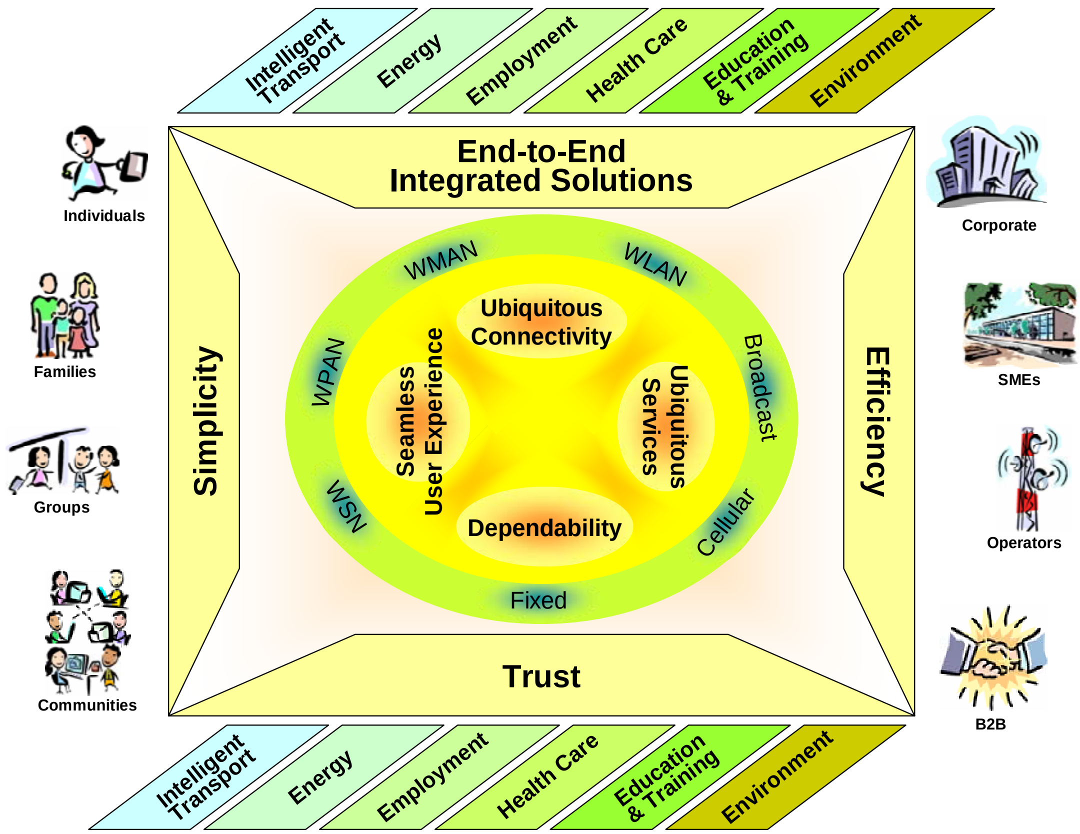
eMobility
Mobile and Wireless Communications
Technology Platform

Strategic Applications Research Agenda
(SARA)
Staying ahead



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List of Acronyms

3D	3 Dimensions
3G	3rd Generation
3GPP	3rd Generation Partnership Project
AAA	Authentication Authorisation and Accounting
ACARE	Advisory Council for Aeronautics Research in Europe
ADC	Analog to Digital Converter
A-GPS	Assisted GPS
API	Application Programming Interface
API	Application Programming Interface
ARTEMIS	Advanced Research & Technology for Embedded Intelligence and Systems
B2B	Business-to-Business
B3G	Beyond Third Generation
BAN	Body Area Network
BAN	Body Area Network
BWA	Broadband Wireless Access
C2C2E	Car to Car to Environment
CA	Context Awareness
CAN	Cognitive Ad hoc Network
CAPEX	Capital Expenditures
CC	Context Consumer
CD	Communication Device
CE	Consumer Electronics
CMOS	Complementary Metal Oxide Semiconductor
CO	Connected Objects
CogNeA	Cognitive Networking Alliance
CP	Context Provider
CPC	Cognitive Pilot Channel
CR	Cognitive Radio
CRN	Cognitive Radio Network
CWA	Cognitive Wireless Access
DAC	Digital to Analog Converter
DMB	Digital Multimedia Broadcasting
DoS	Denial of Service
DRM	Digital Rights Management
DSA	Dynamic Spectrum Access

DSP	Digital Signal Processor
DTN	Delay Tolerant Networks
DVB-H	Digital Video Broadcast - Handheld
DySPAN	Dynamic Spectrum Access Networks
EC	European Commission
ECTP	European Construction Technology Platform
EDGE	Enhanced Data rate GSM Evolution
EoI	Entity of Interest
EPOSS	European Technology Platform on Smart Systems Integration
ERRAC	European Rail Research Advisory Council
ERTRAC	European Road Transport Research Advisory Council
ESDS	Extensible Supply chain Discovery Device
ESMIG	European Smart Metering Industry Group
ETPs	European Technology Platforms
ETSI	European Telecommunications Standards Institute
EU	European Union
FA	Functional Architecture
FCC	Federal Communications Commission
FFT	Fast Fourier Transform
FI	Future Internet
FPGA	Field Programmable Gate Array
GHz	Giga Hertz
GM	Genetically Modified
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
HAN	Home Area Network
HDR	High Data Rate
HFC	Hybrid Fiber Coaxial
HSPA	High Speed Packet Access
HVAC	Heating, ventilation and air conditioning
ICT	Information and Communication Technology
IDS	Intrusion Detection System
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Froce
IMS	IP Multimedia Subsystem
IoT	Internet of Things
IP	Internet Protocol
IPR	Intellectual Property Rights
IPSO	Internet Protocol for Smart Object
IPTV	Internet Protocol Television

IS	Information Society
ISO	International Standardization Organization
IST	Information Society Technologies
IT	Information Technology
ITS	Intelligent Transport Systems
ITU	International Telecommunication Union
LAN	Local Area Network
LDR	Low Data Rate
LTE	Long Term Evolution
LV	Location Verifier
M&WCs	Mobile and Wireless Communications
M2H	Machine –to-Human
M2M	Machine-to-Machine
MAC	Medium Access Control
MBits/s	Mega bits per second
MBMS	Multimedia Broadcast Multicast Service
MEMS	Micro-Electro-Mechanical Systems
MIMO	Multiple Input Multiple Output
MOM	Message Oriented Middleware
MPEG	Moving Picture Expert Group
MTC	Machine-Type Communication
NEMS	Nano-Electro-Mechanical Systems
NFC	Near Field Communication
NGN	Next Generation Networks
NoC	Network on Chip
NQoS	Network Quality of Service
OFA	Objective Function Attack
OFDMA	Orthogonal Frequency Division Multiple Access
OGC	Open Geospatial Consortium
OMA	Open Mobile Alliance
OPEX	Operational Expenditures
OS	Operating System
OSI	Open systems Interconnection
P2P	Peer-to-Peer
PAN	Personal Area Network
PC	Personal Computer
PDA	Personal Digital Assistant
PDAs	Personal Digital Assistants
PDU	Protocol Data Unit
PLC	Power Line Communication

