs in terms of flexibility, both for the network and the architectural design of the nodes.

Visible Light Communications

In the last decade visible light communications has been a subject of increasing interest and development due to scarcity of radio spectrum. Such interest can be traced back to the relatively recent development of white LEDs (Light Emitting Diodes). White LEDs are expected to replace the conventional lighting sources, particularly as 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 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, office, etc.), optical downlinks are possible where information is confined in 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, and 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 does not compete with radio communications, but complements it. 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 in mind. Promising approaches include the employment of multiple antennas that go beyond the 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 design of new air interface and in enhancement of existing ones.

3.2.3 Cognitive Communications (Self -configuration, -optimization and -healing)

Future wireless networks will face diverse challenges, amongst which are efficiencies in cost and resources. 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 match completely the increasing demands. An always important topic is resource efficiency, both in terms of installed/active equipment and in terms of shared resources to harvest on statistical multiplexing. Moreover, in the time of climate change and operational cost, energy efficiency has become more and more 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. The following sections will go into more details with respect to these.

Inter Layer Network Optimization

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 technology. This increased demand may lead to a need for employing new network topologies, such as multi-hop wireless networks, 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 the network stability under a large set of service demands. Traditionally, these control decisions are optimized 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 recognized 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.

Network utility maximization (NUM) provides the mathematical basis for a systematic cross-layer network design. In this framework, the entire network control mechanisms and physical layer signal processing are modeled as an optimization program which maximizes a utility function that reflects certain application needs. NUM enables the derivation of (optimal) network control policies where congestion control, routing, scheduling and physical layer signal processing are jointly optimized to maximize a utility function that reflects certain application needs (such as fairness, throughput, delay, energy efficiency, etc.).

The NUM framework enables an even more fundamental wireless network design problem to be tackled: the optimization of the network control mechanism itself. Optimization decomposition techniques can be used to break the original utility maximization problem into several sub-problems which are independently optimizing their local variables. These sub-problems are analogous to the OSI layers in the protocol stack, but, coordinated by a master program, they can still achieve the global optimality in a distributed manner. In contrast to the standard OSI layering architecture, with a design primarily based on engineering insight, the new layering scheme can preserve global optimality.

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 decentralized. The long-lasting dilemma has thus been on finding a right balance between centralised control vs. self-organised networking (SON). 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 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 utilise the maximum allowed latency as much as possible. Hence, instead of offering a more or less uniform bit pipe with varying delivery capabilities, the services could be delivered intelligently to also take advantage of the operation environment (e.g., existence of alternative access networks, including infrastructure-based or infrastructure-less, availability of bandwidth, radio propagation environment, predicted user mobility pattern, etc.) and to scale the quality according to available delivery capabilities (e.g., scalable video encoding). This is important from both energy efficiency and quality of experience (QoE) points of view.

Cognitive Radio Networks

Future networks, especially in the framework of smart cities, will be populated with various kinds of equipment accessing the wireless channel. Some nodes are calling for big pipes (e.g., for video-on-demand on notebooks and smart phones), others have stringent latency

requirements (e.g., voice over IP, multiplayer gaming) and again others have the need of a maximised robustness/reliability (e.g., digital health streams, car-to-car and car-to-infrastructure). Moreover, a much higher device variety will arise, ranging from those in the Internet of Things to notebooks/smart phones. These aspects ask for a much higher grade of flexibility of the wireless access network. Key enabling technologies here are, for example, cognitive radio networks, in order to cope with the vast number of nodes (machine-to-machine communications and sensor networks integrated into cellular networks). If these nodes would be treated the same way as mobiles are treated today, the resource consumption would be much higher compared to a solution that capitalizes on flexible spectrum management, ad-hoc networking and, potentially, software defined radio.

Summing up, many issues are still to be solved to meet future demands of wireless networks. A multitude of paths to reach these targets are available, but still in their infancy. Additionally, there is still enough space for completely new concepts and schemes able to significantly influence the future of mobile communications within the framework of key enabling technologies.

Spectrum Sharing

The WWRF (Wireless World Research Forum) expects 7 trillion wireless devices will be serving 7 billion people by 2017, implying 1000 wireless devices per person. Therefore, the limited spectrum resources will be rapidly running out because of these devices. According to an estimate by the ITU-R, the overall spectrum demand for mobile radio in 2020 will be 1280–1720MHz. Thus, strong efforts for new spectrum allocation for broadband mobile radio are needed towards WRC 2016.