PN	Personal Network
PNC	Pico-Net Coordinator
POS	Point of Sale
PPP	Public Private Partnership
PQoS	Perceived Quality of Service
PSS	Packet Switched Streaming
PU	Primary Users
PUE	Primary User Emulation
QoS	Quality of Service
QoSA	Quality of Service Adaptation
R&D	Research and Development
RAN	Radio Access Network
RAT	Radio Access Technology
RBS	Radio Base Station
RF	Radio Frequency
RFC	Request for Comment
RFF	Radio Frequency Fingerprinting
RFID	Radio Frequency Identification
RFP	Request for Proposal
RFSIM	Radio Frequency Subscriber Identity Module
ROI	Return of Investment
RPC	Remote Procedure Calls
RSS	Received Signal Strength
RTOS	Real-Time Operating System
RTP	Real-time Transport Protocol
SAA	Strategic Applications Agenda
SB	Spectrum Broker
SDR	Software-Defined Radio
SDR	Software-Defined Radio
SDU	Service Data Unit
SIM	Subscriber Identity Module
SIP	Session Initiation Protocol
SLA	Service Level Agreement
SME	Small and Medium Enterprise
SNS	Social Network Service
SOA	Service-Oriented Architecture
SoA	State of Art
SOAP	Simple Object Access Protocol
SoC	System on Chip
SPIM	Spam over Instant Messaging

SPIT	Spam over Internet Telephony
SRA	Strategic Research Agenda
SU	Secondary Users
SWE	Sensor Web Enablement
TCP	Transport Control Protocol
TDMA	Time Division Multiple Access
TISPAN	Telecoms and Internet converged Services and Protocols for Advanced Networks
TLC	Telecommunications
UHF	Ultra-High Frequency
UI	User Interface
UICC	Universal Integrated Circuit Card
UK	United Kingdom
US	United States of America
USIM	Universal Subscriber Identity Module
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
W3C	World Wide Web Consortium
W3C	WWW Consortium
WAN	Wide Area Network
WG	Working Group
WiMAX	Worldwide interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMN	Wireless Mesh Network
WMNs	Wireless Mesh Networks
WPAN	Wireless Personal Area Network
WSDL	Web Services Description Language
WSN	Wireless Sensor Network
WSSTP	Water Supply and Sanitation Technology Platform
XML	Extensible Markup Language
ZEP	Zero Emission Fossil Fuel Power Plants

Executive Summary

In less than a decade from now, communications, information technologies and Internet will play even greater role, in all aspects of European citizens' lives, than predicted about five years ago. In addition to telephony services, ICT will be essential, to name a few, in providing individual's/family well-being and health, more efficient transportation systems, smarter energy generation/distribution/consumption systems, efficient factories, more accurate monitoring and control of our environments. As the consequence, ICT will remain as corner stone to Europe economy growth and its sustainability. In particular Mobile and wireless networks is now considered by many Governments as part of national critical infrastructure.

This document presents some of the work carried out in numerous long discussions and brain storming with many experts and stakeholders in the field of communications, Internet, health, transportation and environment in order to identify essential technologies for the above scenarios. It also bears the intention of mobilising researchers to focus their efforts and create awareness for EU and National research funding organisations to the strategically important application areas and technologies for keeping Europe industry a step ahead of the game compared with the rest of the world.

The effort was made by many experts in Europe to identify and rationalise research topics which are considered as strategic for Europe to invest in, beyond topics that are being currently funded through the EU and National programmes. This work can be arguably considered as highly in line with the recently published EU Digital Agenda objectives and could be used as a useful source for its implementation.

It is important to note that some of the Chapters in this document are duplicated or slightly updated from SRA version 7, as they were considered to be still relevant and important and for the benefit of completeness of the document. These are chapters 5, 10 and 12 addressing, "Trust, Security, Dependency and Privacy", "Mediation Bus for Ubiquitous Services" and "Green Wireless Communications" respectively.

The section on research methodology and "SET" are also repeated in this document as they are now started being adopted in various collaborative programmes and in particular considered as effective means of delivering the objectives of the EU Digital Agenda.

The work started with review of the" Vision of Future" developed by emobility technology platform and examined its relevance since its publication five years ago.

This was done on a continuous basis through regular examinations and reviews of other vision documents such as; WWRF Future Vision, EU Digital Agenda (with emphasis on horizontal use of ICT in other domains, such as transportation and health, etc..), Digital Britain and other European Governments' publications for example; Germany, Portugal and Ireland. Based on slight enhancement and fine tuning of the Vision, mainly in terms of more emphasis on Energy Efficiency, the experts identified the strategically important application areas and in parallel the strategic technologies that are needed in efficient support of the application areas towards realisation of the Vision.

The strategic application areas coverage were; "health and health care", "transportation systems" and "environment monitoring/control". The identified technologies for these application areas as well as technical requirements specific to the future mobile and wireless communications and Internet were identified to be; Broadband communications, machine to machine communications (M2M), power and energy efficiencies as well as a new approach to the future Internet specific to Europe industry interests and strengths. The common and underlying requirements for all the applications were identified to be; security and privacy, trustworthiness and dependability of networks and impact of all these on Networks of Future as a migration path to the future Internet. The work done and published by eMobility Technology Platform on "security and trust" was deemed to be so important and still relevant that was repeated in this document again.

The following matrix captures the required technical and technologies for efficient implementation of the identified application areas.

	Application Areas		
Technology Areas	**Health and Inclusion**	**Transportation**	**Environment**
Context and User Profiling	-Assisted living. -Personal records. - Environment context information (home, hospital, etc..)	-Road traffic condition (context). -Car (driver or passenger Context) -User profile (travel map, route planning: where, when, who, what) -status of mind and health)	-Environment context. -Face recognition -criminal profiling and tracking
Security Trust Dependability	-High integrity of information, -High dependability	-User privacy -user trust in system -dependability (very low system outage)	-Privacy (identify) -High integrity and reliability

M2M	Essential (wearable devices)	-Car-to-car -Automatic payment -In-vehicle context collection	-Essential technology -Machine-to-infrastructure
Cognitive Systems	No	-spectrum sensing -spectrum sharing -distributed control	-distributed monitoring, control, -data fusion
Broadband Communications	-High quality images, video and low latency	-car-to-car -car-to-infrastructure -In-vehicle networking	Yes
Optical Technology and RoF	-Not essential from technology requirements. -Potential impact on system cost reduction	-Not essential	-Potential impact on system roll out cost reduction
Mediation Bus	-Availability of services and user profiles across different heterogeneous networks. -Quality of Service	-In-car service platform	-Open access provisioning
Future Internet	Essential application and usage area	Essential application and usage area	Essential application and usage area
Green Wireless (Energy Efficient wireless communication systems)	Energy efficient and ---Long-life devices.	-Energy efficient communications	-Not critical

To support all of the above applications, the future ICT system would be highly complex and sophisticated to deploy, maintain and operate. It will be a network of networks consisting of a multitude of services and network types ranging across Wireless Sensor Networks (WSN), Personal Area, all the way to wide area broadband Cellular Networks. This will require new technologies that can hide complexity from users whilst achieving massive reduction in ever increasing cost of their operation and maintenance. For this, work embarked on definition and specification of network, user, terminal and environment context categories to be used for self-organising and cognitive networking. To minimise further the network costs and CO_2 emissions to the environment the work also identified mechanisms, technologies and protocols that are essential for both power and energy efficiency of future cellular networks as well as technical challenges and benefits of a hybrid of radio and fibre optic technologies.