Spectrum sharing is a potential method of increasing spectrum efficiency. Sharing occurs in various ways, through license-exempt bands, or usage of the same spectrum for satellite and terrestrial applications. Dynamic Spectrum Access (DSA) is a well-known technique in spectrum utilization context, in which each user observes different frequency bands and exploits vacant bands for transmission. With Opportunistic Spectrum Access, also called overlay spectrum access (a cognitive radio prospect), license-exempt users access licensed spectrum bands whenever the primary user is off. Spectrum Sharing, also referred to underlay spectrum access, allows secondary users to transmit over the licensed channel simultaneously, as long as the interference at the primary receiver is kept below a threshold value. A promising approach is to open TV spectrum due to the digital television switchover, which means most of the TV channels are cleared and could be exploited by TV white space devices. The use of a Geo-location Database is one of the well-known techniques for current wireless technology. Cognitive Radio is a worthy concept in spectrum utilisation context, which can observe the environment and adapt its radio parameters to new radio links intelligently. The combination of the increasing demands for spectrum and new technologies, such as SDR, present new challenges and opportunities for sharing spectrum. Wavelet Radio technology encompasses intelligent radio transmission systems based on wavelet technology, in order to optimize spectrum utilization, opportunistic operation in spectrum holes and interference mitigation.

In order to utilize current spectrum bands, spectrum sensing, spectrum predicting, spectrum allocation, spectrum fragmentation, and spectrum mobility are the main challenges in next generation wireless devices. High-speed processors with low power consumption, wide-band filtering, wide-band RF front-end, and accurate A/D and D/A converters are the core challenges in the future technology. Mathematical analysis complexity, adaptable scheduling, minimum delay, cooperative complexity and standardisation techniques are under significant consideration.

The vast majority of the advanced spectrum access technologies are already permissible with current regulation. However, there are still a number of issues to be resolved, including the real-time transfer of ownership or the implications of spectrum pooling approaches.

Self-organizing Systems

An interest in self-organization has appeared in recent years, due to a plethora of parameters in emerging wireless networks, which have to be configured. While this process has been done manually in the past and required tremendous human efforts, the operators have great expectations for the OPEX reductions that should result from automation. A paradigm shift in wireless network organization is needed. The off-line, open-loop planning, repeated only after major changes in the network, will be replaced by a closed loop, frequent optimization of network parameters, based on the signalling and measurement reports during the normal operation. Furthermore, as foreseen by the 3GPP and NGMN initiatives, the self-organizing systems will not only be simpler to roll-out and maintain, but the end user QoE will be significantly improved by the faster, optimized adaptation to changes as well. Future initiatives should focus on attributing self-organizing mechanisms with learning capabilities, in order to increase their efficiency in terms of decision-making speed and reliability.

However, the problem of self-organization is rather involved, due to a large number of optimization variables, often conflicting objectives, and ever-increasing heterogeneity of radio access technologies, the latter assuming coexisting cellular (GSM, UMTS, LTE/LTE-Advanced) and other wireless systems, as well as various cell types/sizes (e.g., macro-, pico-, femto-cells). The first step in the self-organizing systems framework should be the automated detection of shortcomings in the network. The problem detection is followed by the corresponding countermeasures, with the two stages constituting the closed loop.

In automated problem detection, a classification of problematic cells or areas in a cell is performed, based on the key performance indicators in the network (such as the delay, power, throughput, and statistics of access and connected modes). While much of the research relating to self-organizing systems starts from the assumption that the problem is known, it turns out that it can be quite difficult in practice to extract the exact nature and cause of the problem from the realistically-available measurements. The problem detection should establish a map of shortcomings (such as coverage holes, overshooting, hotspots, etc.) and relations among the cells in a network (interfering, unnecessary handovers, etc.), which will serve as an input for potential countermeasures.

After a problem has been detected, countermeasures should be applied in order to alleviate it. These might vary, depending on the problem, in terms of adjustment speed and complexity; they include the adaptation of antenna tilts and azimuths, power control, change of scheduling parameters, load balancing, and mobility robustness optimization, amongst others. For example, a few cell-edge users with high data-rate requirements might easily exhaust the resources of one cell. This problem might be resolved by assigning some of the troublesome users to a neighbouring cell having more favourable channel/traffic conditions. The potential for research and improvements in this area is enormous as there are many methodologies which are still waiting for a proper utilization. Some of the examples are multi-objective and distributed optimization, machine learning, and prediction techniques. It should be remarked that the countermeasures might also need to account for certain operator policies with respect to prioritization of certain users (e.g., gold/silver/standard classes).

To summarize, while there exist still many open issues, the benefits of a self-organized wireless cellular network seem appealing enough to place it among the hot topics in communications research and development. One should also notice that generic results on self-organizing systems might be transferred from the wireless cellular domain to other

communication scenarios, in order to achieve the long-term goal of making our networks significantly smarter than they are today.

3.3 Technology Road Map

	In 5 Years	In 10 Years	In 15 Years
Network	<ul style="list-style-type: none"> - small cells - Cloud RAN - local intra-site CoMP - inter-site cooperation - coverage relays - fast inter-RAT load balancing 	<ul style="list-style-type: none"> - 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 	<ul style="list-style-type: none"> - ultra small cells - immersed radio (massive multi antenna) - radio virtualization - complete inter layer/system CoMP - all photonic RF "leaky RF fibre" - cooperative relays - load balancing with multitude of systems incl. full device-to-device
Radio	<ul style="list-style-type: none"> - <i>data rate</i>: several tens of Mbps up to 100 Mbps, - <i>bandwidth</i>: up to 40 MHz - <i>antennas</i>: roughly 10 layers spatial multiplexing 	<ul style="list-style-type: none"> - <i>data rate</i>: several 100 Mbps up to 1 Gbps - <i>bandwidth</i>: at least 100 MHz - <i>antennas</i>: tens of cooperative antenna elements 	<ul style="list-style-type: none"> - <i>data rate</i>: multi-Gbps - <i>bandwidth</i>: GHz range - <i>antennas</i>: hundreds of cooperative antenna elements
Energy	<ul style="list-style-type: none"> - network architectures are adapted to energy efficiency needs - intelligent switching on/off of resources using current technologies is optimized 	<ul style="list-style-type: none"> - novel transmission schemes and novel form factors for equipment are employed 	<ul style="list-style-type: none"> - technology leaps provide further enhancements
Cognitive Radio	<ul style="list-style-type: none"> - opportunistic spectrum access in femto cells - SON for LTE-A 	<ul style="list-style-type: none"> - spectrum usage data bases - cognitive engines for access networks 	<ul style="list-style-type: none"> - secondary spectrum use via sensing - SON over heterogeneous networks
Spectrum	<ul style="list-style-type: none"> - opening TV white space - geo-location cooperating 	<ul style="list-style-type: none"> - licenses shared by co-operating operators - multi antenna signal processing - dynamic spectrum allocation location based 	<ul style="list-style-type: none"> - dynamic spectrum access - dynamic spectrum management (sensing, sharing, trading) among operators - visible light communication

3.4 Summary and Conclusions

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

Key Drivers

- 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

Potential Technical Approaches

- Heterogeneous networking solutions
- Large MIMO constructions
- More efficient duplexing and modulation techniques
- Co-operative networking concepts
- All-photonic RF
- Mobile cloud techniques
- Inter-layer network optimization
- Clustered small cells
- SDR
- Visible light communication

3.5 Recommendations

With the drastic traffic increase predicted for 2020 and beyond, strong research efforts on innovative evolutionary and revolutionary radio access network solutions are indispensable. These efforts need consolidated activities between industry and academia on a global scale. The following recommendations for successfully setting up joint research initiatives have been identified:

- 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.
- R2) In order to meet the high requirements on 5G systems, research on new radio technologies (access, multiple antenna schemes, interference handling, etc.) must have high priority.
- R3) There is a strong need for collaboration between wireless experts and optics experts towards new network technologies with very high performance at reasonable costs.

- R4) 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.
- R5) Cognitive capabilities have to be incorporated in the network design on all layers supporting a flexible network adaptation at low operational costs towards a SMART 5G Wireless System.

Chapter 4 Next Generation Network: Wireless-Optics Technologies

4.1 Rationale

The expected increase in data rate, in access networks, to 50,000 Exabyte per month in 2012 will mean urgent requirement for new technology. This consequently will lead to substantial increases in electrical power to cope with such high data rate in order of 20 TWh per year and this is approximately 8-10% of the total generated power for ICT. The access networks are responsible for about 70% of overall energy consumption by telecommunication networks. In addition, the cost per bit/Hz is decreasing which will allow more users. According to the "Green IT Initiative" report by the Japan Ministry of Economy, Trade, and Industry (December 2007), 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 sent from a PC, is modulated onto laser light and transported through optical fibre shortly after it enters the core network. The transition from electrical transport to optical transport 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 the end users' homes. Hybrid of fibre and radio networks will help in bringing the fibre as close as possible to the wireless antenna. All this is motivated by the end users demand for higher bandwidth, better quality video on smart phones, IP-based television, smart homes with networked appliances, data-hungry business applications, 3D-video conferencing. All require data rates that require efficient network infrastructure based on 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, 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 definition/ultra high definition, or 3D formats). Some of these are high-performance and/or data-intensive network-based applications with strict network resource requirements (e.g. computing and data repositories) and bandwidth requirements sometimes beyond 1Gbps.

New architectural solutions are needed capable of efficient handling of 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 the traffic growth. It is therefore important to address new architectures that replaces electrical data plane with more optical data planes in performing data aggregation and routing operations.