For the Future Internet, a new approach is proposed based on Europe's unique strength and know-how. The approach takes into account technical/commercial requirements of the FI and questions political acceptability of the current approaches adopted worldwide. The idea is to develop a "parallel Internet" to the "current Internet" from a unique starting point of present and the future expected evolution of "Mobile and Wireless Networks". A number of strategic research areas have been identified for realisation of an efficient, scaleable, evolvable and open Future Internet (FI) based on a paradigm called "One Network". This approach is novel and technco-economically more practical compared with the ongoing approaches to the FI. More importantly it is based on Europe's industry strength and assets. If the "One Network" idea is supported, in Europe, it will arguably provide a much smoother migration path to the FI and will put Europe industry in driving seat to influence direction and specification of the FI with potentially massive global market share.

Research methodology proposed here is based on Europe’s traditional and successful approach to research and development of telecommunication systems as has already been experienced through GSM and UMTS work. It is now even more important to be adopted again in realisation of the EU Digital Agenda goals. The approach was presented in the e.mobility SRA version 5, under the concept of "SET” that underpins the need for a 3-dimensional vision of research goals that will deliver Simplicity, Efficiency and Trust, strongly advocating “integrated” research and “end-to-end” solutions. This end-to-end approach has now been widely accepted and will be implemented in Future Internet PPP programme of research.

1. Vision of the Future Mobile and Wireless Communication

Telecommunications infrastructure and extent of its connectivity in the world is massively enabled through widely adopted mobile communication technologies. Mobile communications, today with unprecedented penetration of more than 5 Billion users in the world, has become the basic necessity in life and now is part of national critical infrastructures. The reliability and its availability is now considered to be beyond purely business interest. For these reasons trustworthiness and its high degree of dependability is paramount for European Citizens, various industry domains, Governments and European employment and economy as a whole. The industry sector will continue contributing substantially to the European business prosperity through vertical and horizontal of its use to own and other industry domains respectively. Technology will need to greatly evolve from the current concept of "anywhere, anytime" to a new paradigm of ;

"any network, any device, with relevant content and right context in a secure and trustworthy manner and support efficient operation and delivery of other industries and services".

This stretches the art of mobile communications beyond radio and computer science into new areas of biology, medicine, psychology, sociology, human sciences, nanotechnologies, energy, transportation, health and environmental sciences. The ICT in general, as presented in the EU Digital Agenda, is the corner stone technology for creation of smart Europe, Efficient energy (Water, Gas, Electricity), smarter transportations towards zero road accident and efficient traffic management, smarter health care for ageing and young populations and many other aspects of life and industry.

The following sentence articulates the essence of the eMobility aims and vision:

"The improvement of the individual's quality of life, achieved through the availability of an smart environment for instant provision and access to meaningful, multi-sensory information and content".

An *Individual* person is in the focal point and reinforces the idea that users will have a much stronger role in defining their own communication sphere, for example, effecting personal preferences independently of network, device, location, operator and service. This also means that network and service provision should be based on users' needs and interests, namely the establishment of group communications, user safety and health care and smarter transportation and cleaner environment. *Improvement*, in parallel with novelty, constitutes one of the basic reasons for R&D, i.e., the ultimate goals are achieved not only by inventing and proposing new things, but also by improving existing ones, which, in the end, serve as enablers for new products and services. However, one must also recognise the possibility of disruptions that can totally change complete businesses; disruptions will most likely also shape the face of communications and impose completely new business models in many cases.

Quality of life is a major human goal, and eMobility contributes to it beyond the very basic provision of a communication means. The starting point of future system and service design is a person's basic needs and interests, which span one's personal, family, professional and private lives. Technology needs to improve the quality of life in terms of not only wealth creation, but also education, job skills improvement, health enhancement, security and safety and ensure living in better and less polluted environment for present and future generation of people. Machine-to-machine communications is an example to be taken into account, because it helps in increasing system intelligence and hides complexity and technology from the user, they should be embedded in our surroundings for monitoring and control of environment, user context, energy consumptions

Achieving through the availability implies tangible benefits through an integrated system made available. High degree of trustworthiness, reliability, security and ubiquity is required of present and future ICT systems. This leads to dynamic solutions, resource harvesting and borrowing. Seamless connection between private and public services, local and long-range communications, will be a major enabler in the future communications. To achieve this, it is more important to focus on information networking rather than just networking of networks.

Environment means that the users will strongly interact with the environment that surrounds them, e.g., by using devices for personal use, or by having the location as a basis for many of the services to be used. This implies a totally different structure for the networks. Also context recognised by the system and it acting dynamically on the information is a major enabler for intelligent applications and services. This also means that sensor networks and RFIDs, M2M are increasingly important. The number of devices that people carry (knowingly or unknowingly) will increase. Furthermore, the increased interaction between devices will consume power. Therefore, the problem of power consumption, and the limitations thereof, will continue to be of importance.

Instant communication, as perceived by the user, is the essence of the game, in the sense that the user will be capable of communicating how, where and whenever needed, as well as, capable of using more than one system or network simultaneously to carry the information.

Provision and access carries the two-way communications as we know it, but it goes beyond that, as the users will be provided with and have access to content and information they want in a useful way. In the future, much of the information a user require will be local for example from objects or people in close vicinity of a user or a device. The provision of, and access to the "right content" at the "right time" with high degree of integrity is perceptual, and should be provided when a user is ready to receive it, in a format that considers user privacy and present context. Sometimes the user requests the information, i.e., "user access to information", while other times it is the "information that accesses the user", based on user's personal or community profiles. The success of such a vision depends very much on simplicity of access and use of services and on operation of the devices.

Meaningful is key in the vision. On one hand, undesired information (e.g., unsolicited advertisements, spam, and viruses) and privacy are growing challenges of today's communications. On the other hand, it means that information filtering is very important, so that the users really get what they want. The users need to be aware (if they so desire) of information and content that are of interest to them. The information accessed or provided to users has to be devoid of unnecessary, irrelevant and redundant components. This requires better understanding of a user context and a user profile of interest, cultural background, profession, and many other parameters that collectively for model of a user profile.

Multi-sensory is related to provision of services and application to a user based on multitude of a human senses. The most important ones are visual and hearing and as has recently been witnessed in new product touch sense, for easier user-device-application interactions, is important in facilitating simplicity of use. Research is required in use of other human senses as well as gesture and context in further simplification and adoption of new products and services. This extends the mobile and wireless communications beyond radio and computer science, into new areas of science, like biology, medicine, psychology, sociology, and nano-technologies, and also requires full cooperation with other industries not traditionally associated with communications. Finally, the information should be multi-sensory and multi-modal, making use of all human basic senses to properly capture context, mood, state of mind, and, e.g., one’s health state. Clearly, the realisation of this vision of mobile and wireless communications demands multi-disciplinary research and development, crossing the boundaries of the above sciences and different industries.

The chapters of this document in terms of applications and technology areas were carefully selected to reflect the above vision requirements.

2. Research Methodology

Many steps are required to turn fully the future vision, established purely from a macroscopic and user centric point of view, into a reality. However, it is correct to say that, after five years since this vision was introduced, we are beginning to witness some aspects of it either in products on market or being intensely researched on worldwide. The remainder of this document, considers some strategically important application areas and identifies essential technologies needed to deliver the vision and the associated applications. Each identified technology is justified through a rationale statement and a list of research priorities that needed in delivering them.