4.2 Research Priorities

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 number of Optical-Electrical-Optical (OEO) conversions in the transport network (backhaul, aggregation and core). This way 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 to the growth rate of demanded traffic of end-users to Exabyte per month the requirement for high-speed transportation network is essential. The main challenge that next-generation networks will face is congestions in the core, metro and access network. The congestion in the core network is due to the impact of the 3R signal processing (re-timing, reshaping, and re-amplifying) in electronic domain. This process inserts the delays of optical to electrical signal conversion, signal processing in electrical domain that significantly increases the signal processing time due to lower speed electronic system compared with that in photonic, 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 of optical and electronic switches and routers with only optical switching and routing devices and optimisation in form of hybrid switching such as packet or burst, and switching with proper protocols implementation can significantly mitigate the congestion problem.

All-Photonic Digital Radio over Fibre

Digital radio over fibre (DRoF) system is significantly more robust against the impairments of the optical communication link compared with an Analogue Radio over Fibre (ARoF). Therefore, in DRoF system, by using free spectrum of the metro and access optical communication network infrastructures, more operations and signal processing centralization at the central stations would be achievable in comparison to traditional ARoF and it can cost effectively supports the future broadband RoF access networks deployment.

The main challenges in the DRoF link implementation, however, 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, the integration of system and devices and system cost.

4.2.2 Super Broadband

The main challenges of broadband radio over fibre and fibre access are:

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 that cause serious disruption and restriction for broadband data transportation through long fibre length without periodic signal relaying. In spite of 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, the wavelength division multiplexing (WDM) techniques is a necessity, other/alternate solution is to compensate the dispersion by using either zero dispersion shifted fibre, fibre Bragg grating dispersion compensator, and, using ultra/very high dense wavelength division multiplexing (UDWDM) technique as another solution. Furthermore, implementation of high-speed all-photonic signal equalization might be the way forward as a solution.

Attenuation

Due to wireless spectrum limitation the requirements for switching to higher frequency carriers such as license-exempt mm-wave range frequency 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 sizes at high frequencies and replacing the electronic components with 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

The traffic routing and handover in converged wired and wireless networks are an extra concern, because of the bandwidth limitation, requirement for fast signal processing regarding to 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. The dynamic traffic routing and handover is main issue in the future super/ultra broadband network.

Traffic Asymmetry

Access networks capable of interconnecting orders of magnitude higher number 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 10Gb/s for the residential users and between 40 Gb/s and 100 Gb/s for the business users. 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 concern 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. The future long reach access networks will result in consolidated metro-access networks. This will reduce the number of central offices (COs) 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

The dynamic wavelength allocation (DWA) is one of the best solutions to the high data rate and high bandwidth which the wavelength division multiplexer (WDM) can provide up to 160 signals (wavelength) and data rate up to 2Tbps. There are different (DWA) types according to the assignment schemes (centralized and distributed) and each one has different types.

The wavelength conversion (WC) has been used in the DWA with different schemes and types to develop any network and overcome challenges listed below:

- To increase the network capacity by developing wavelength reuse.
- To decrease the blocking probability in the network by utilizing an improved algorithm.
- To minimize the network cost by minimizing WC utilization in the network.

Everything on IP

Progress in VoIP, IPTV and high-definition video streaming has impacted the access segment of service-provider networks. Moreover, many access lines today 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 spectrum of new IP-based applications are fuelling more demand for bandwidth is 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 relative location of supply and demand. In addition, the 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 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. Thus 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 optimal network architecture. Installation costs are also an important consideration for RoF networks. One of the prohibiting factors of FTTx installations is the labour costs 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 many of the final connection to the end user using wireless. The drawback of this scenario is that the network bandwidth may suffer as potentially large amounts of users and their devices crowd the wireless link. Thus the tradeoffs 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 as 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 uncoupled 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 several Pbps capacity and Core network node architectures reaching hundreds Tbps capacity. As a result of the deployment of deep reach access, traffic demands at edge aggregation nodes will add to multi tens or hundreds of Tbps which will aggregate into multi Pbps traffic load across the backbone network and into core Transit Node throughputs at the order of 100s Tbps.

Considering these demands, ultra-high bit-rate transmission (400 Gbps-1Tbps) is becoming a central consideration for research. Challenge is in leveraging 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 1Tbps 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 both in switching dimensionality as well as in 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, 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 is needed on the following topics:

New Control Plane architecture enabling:

- Scalable for multi-domain and multi-technology scenarios
- Automated end to end service provisioning and monitoring between different network segments and operators
- Network resources optimization by an integrated control of different network technologies (e.g., wireless and optics)
- Virtualization of the network infrastructure
- Convergence of analogue and digital communications and unification of heterogeneous technologies

- Unified OAM mechanism able to operate in a complex (multi-technology, multi-domain and multi-carrier behaviour)

New Service Plane for:

- Composition of wireless+ optical network 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 architecture 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 could be eventually involved, branches could be dynamically switched on and off depending on, for instance, traffic requirements in a certain areas. Such a concept would have a positive impact on the overall power consumption of the network. Similarly, other requirements besides the energy efficiency maximization could be diversity and interference management.

Advanced architectures are also needed in order to provide increased reliability. This can be realized by exploiting redundancy (diversity) in different ways. Redundancy at 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 these. 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 in outdoor and indoor wireless optics. Each of these categories has different approaches and techniques, with very particular technical solutions. Representative of outdoor optical wireless communications include 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 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 standardized technique in some cases and new concepts being developed currently. 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 unicast/multicast manner to users in the rooms.

In the context of femtocells, 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 femtocell RF signals to be transferred to/from antennas from/to the remote McBS exploiting telephone wires or optical fibres connectivity in place of the digital link as for xDSL. In the long term, fibre-to-the-home (FTTH) paradigm would provide the ideal cabling situation for femtocells. The concept of distributed antennas can be also implement win within femtocells, 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

Technology	5 Years	10 Years	15 Years
Physical layer	Photonic A/D and D/A	60% of Electronic components converted to optical	80-90% of Electronic components converted to optical
Super Broadband	1 Gb/s 20 % FTTH	10 Gb/s, 50% FTTH	100 Gb/s, 80% FTTH
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 one
Wireless Optics and new air interface (including femtocells 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

Important steps for implementing technology roadmap:

- Standardization: in particular in the fields of network control plane. Implementation of network prototypes comprising the innovative data and control plane solutions, in particular, pre-commercial software (control plane, network-service interworking...) 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.
- Define a next generation business models and consolidate a generic reference model under a bottom-up approach

4.4 Recommendations

- R1) Researching in 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, the solution to reduce the energy consumption and power saving should be investigated to allow us using the network optimally.
- R2) 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. The work should identify the ultimate limits of capacity and reach of wireless-wired technologies in providing network solutions.
- R3) 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 1Tb/s. By utilizing corresponding photonic system, the power consumption of network will decrease remarkably, while the processing speed and allocated channels bandwidth significantly increase.
- R4) Dynamically wavelength and channel allocation throughout the network will increase the network throughput and decrease the service cost as well as providing better spectral efficiency and lower power consumption.
- R5) Development of new wireless air interface and optical wireless to cope with the high data rate at home and in building applications.

Chapter 5 Future Networks and Management

5.1 Rationale

The continuous and fast evolution of technologies as well as user requirements drives the research community to revisit new concepts and paradigms that need to be addressed in the following 5-10 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.

5.1.1 New Architecture Capable of Evolution and Support for Integrated Services

- *Interworking:* Future Networks (FN) 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 provision of any service in a simple and pervasive manner. FN encompasses all levels of provisioning, operation, interoperability and interfaces for enhanced manageability, for diverse services and for optimal access and utilisation of shared resources.
- *Service Access:* FN should offer unrestrictive access to different service providers: FN should provide to service providers qualified access mechanism to a set of network embedded resource-facing services, providing scalable, self-managed inexpensive networking infrastructures on demand.
- *Service Provisioning:* FN can provide services of any complexity: FN should support the complete lifecycle of services that can be primarily constructed by recombining existing elements in new and creative ways.
- *Network Empowerment:* Distinguishing general characteristics of FN are: Service cognisance, Content cognisance, Knowledge cognisance, Environmental cognisance, Energy cognisance, Economic cognisance and Social cognisance.
- *Software defined Networking:* FN should support the following design goals as software defined and driven objectives, which are differentiating FN from existing networks: Functional Programmability and Elasticity; Integrated Virtualisation of Connectivity, Storage, Processing and Smart Objects Resources; In-Network Management.

5.1.2 Next Generation Networks versus Future Networks

The fundamental difference between FN and NGN is the switch from 'packet-based' systems such as those using Internet Protocol (IP) with a separate transport and service strata in NGN to a service and management - aware packet-based network, which is based on shared virtualised resources in form of processing, storage, smart objects and communication resources. These features of FN are shown in Figure 1 below.

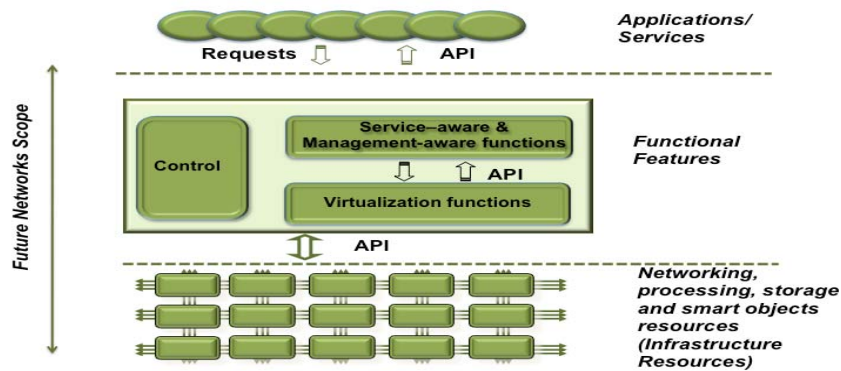


Figure 11 – Key Features in Future Networks

5.1.3 Multi Radio and Fixed Access Technologies Networks

Upcoming mobile networks are characterized by the convergence between fixed and mobile networks and the convergence of heterogeneous wireless access technologies (multi-RATs including the Fix). Furthermore, in future, networks will be extended and complemented by users themselves. The 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 the current standardized technologies in order to address the anticipated growth in the number of terminals and traffic capable of handling 1000 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 therefore 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.