It is not, however, sufficient to only define a list of isolated but strategically important technical and non-technical issues and projects. There is a great need to define a suitable framework with a common and complementary research policy, goal and strategy for bringing the results of research done to be integrated, harmonised and optimised and also provide a route in influencing future standards . Adoption of this common research strategy by all projects within National and European research initiatives guarantees their outcomes to be complementary and of high relevance and value. Emphasising this in European research context is the concept called the "SET Concept" that underpins the need for a 3-dimensional vision of research activities that should deliver **S**implicity, **E**fficiency and **T**rust.

2.1 SET Concept

The SET Concept was designed to overcome potential technical, business and psychological barriers to the adoption and acceptance of new technologies and services by simplification of a general and common purpose for doing research in realising the future vision . It takes into consideration the interests of users, network operators, service providers, and manufacturers, and provides a challenging research agenda for all.

Simplicity - It emphasises research into new solutions for managing complexity seamlessly on behalf of service providers and for hiding complexity from a user in accessing, using and creating services. Complexity is delegated from a user to the communication system which must adapt to the individual's life stage preferences and situation, and a variety of contexts.

Efficiency - Solutions which result in efficient use of spectrum, power and energy and generally network resources towards Greener environment, and higher throughputs, through appropriate energy aware cooperation and adaptation techniques. The new target is not necessarily higher bit rates as in the past. Autonomous self organisation is needed to continuously operate at the optimum point under dynamically varying conditions, as well as capabilities to easily incorporate (as yet un-conceived) future services and requirements.

Trust - Wireless communications will enable an always-connected environment, facilitating services to support private and professional life of individuals, families, and special interest groups. Intelligent services will be based on sensitive personal information, context and profiles traversing different network types, and multiple business and administrative domains. Any successful adoption and use of future services and networks in all walks of life, imposes the creation of a trust environment. This is necessary to overcome possible psychological barriers through building a sense of trust in the integrity, privacy, security of information and networks, as well as to protect society against malicious, criminal or terrorist activity. From another point of view, ICT systems are becoming increasingly part of national critical infrastructures. It is the corner stone technology on which many different domains and industry (energy, transportation, health, security, etc..) will be dependent on its high availability and integrity. Future research, as part of their high-level objectives, should be emphasis on making the future ICT systems highly dependable.

2.2 Building on Europe's Strengths

As was achieved with GSM, the SET Concept offers new opportunity for Europe to be the leader in adopting a holistic and balanced approach to realisation of the future mobile/wireless communication system and Internet. The SET Concept will result in efficient and usable technologies and was developed taking into great consideration users' interest/needs as well as recognising the important role of wireless communications and Internet in Europe's economy. The research programmes will need to be focused on enhancing the axis of research (Simplicity, Efficiency, Trust) in the SET Concept through innovative techniques and technologies and targeted towards a system that comprises of multiple network types. The SET framework offers a useful means to measure the relevance and output of research programmes, also facilitating faster standardisation processes and reducing time to market. Supporting measures to evaluate the evolving European policy environment against the SET framework are also needed, if effective and timely research exploitation is to be secured.

As a further step to ensure such exploitation, the most relevant research results should be integrated and demonstrated in an open and large scale infrastructure for research and education purposes that facilitates joint optimisation of different sub-systems under the same conditions. These include, for example, use of different and new frequency bands, new spectrum sharing methods, interworking and seamless mobility solutions, new security techniques, cognitive paradigms, Broadband ubiquitous communications, Machine to Machine communications, ambient intelligence, and new usages and context aware services. This infrastructure is expected to act as a European showroom of advanced mobile technologies, services and other domains usages (Energy, Transportation, Health,..) highlighting achievements from leading projects, and an open testbed to host SMEs and students through partnerships with Universities, research centres and through international cooperation, paving the way towards the Future Internet. It is pleasing to see this message, originally proposed in e.Mobility SRA v5, has been heard, noticed and now widely adopted particularly in the context of the PPP Future Internet programme. It is an efficient way of carrying out collaborative research with tangible economic impacts. It should also be adopted for efficient and timely implementation of the Europe Digital Agenda goals.

3. Application Areas

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 the changes above have to be faced, such as chronic and degenerative diseases, addictions, obesity, depression, etc. Mobile technologies enable new services that could lead to a dramatic change in health organisations and healthcare delivery practices.

In recent years, consumer demand for Mobile and Wireless Communications (M&WCs) has become a global mass market business, from which European organisations have greatly benefited and Europe has consolidated its leading position in mobile communications. However, uptake of wireless and mobile technologies as an integral part of professional application systems, designed to be stand-alone or integrated into wider systems, has yet to reach mass market proportions and is largely untapped as a market in Europe and globally. Many small scale prototypes and some field trials have demonstrated the technical feasibility of solutions, but market exploitation of the results has often not taken place, or not had lasting success, when it was attempted. The reasons why M&WCs have not yet successfully been integrated into applications on a mass market scale, generating economies of scale and scope, are often not clear and the barriers to progress are often not of a technical nature. However, clearly, the lack of international standards and the use of proprietary solutions are some of the reasons for the slow uptake of these solutions. Current understanding of the barriers to exploitation is fragmented and exists in partial form in some application domains.

Within eMobility, a WG on Leading-Edge Applications has been formed, in order to address non-technological aspects related to services and applications in M&WCs. This WG aims at establishing further links between M&WCs and other areas, find new applications for M&WCs, develop disruptive ideas for R&D in M&WCs, gather further contributions to the SRA (Strategic Research Agenda) and establish an SAA (Strategic Applications Agenda).

One of the main objectives is to establish links to players in various sectors, to identify applications and services with the purpose of fostering their rapid development through the definition and maintenance of an SAA. As a global leading technology sector, the European mobile and wireless community has a lot to offer to applications sector actors. The SAA intends to capture the mobile and wireless requirements of promising new applications in various areas, through the road-maps available in these sectors, and identifying synergies between these road-maps and those of the mobile and wireless sectors, leading to the definition on new joint priorities for research and development.

The sector of M&WCs has known a profound and fast development in the last decades, which is somehow expected to continue in the next years. The evolution, from an end-user viewpoint, has been basically in the increase of the data rates, and the appearance of a myriad of services and applications that are enabled by these augmented throughputs. A cycle of around 10 years has been observed in the sector, Figure 3.1, and in fact commercial deployment of LTE is starting in 2010.

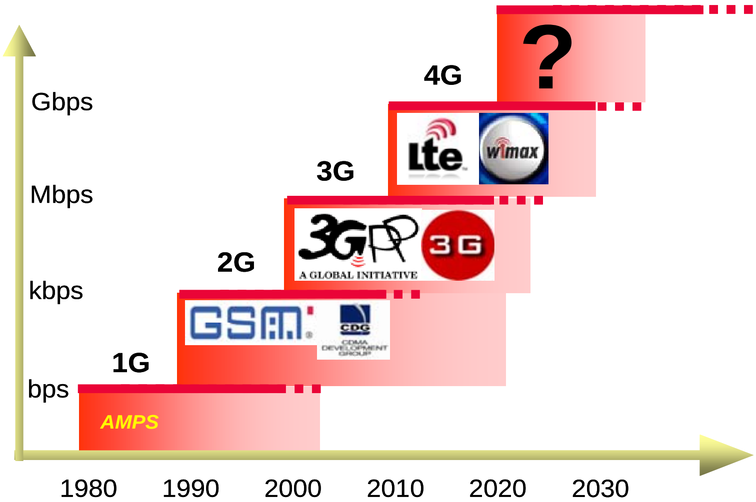

Figure 3.1 – Mobile Communications roadmap (extracted from [WWRF10]).

The task of addressing all areas of applications for M&WCs would require an enormous effort, beyond the reach of this WG. Therefore, it was decided to focus on four areas: Health and Inclusion, Transport, Environment, and Future Internet. The approach for establishing the SAA was to combine the use of desk research with published calls for ideas and contributions, inputs being solicited from a wide range of projects and programmes, together with workshops to consult a wider audience of interested parties, particularly in the involvement of the *e*Mobility constituency.

In the incoming PPPs will address these areas of applications, not only from the technology development itself, but also concerning applications and usage scenarios.

This chapter is based on the information on the SAA [eMob10], and is divided into sections concerning each of the focus areas. For each area, first, the domains according to the SAA are identified, then, challenges are listed, followed by an analysis on how to address these challenges, and finally a view on looking into other Platforms and linking to eMobility is presented, including roadmaps.

3.1 The future of Health and Inclusion

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 the changes above have to be faced, such as chronic and degenerative diseases, addictions, obesity, depression, etc. Mobile technologies enable new services that could lead to a dramatic change in health organisations and healthcare delivery practices.

Regardless of technology advances, the health sector currently lags behind other sectors in the use of recent advances in information and communications technology. This is both due to technical barriers and to limited professionals' adoption of mobile technologies for healthcare. There are several factors that have an impact on health professionals' adoption of mobile technologies for healthcare, e.g., technological, human, to get more information see the SAA [eMob10].

The core vision in the area of Health and Inclusion is "To support individuals and professionals via future mobile applications to enhance healthcare delivery, clinical performance and lifestyle."

The working group identified key areas in health and inclusion where M&WCs can have an impact, which are briefly described below.

3.1.1 Domains according to the SAA

The areas identified for Health and Inclusion were:

Future wireless diagnostic and disease management systems
In the future mobile applications will lead to simpler, safer and more personalised care. Everyone will be able to monitor his/her own health status, with wearable, smart and portable connected devices, and to share the relevant data with health personnel and doctors who will be empowered with a view of health records across multiple sources.

Hospital consultation and emergency scenarios
Telemedicine, such as hospital consultation and emergencies, is among the most challenging scenarios, in particular due to the requirements of high medical quality for multimedia data and often high mobility and real-time operation.

Hospital consultation includes streaming of medical video data from the patient site to the hospital, where specialists can perform a diagnosis according to the data received.

Emergency scenarios include data transfer between ambulance and hospital and temporary communication systems deployed after disasters (earthquakes, war, etc.).

Assistive technologies
The decrease in mortality rates among elderly people is increasing the ageing population in Europe. As a result governments must spend more money to assist these seniors' needs.

Disability problems as well as co-existence of several chronic conditions (co-morbidity) are increasingly common situations mainly for the elderly. These situations require the development of integrated technological solutions in a flexible and appropriate way.

Assistive technologies, which support people with disabilities and chronic diseases, including robotic applications and new ways of man-computer/machine interaction, represent one of the main areas where ICTs can provide opportunities to improve a persons' quality of life.

Well being and personalisation

Well being and personalisation technologies enable all citizens at home, work and leisure, to utilise and make the most of the technologies available in the benefit of health, fitness and independent living. These technologies include the areas of fitness (smart fitness and rehabilitation devices as well as concepts for fitness-training, nutrition and top-sport), personalised applications (making systems and services completely adapted to the real necessities of the final users) and home automation and intelligent environment.

3.1.2 Challenges

For each of the domains described, some challenges have been identified, and a brief description of them is given bellow.

Future wireless diagnostic and disease management systems

The European Commission has published a pan-European survey on electronic services in healthcare (eHealth) [eMob10]. The report highlights where doctors could make better use of ICT.

According to the results, telemonitoring, which allows doctors to monitor a patient's illness or manage chronic diseases remotely, is still far from being widely applied in Europe. Doctors not using ICT cite a lack of training and technical support as major barriers and note the quality provided by the systems available is quite low.

Pervasive healthcare systems and applications set demanding requirements regarding energy, size, cost, mobility, connectivity, and coverage. The technological advances of the last few years in mobile communications, location-aware and context-aware computing have enabled the introduction of pervasive healthcare applications, which implement healthcare platforms to work on personal digital assistants (PDAs) and smart phones. These systems are very critical, as they deal with a person's health, and therefore they raise high standards regarding reliability, scalability, privacy-enhancing, interoperability, and configurability, among other challenges.

Considering the fact that healthcare systems are intended to be used by beginner or moderately computer literate users, it is of high importance to build a user-friendly platform reducing complexity through better design.

Furthermore personal data security and location privacy are considered to be the most important future challenges. However, enhancements of the main functionalities in terms of speed and data compression are also considered important.

Related to challenges within the field of IT security aspects one of the main challenges in this key area relies in the trustworthiness of the gathered physiological parameter information and also on the privacy and confidentiality of the patient's health status data.

Hospital consultation and emergency scenarios

The main challenge in this area is secure delivery of medical quality (multimedia) data over wireless channels.

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.

Legal and regulatory issues need to be addressed in the near future, since there are still uncertainties about liability of healthcare services providers.

Security and privacy issues and their integration/interaction with the whole transmission system is another important challenge in the area. From the perspective of IT security the main challenges in this key area relies in the issues of confidentiality, integrity and availability of data within a system that has the two major goals the protection of the medical condition of patients and the data protection of patient's data records. This key area requires that data is sent to/from hospitals or emergency specialists in case of an abnormal medical condition. The challenge in this key area is to provide a balanced approach between privacy, data sharing and data administration. A comprehensive model of a role-based access and its deployment is an organisational and technical challenge in the medical sector with its significant number of attendees like hospital personnel, doctors or care assistants and its different players like relatives, hospitals, nursing services and registered doctors.

Privacy issues are in tension with other important demands in the environment of emergency medicine. Here, for example, the rapid availability of required information and the general availability of the service are essential to protection of the medical condition of patients and their lives. Therefore, it is necessary to anchor the privacy requirements per se fundamentally in the design and architecture development.

In addition to the confidentiality of the data sent to the teleambulance and teleconsultation service and the integrity of the data has to be considered from the sensor up to the doctor's reporting unit.

Assistive technologies

The main challenge for assistive technologies is offering independence and autonomy to senior citizens and people with disabilities. Also it will be necessary to consider ethical issues in this application domain to ensure adequate respect for the individual end user's rights, such as self-determined private life and others.

The use case within the key area of assistive technologies induces different security challenges. First, secured multimodal user interfaces have to fulfil the usability aspects of the user as well as that they do not enlarge the attack footprint of the user system itself. The later aspect means that the analysis and filtering of multimodal inputs should not be usable for attack techniques, which is definitely a current challenge in IT security research. Second, potential challenges in this field of activity refer to the secured record, storage, transfer and usage of physical activity data of the patient. This applies to the vital parameters and the geographical position of the patient, that have to be handled securely in the recording device itself, its operating system architecture, software components and evaluation services.

Well being and personalisation

Well being and personalisation have been recognised as important features for improving mobile services. But although these technologies are expected to be applied in other fields such as the occupational health and corporate wellness and new service concepts like the health couch or the self controlled stress monitoring system have been developed, these concepts and solutions are still far from being settled. Potential frustrations are among the weight of devices, the duration of battery-life, security and privacy as well as the accuracy of measurements.

More specifically, until recently personalisation has focused on social requirements, and this is popular among teenagers. However, personalisation to facilitate daily lives for the well being of all kinds of people has great potential for growth. There are a lot of services and devices personalised to the different disabilities and impairments of the people. Researches face multiple kinds of impairments, so even if people are provided with an adapted device, they only have access to a limited set of services.