However, despite the on-going extension and convergence of networks, it can be expected that network resources will not be sufficient in support of 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 learn 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 the software radio technology. The same idea should be extended to network resources, leading to the requirement for a cognitive (smart) network operation.

5.2 Research Priorities

Based on the identified requirements, as described in the previous section and the key drivers listed below, the following is the description of several strategically important research topics for realisation of the Future Networks.

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

5.2.1 Cognitive Network Operation towards a SMART System Paradigm

Traditional network management is generally statically configured, for example, 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 Self-Organizing Networks (SON) in 3GPP have paved the way for a more local and autonomous management paradigm. Cognitive Radio applies the idea of self-organizing to air-interface and generally aims at enabling spectrum sharing. Cognitive Network Operation (CNO) is extending the self-organization techniques used for radio access sub-system to include entire network with knowledge representation, automated reasoning and learning. CNO encompasses adaptive mapping of a user's requirements, preferences, context and situation onto 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 network and its resource status. The autonomous decision-making aims at optimization of 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 optimization 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 realizing 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 the 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 to the available resources within the network domains (for example, the used access technology, core/transport capacity etc.). For this purpose an intelligent end-to-end traffic steering will be necessary that spans all network parts required by a dedicated service and a dedicated user, but provides a single interface towards the network operator for defining rules and policies that autonomously set up and control the requested network services.

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 by on-demand, 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 areas, an economic viability.

It thus fosters the participation of all Europeans in the Digital market/economy and addresses one of the challenges identified in the EU Digital Agenda.

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 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 provides necessary 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 optimizing the network operation according to the characteristics and demands of the service while taking into account user profile information and user preferences opens up new possibilities for the management of the network or even the introduction of new services.
- The basis for any SMART system, especially in the case of cognitive network operation, 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 optimization process. In general, the increase of resource usage efficiency is in 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 virtualization is an important enabling technology. It also facilitates flexibility in new services introduction and deployment whilst help in hiding technical complexity and inter-operability between heterogeneous technologies of network of networks.

In parallel, the focus of the cognitive network operation can shift from optimizing resource usage efficiency towards a context aware networking where the traffic is steered primarily according to the demands of the service and the user. 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 with which 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 in internet's design), along with the increase in power of CPUs and the increasing link capacity of networks argues for a clean-slate approach when considering the redesign of the traditional end-to-end networking model. Such a model should take into consideration the factors mentioned above 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 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 storage of large amounts of content in-network as it is transmitted through the network. This enables the use of content caching throughout the network increasing efficiency and speed. Content caching can itself be seen as an additional service of the network, which can be searched, archived and updated in real-time. Another feature facilitated using such an 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 cases the party whom 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 they can deal with, however, it 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, optimization 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. Thus, at this point is where network virtualisation will bring the envisaged flexibility and transparency for the network infrastructures.

Although many virtualization technologies exist for storage and computational resources an optimum virtualization 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, API's and SDK's to allow that control and management planes deliver any type of service; independently 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. It is because they would be concurrently managed and operated, and would share the same physical substrate. In that sense, Virtual Infrastructures would consist of a dynamic composition,

interconnection and allocation of these virtual or physical resources. Additionally, these Virtual Infrastructures would offer its infrastructure capabilities as a service to third entities or control/management planes.

Actually, Virtualisation would have a larger impact in networking that is not restricted to the physical substrate. Its flexibility would allow and facilitate the deployment of new services at the control and management plane (higher layers), with new type of open interfaces, business models and relationships between entities. Moreover, the dynamically deployment of Virtual Infrastructures would allow creating customized 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 in or 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 autonomicity 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 minimization 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 the in-bound management operations should be realized along a number of dimensions, as follows:

- Degree of embedment: management functions and operation are realized 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, for example, weakly distributed management approaches. Integrated operation designates visible and modular management capabilities, but which 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 allows 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 realize an extension. Extensions can be through as the addition of new functionality, new characteristics or through modification of existing functionality and characteristics, while minimizing 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, which 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