The advantage of personalisation in this key area is given, but currently users are becoming increasingly privacy-conscious and less willing to disclose personal data. Privacy-preserving personalisation is a huge challenge in research, including the goals and methods of user modelling and personalisation with privacy constraints imposed by individual preferences, conventions and laws. Privacy in this context it has to include, that an information or privacy setting should be changed if the setting could be sussed by others by observing the effects. That refers to analyse a huge number of dependencies that have to be met to preserve patient's confidentiality demands.

3.1.3 How to address the challenges

As indicated in the previous subsection, there are a lot of challenges in the health area, but having identified them it is now necessary to try and give some indications to how these challenges can be overcome.

There are usability issues such as user friendliness, simplicity, HCI and ergonomics to increase the functionality that users need. This is an important factor in the design of pervasive healthcare systems.

Government policy and regulation

As mentioned, privacy and confidentiality of the patient's health status data is another challenge. It has to be ensured, that a manageable access control management system is in place that ensures that only authorised persons (e.g., doctors, relatives, clinic personnel, etc.) are allowed to access the data and ensures that the data is protected to achieve confidentiality. The authorisation should be managed by the data owner that is supposed to be the patient himself.

Legal and regulatory issues need to be addressed in the near future, since there are still uncertainties about liability of healthcare services providers.

Also, a security and privacy issues together with the confidentiality and the integrity of the data and their integration/interaction with the whole transmission system is another important challenge in the area. Furthermore Hospitality Consultation and emergency scenarios require fast information flows with enhanced security. That time-critical factor could be solved by the addition of trust, in a similar way security is handled in human societies. A person is trusted if someone we trust, says that the person can be trusted. In terms of distributed computing, a user is allowed to access a service or information, if the user has the access right to do so, or if the user has been delegated the ability by a trusted authority. To address this challenge methods and protocols are required to support this delegation. Security issues may be in tension with other important demands in the environment of emergency medicine. Here, for example, the rapid availability of required information and the general availability of the service are essential to protection of the medical condition of patients and their lives. Therefore, it is necessary to anchor the techniques and concepts emergency case to the usage control and access control frameworks. The so called “Break the Glass” obligation/privacy policies may provide a basis for a solution tackling this challenge.

It will be necessary to consider ethical issues in the assistive technologies applications domain to ensure adequate respect for the individual end user’s rights, such as self-determined private life and others. Although the ubiquitous Networks will require in more detail Individuals profile information, transparent policy in terms of personal data use is necessary for Individuals to agree on this upcoming technology trends. The privacy challenge is being addressed in *e*Mobility’s Strategic Research Agenda.

Industry structure and technology

Following the referred challenges Pervasive healthcare systems and applications set demanding requirements regarding energy, size, cost, mobility, connectivity, and coverage. The main areas of power consumption challenges are being addressed within *e*Mobility’s Strategic Research Agenda. The durability, size, weight, cost and other features could be addressed through the development of new materials and techniques to develop wireless sensors while the connectivity, and coverage could be addressed through the introduction of Multimode terminals able to adapt to both new services and new wireless access technologies and through the Wireless Mesh Networks (WMNs) which have the capability of enhancing network coverage and reducing deployment costs.

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. Smart user interfaces and interactions with learning capabilities, intelligent customer care of support in real-time and 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 which analyses the sensor data to enhance the healthcare services are recommended.

The speed and data compression challenges are being addressed through the introduction of Media formats, media compression, Media transport and Media adaptation sections of *e*Mobility's Strategic Research Agenda.

Furthermore 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. The later point means that both entities consistently are able to attest mutually that they behave in the expected way. 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 in the 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, even if data is locally stored in a medical practice, the access control system has to approve data usage according the current access permissions. That also implies that access rights have to be revocable within the data life-cycle. Furthermore in the service scenario introduced above trust models are important means to achieve it. If certain information gathered from external resources has to be seen as authentic, all elements of the service scenario have to be building blocks of a (distributed) trust system. This trust system has to ensure that the authenticity, integrity and confidentiality of a data portion that is transmitted, processed, applied or stored within the overall system is always applicable. The construction of such a (distributed) trust system could base on hardware trust anchors that have to be developed to interact with infrastructure for handling distributed security and trust. Furthermore accepted methods for access control across domains handling complex inter domain trust relationships have to be established.

The "Hospitality Consultation and emergency scenarios", as mentioned, require the transmission of demanding (medical) multimedia data over wireless links with high quality medical video. Rich media technologies should address among the others the standardisation and optimisation of rich media and enhanced rich media services (with W3C, MPEG and OMA). Most of the multimedia data transmission challenges being addressed in the Content and Media section of eMobility's Strategic Research Agenda.

Also in order to keep the required quality, lossless compression techniques are usually considered when medical video sequences are involved, resulting in huge amounts 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 in some cases acceptable, although due to the high compression ratios and to the effects of the wireless channel, such systems are of interest for a first diagnosis and in emergency scenarios, and a second diagnosis is usually required.

The most recent broadband wireless access technologies, including WiMAX, HSxPA, ev-DO, LTE, allow a broader bandwidth, which provides the means to make multimedia telemedical 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.

Because the emergency services should provide dependability and reliability 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.

In order to achieve independence and autonomy to senior citizens and people with disabilities, efforts should be focused on research projects about:

- 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 seniors' confidence. The implementation of stress detectors and face recognition applications utilising emotion recognition techniques is expected to meet the expectations and cognitive capabilities of the end users.

Economic and environmental aspects

The challenge of secured multimodal user interfaces that fulfil the usability aspects of the user as well as that they do not enlarge the attack footprint of the user system itself can be addressed by standardised GUI platforms, that are evaluated to meet the demanded IT security characteristics. These refer to that analysis and filtering of multimodal inputs should not be usable for attack techniques.

Durability, size, weight, cost and other features could be addressed through the development of new materials and techniques to develop wireless sensors. Furthermore these challenges could be addressed through the research and development of intelligent agents, ambient intelligence, smart shirt sensory architecture and wearable sensors for activity monitoring and in-home and domotic sensors. The challenge of personalisation now is not to invent new devices but to make any service adaptive to the conditions of the users and the device there are using, not the contrary. In this way, we would start to taking about equality and design for all. In parallel, artificial intelligence developments, smart user interfaces and interactions with learning capabilities could be evolved with emphasis on portable personalisation of services and networks. New mechanisms for privacy-aware collection, storage, processing and disclosure of medical contents are being required to investigate and address these challenges. The innovation here will be the centric role of patients in the definition and enforcement of privacy protection mechanisms. The main investigation topics are privacy-aware access control, usage control and transparency (i.e., auditability) concepts that are suitable for medical content delivery. Furthermore a usage control and transparency is needed to face the challenge. The integration of mechanisms will allow patients to define their privacy preferences with respect to the secondary/ downstream use of medical records, and to monitor the enforcement of such preferences. One approach to handle the challenge is the combination of a policy framework for access control with advanced auditing and a-posteori policy conformance check primitives in order to put the patient in control of her medical information.

A view

Other Platforms have looked into this area, and some links can be established.
According to Artemis [Arte06], cybernetic systems that contextualise, learn and act autonomously present fascinating challenges and open new perspectives at the borders between ICT and other disciplines such as cognitive science and biotechnology. M&WCs can play a role in here, by providing communications capabilities in between the many devices that will be part of this reality.

EPOSS [EPOS07] established a timeline on assisted health checking until 2020, Figure 3.2, and states that advanced imaging technology will be the key technology, moving from today's ultrasonic devices to future intra cardiac imaging. The combination of intelligent IT technology (data management, telemedicine) with individual diagnostic systems will lead in 2015 and beyond to a totally integrated home care system.

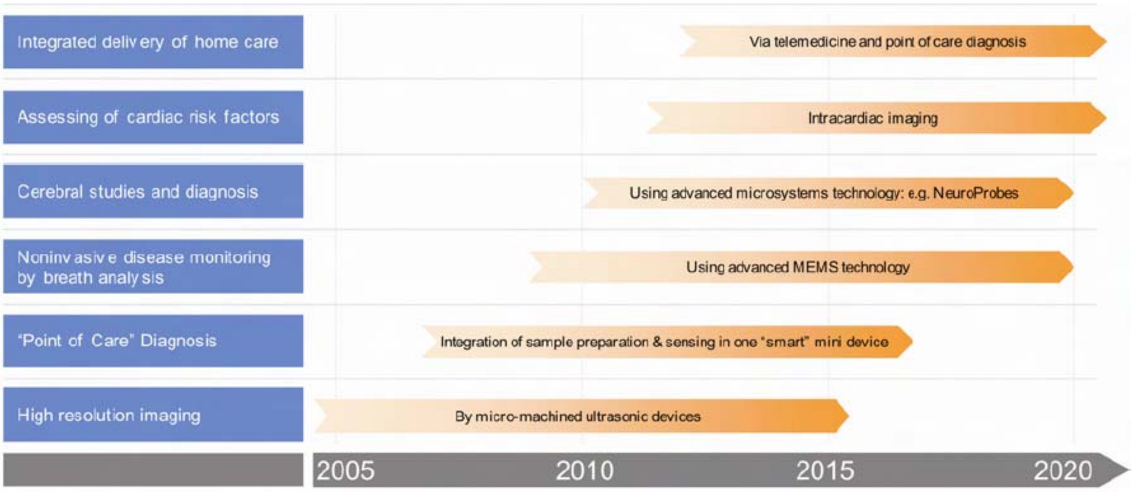

Figure 3.2 – EPoSS Assisted Health Checking timeline (extracted from [EPOS07]).

Similar timelines are identified in EPoSS for other areas in the healthcare sector, in which M&WCs will play a key role:

- In assisted therapy or therapy control, it is considered that a major technology will be the development of medical data analysis software which will allow direct data exchanges between patient and medical practitioner for diagnostic analysis and decision support. Intelligent and collaborative environments will then become available, allowing greatly increased efficiency in providing patient care. Personalised, web-based portals will provide ubiquitous, secure access to healthcare IT systems. Personalised and optimised diagnosis and therapy using genetic technologies (e.g., DNA chip), and drug-on-demand technologies (e.g., nano drug transportation) will lead to a more personalised medicine with greater patient empowerment. The ageing society will make the monitoring of cardiac function a major issue for the future. The development of active implantable cardiac devices (e.g., cardiac defibrillators, smart pacemaker) will extend on-board cardiac function monitoring. Smart robotics (biorobotics) or bio-mechatronic devices can assist minimal invasive surgery that reduces patient trauma and accelerates recovery. These various developments will lead to a totally digital hospital with fully automated functions, like digital imaging and networking.
- In full functional substitution and rehabilitation, the integration of smart sensor systems is a prerequisite to improve functionality. Trends for the future (2010 and beyond) are neural prosthesis for visual, motor, deafness, respiratory and bladder control. These applications will require the development of specific neural technologies, such as artificial retinas, optical nerve stimulation, FES for walking and standing, vestibular implants or bladder stimulators. Also neuro-modulation technologies that address back pain (spinal stimulation), Parkinson's disease essential tremors, epilepsy, depression (DBS), migraine (occipital nerve stimulation) are targeted subjects. Assisted living for full rehabilitation at home or in hospital can be supported by smart robotics in homecare units or in home-support devices for the elderly, e.g., machine-assisted physical rehabilitation. Obesity, diabetes and

hypertension (VNS) are chronic diseases that will need assisted devices. Trends for the intra-cardiac market are preventive and predictive medicine to assess risk factors and the monitoring of the at-risk population. Reliable and biocompatible cardiac resynchronisation therapy will be supported by implantable cardiac rhythm management devices. The longer-term perspective is complete functional substitution, including automated surgery by smart sensor systems (bio robots), smart prosthesis, and implantable sensors.

- In the monitoring and control of external influences, future applications of smart sensor systems will lead to a complete environment assistant for the home.

3.2 The future of Transport

Mobile and wireless technologies can contribute to the sustainable development of cities and facilitate more efficient and effective transportation. In this section we analyse new approaches for reducing traffic congestion, shortening travel times, and to provide users the most advanced and secure services while travelling. A deeper description of the concepts here described can be found at the SAA [eMob10].

The core vision in the area of Transport is "*Contribution to the sustainable development of cities and facilitate national and international transportation.*"

3.2.1 Domains according to the SAA

In this section we explore five key areas for applying mobile and wireless technologies to transport systems.

Urban and road traffic control
There are many solutions which contribute to urban and road traffic control. They include: advanced vehicle control systems, travel information and traffic management systems, public transport applications, digital mapping solutions, smart cards and communications technologies that enable the various components and applications to interact. Many of these applications are focused on integrating the vehicle movement with the road and a wider transport environment.

Efficient trip management
Providing efficient and cost effective public transport is considered a key objective of any national transport policy in order to cope with ever increasing mobility demands, and to manage increasing energy prices as well as environmental pollution. Today the traveller using public transport is faced with multiple alternatives for which multi-modal travelling solutions are required.

Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications

Wireless vehicular cooperative systems are an attractive solution to improve road traffic management, thereby contributing to the European goal of safer, cleaner, and more efficient and sustainable traffic solutions. The use of V2V and V2I communication technologies (also known as C2C2E, Car to Car to Environment) can help to reduce road fatalities and also to provide more efficient and adaptive traffic management that contributes to reduce energy and environmental costs while improving lives. The V2V-V2I communication capabilities offer the ability to detect traffic problems through the dynamic exchange of position and speed information among nearby vehicles. These capabilities can also improve traffic management through real-time exchange of data among vehicles and with road infrastructure.

The mobile office

Mobile users wish to use their devices in multiple locations, and they want to access the information they require at any time. Furthermore, this will be amplified over the coming years as more handheld Smartphone devices proliferate, personal mobility increases, access to a range of broadband wireless networks is available and "mobile workers" continue to desire access to their working environment with the same tools and applications they would have at their office. New working environments across organisational boundaries have become important, if not imperative, and are enabled by user-friendly information, new communication technologies and new ways of working.

Security, trust and privacy

Security, trust and privacy are an essential part of any system, and the user acceptance of new applications in the transport area is often linked directly to the existence of underlying security mechanisms providing trust and privacy.

3.2.2 Challenges

Certification guidelines are needed across a wide range of areas including safety issues which are very important for all forms of cybernetic transport systems. Issues with regard to personal privacy and trust arise across many of the services and applications.

The consumer market may not yet be ready for some of the location information services and further education may need to take place. The price for the service, and other barriers including equipment technically immature and too much information not really adapted to the end user could be determining factors for the deployment of these technologies.