TIMELINE	<2015	2015- 2020 Combined approach of CNO+InNM	2020+ SMARTSoftware- Defined System
Software Defined Networks	<ul style="list-style-type: none"> • Separate resource virtualisation layers operations and optimisation (connectivity, storage, computation, control resources) • Partial Network Empowerment (Service -, Content-, Knowledge-, Environmental-, Energy-, Economic- and Social-cognisance. 	<ul style="list-style-type: none"> • On-demand network provision and operation • Integrated virtualisation of all resources – operations, optimisation and usage • Partial Network Empowerment (Service-, Content-, Knowledge-, Environmental-, Energy-, Economic- and Social-cognisance) • Separate in-bound manageability in all dimensions (embeddiness, automation, autonomicity, extensibility) 	<ul style="list-style-type: none"> • Services of any complexity and any composition • Full Network Empowerment Integrated in-bound manageability • Combined approach of CNO+InNM+content centric • Dynamic service aggregation from different providers to create new complex services
Cognitive network operation	<ul style="list-style-type: none"> • Monitoring for multi-access and multi-path • Decision: autonomic and near-real optimization (centralised vs. distributed) 	<ul style="list-style-type: none"> • Monitoring: knowledge management • Decision: Cognitive, self-learning real time optimization • Autonomic adjustment based on application requirements 	
Resource sharing across administrative boundaries: Modularisation and Network virtualisation	<ul style="list-style-type: none"> • Optimised infrastructure sharing. • Virtualization 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 	<ul style="list-style-type: none"> • Modularization through the separation of functionality into generic self-contained building blocks to support a variety of business models and regional specifics • Knowledge based Virtualization of network functionality as well as of computational, communication, and storage resources in order to deliver cost- and energy-efficient operation especially in multi-administrative domain environments 	

Content centric networks	<ul style="list-style-type: none"> • Content centric optimization in order to deliver cost- efficient operation especially in multi-administrative domain environments 	<ul style="list-style-type: none"> • Cognitive content centric optimization in order to deliver cost- and energy-efficient operation especially in multi-administrative domain environments
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5.3.1 Networks Evolution Roadmap

The following figure portrays 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.

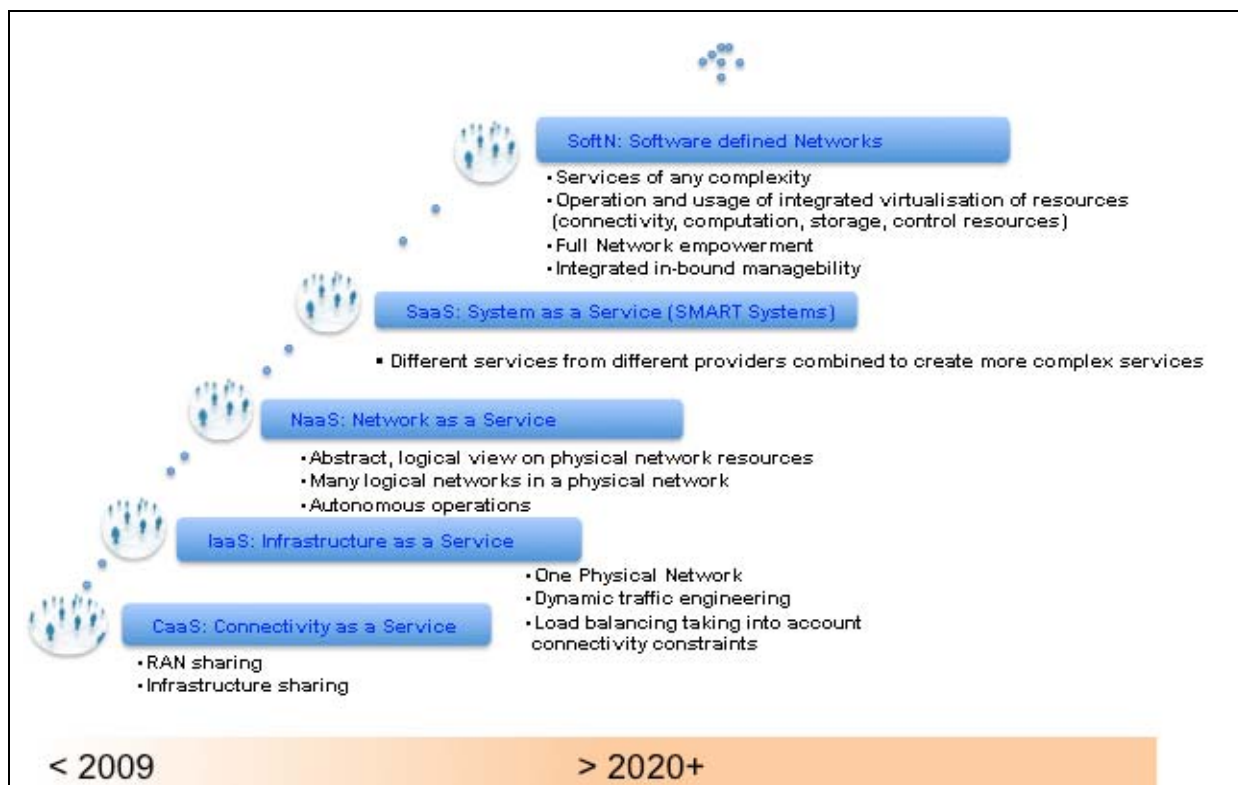


Figure 12 – Networks Evolution Roadmap

5.4 Recommendations

The following are recommendations for inclusion in the FP8 program based on current trends in services/ applications and key drivers in evolution of networks towards future smart software-defined networks.

R1) Future Networks - Definition and Design Goals

Support both clean slates as well as evolutionary research towards Future Network. Starting point in Evolutionary approach should be current networks with aim of full infrastructure sharing and optimisation to provide IaaS, NaaS and SaaS towards a smart software defined network. Energy efficiency should be a design parameter together with flexibility and robustness in the research on

FN. Future Network 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.

R2) Future Network Architectures

Research should centre on designing new architectures that can meet the research and societal challenges and opportunities of the Future Networks and Digital Society. Incremental changes to existing architectures, which are enhancing the existing Internet, could also be considered as a secondary option.

Software defined network architecture projects should address connectivity with as many as possible of the following topics:

- Unification and higher degree of virtualisation for all infrastructure systems: virtualisation of applications, services, networks, storage, content and resources as the means of enabling change from capacity concerns towards increased and flexible capability with operation control.
- Software defined and driven objectives: functional programmability and elasticity; integrated virtualisation of connectivity, storage, processing and smart objects resources; In-bound Management.
- New integration concepts enabling better integration and usage of the communication-centric, information-centric, resource-centric, content –centric, service/computation-centric, context-centric, management-centric faces.
- New virtual infrastructures addressing the unification and integration of connectivity, computation, storage and control resources
- In-bound manageability: Embedded autonomic management in systems and elements.
- Cognitive network operations (SMART systems)
- Full network empowerment including Service-, Content-, Knowledge-, Environmental-, Energy-, Economic- and Social- cognisance
- Explore and address explicitly a number of the following design requirements including: openness, economic viability, fairness, scalability, manageability, evolvability and programmability, autonomicity, mobility, ubiquitous access and usage, security including trust and privacy.
- Evaluate the proposed architecture and present results for large-scale systems integration and deployment

R3) Future Network Programmability and Elasticity

Research in FNs architectures with functional flexibility, elasticity and programmability. It should support safely the stakeholders' triggered dynamic deployment of new resource-facing and/ or new end-user facing services keeping pace with their rapid growth and change. It is supporting the means by which environment would dynamically and autonomically modify functions of the network to operate various new protocols for network services that have specific demands for in-network processing, storage and communication. These services would be placed and deployed without interferences between each other, to avoid intrusion when a function is modified to a certain service. FNs should have its architectures enabling graceful migration from experimental resource-facing and end-user facing services to operational services, to enable rapid new service deployment. It should also support trial resource-facing and end-user facing services for evaluation purposes. FNs should have its architectures optimizing capacity of network equipments based on service requirement and user demand. FNs should also perform various optimizations within the network with consideration to various physical limitations of network equipment.

R4) Integrated Virtualisation of Connectivity, Storage, Processing and Control

Research in FNs architectures supporting the creation and management of an integrated virtualisation layer concealing the underlying physical infrastructure of connectivity, communication, computation, storage, control and smart objects resources. Such layer would present to resource-facing and end-user facing services with a logical view of all types of resources. It would enable the runs of multiple services on the same physical resources. Such layer would support dynamical partitioning of physical resources so that multiple virtual resources can use a single resource concurrently and a given virtual resource would not necessarily correspond directly to its physical characteristics. Different networks would be realised on top of such integrated virtualisation layer without interfering with the operation of each other while sharing the network resources. The virtualisation layer would enable through open interfaces the management of its virtual and physical resources and also enable updating of the capabilities in networks without causing instability or integrity problems. The virtualisation layer would also support and enable dynamic movement of logical network elements (e.g. virtual machines representing service components or virtual routers or virtual objects) and capabilities among the logically isolated network partitions. Validation of integrated virtual infrastructure in terms of on-the-fly creation, deployment, management and run of new services on shared physical infrastructures.

R5) In-bound Cognitive Management

FNs should have its architectures supporting efficiently the operations, maintenance, and provision the increasing number of resource-facing and end-user facing services, entities, and the heterogeneity of physical and virtual resources through build in management functionality. In particular, FNs should be able to process massive amounts of management information efficiently and effectively transform such data into relevant knowledge for future network business. In addition all network functionality needs to be managed with ever increased automation and autonomy allowing for the network operator input as far the business and governance goals are concerns.

Priority should be given to In-bound management systems covering multifaceted integration of embedness, automation, autonomy, cognition, control orchestration and extensibility realising the benefits of inherent support for self-management features, integral automation and autonomy capabilities, easier use of management tools and empowering the network with inbuilt cognition and intelligence and manageability by objectives.

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