In order to achieve a vision of a world where services are made available to all citizens everywhere, at any time, in any condition and by anyone, new technologies for service creation, customisation, deployment and provisioning are needed. This includes services for: increasing the safety of pedestrians, providing the right information at fingertip (e.g., free parking places), friendly service creation for end users, including personalised and context aware features; and finally with the right set of APIs for application developers.

Next we describe some challenges according to the transport domains analysed in the SAA.

Road and urban traffic control
Research needs to be conducted to design and optimise new dynamic, self-configuring and real-time traffic management schemes to redistribute traffic flows, and to ensure the reduction of journey times, fuel consumption and pollution. It is also of great importance to investigate the adequate combination of V2V-V2I technologies to ensure the continuous and cost-efficient operation of traffic management based on wireless vehicular cooperative solutions.

Future standards in the Intelligent Transport Systems (ITS) field must provide multiple services, over multiple platforms, that will work in different countries (as vehicles can easily cross borders), while maintaining a simple-to-use interface that requires minimum intervention from the driver. With more and more players becoming active in the ITS, the interest of developing a global standard for V2V-V2I is increasing. The problem is that there is a risk that the technologies currently already deployed in the field will prevail, not necessarily because they are the best, but simply because they are already there.

Efficient trip management
Multi-modal journeys need greater coordination of the location and time tabling of all types of public transports. More importantly, information technology needs to provide single ticket booking of multi-modal trips automatically offering the purchaser the optimum route. Additionally, the technology advances needs faster and more reliable public transport means to reduce journey times and provide more attractive alternative solutions for the transport of people or goods.

Vehicle-to-vehicle and vehicle-to-infrastructure communications
Mobile users can be classified into the following main categories: pedestrians, public transportation users, vehicular users in both urban and non-urban areas, and transportation fleets. V2V-V2I applications have to perform the creation and delivery of value added services to mobile users using multiple communication technologies and paradigms.

Wireless communications for vehicular applications have not yet reached the "one size fits all" or "one technology fits all" solution. There are not still standards at all layers, and there is also a lack of integration among them. Regardless of the selected technology, there are always three competing factors:

- Cost (e.g., equipment cost, usage cost: airtime, flat fee, data volume …).
- Quality of Service (e.g., bandwidth, latency, scalability …).
- Availability (e.g., coverage area, indoors, outdoors …).

Communication technologies have considerably progressed, but intense field trials are still needed to achieve requirements in a vehicular environment (high mobility), such as reliability, timeliness, bandwidth, priority, latency, scalability, etc. The introduction and the wide-scale deployment of technologies providing those requirements have to be faced accordingly by companies, government and road operators, since a minimum market penetration of equipped vehicles and infrastructures is required for applications to work.

The mobile office

Designing applications and services which appeal to *"mobile workers"* and cater for distinct usage environments mean that adaptation needs to be built into the system. In the coming age of ambient intelligence, context awareness will become a necessity rather than a nice feature to have. Workers will be able to select and mix service/content components, and even create their own services. Furthermore, the availability for a multitude of devices to play content and deliver services requires open interfaces and standards for communications and rendering.

In terms of access, mobile workers are expected to retrieve all kind of digital content and interact with it while being on the move. In terms of collaboration, technologies need to leverage the increasing computing power, data capacity and connectivity of surrounding services, and exploit a distributed concept. While cost and ecological impact of virtual collaboration is obvious, their potential advantages of convenience and practicality are less apparent. Consequently, research needs to focus on creating sophisticated environments, where all the human senses are engaged and where communication via technological means preserves (and maybe augment) the richness and subtle characteristics of human to human communications. Moreover, multimodal interfaces need to be exploited and improved. Speech recognition, tangible user interfaces and emotional user interaction need to be combined and adapted to provide a suitable working space to the mobile workers.

Security, Trust and Privacy

One of the main challenges across a wide range of new, converged applications is to provide security, trust and privacy in such a manner that it enhances the user's experience and the quality of the application without annoying the user or hindering the usual workflow. In the transportation domain, applications must facilitate devices moving within and through different networks and infrastructure types.

From the security point of view, guaranteeing the anonymity of users, the trust into the information, and the availability of services and the scalability of security applications are important long-term considerations that have to be taken into account. Privacy also remains a top challenge, as information about the user is measured, transferred, stored and distributed in some cases even without the knowledge of the user. Additionally, interoperability between old and new technologies can be viewed as a hurdle that has to be cleared.

The differences between national laws can be considered as a major challenge concerning secured applications. Security mechanisms are often linked with export restrictions, which already is a concern for traditional applications that are marketed internationally. Considering applications using these functions whilst travelling through different regions of the world, makes this concern weighs even more.

How to address the challenges

In this section we provide some key research topics, to address the challenges described, from three different perspectives.

Government policy and regulation

Governments must facilitate trans-national aspects of intelligent transportation and states must implement their own strategies and action plans. The principles on safe and efficient in-vehicle information and communications systems must be used as an input to a wider regulatory framework for safety issues.

Common methods must be employed by governments at national, regional and local levels in urban, sub-urban and inter-urban environments while recognising the differing needs of countries. Governments, at all levels and working with all the stakeholders in the value chain, must ensure the integration of the many vehicles management and monitoring systems will reduce congestion and pollution.

Industry structure and technology

ICTs have been a key enabler in the development of Intelligent Transport Systems to have a more effective and efficient use of road infrastructure. Intelligence (sensors) should be embedded into cars, buses, taxis, freight vehicles, roads and related systems such as traffic signals and full on board assistance to motorists. Industry should be able to turn the data into useful management information and vehicles should use the data directly as required through sophisticated data collection and analysis processes.

Mobile devices should be fully context aware and able to provide multi-modal (train, car, bus, boat and plane) applications to customers, and the sharing of information and applications across a journey. Awareness rising must be undertaken across the range of related stakeholders including the public sector, manufacturers, auto makers, etc. The integration of the location based information will ensure that consumers have vastly better information to hand to plan and enact their journeys. This in turn can cut down on lost time, wasteful carbon emissions and traveller frustration.

Today a vehicle and its relation with its context or environment have to be understood much more as a complex system where all the automotive and infrastructure functionalities act together. Cooperative systems must be promoted by the automotive industry including cooperative driving, anti-collision and warning systems to improve road safety.

Standardisation of interfaces to system functionalities is an important enabler for system integration and will have a direct impact on cost and time-to-market. Human machine interfaces are needed to fit both driver and vehicle. User friendly human-machine interface solutions must be developed to enable drivers to easily access the technology without putting themselves or other road drivers at risk.

Virtual and augmented reality, together with conferencing facilities, will enable a more natural and effective team collaboration in the "virtual workplace", and will also empower virtual communities to create user-generate services and applications.

From the software point of view, the development of systematic approaches and tools for an appropriate separation of concerns is a promising strategy to reduce software complexity and improve software maintainability. In the run-time context, self-organising software systems are expected to be able to react and adapt to unpredicted environmental changes. At the same time Service Oriented Architectures will allow the reuse, composition and sharing of modules between applications, and will provide flexibility according to new features and business challenges, openness and interoperability between platforms and environments, distribution for remote access, independence of modules, as well as performance and scalability.

Finally, standardisation of general security and privacy solutions in the domain of transportation is a key factor for success. Due to the wide spectrum of different systems and components, that have to exchange data in a secure way, the design of security solutions has to be based on common standards.

Economic and environmental aspects

Scale economies should reduce the actual operating costs to reasonable levels to make the applications practical for most users. Positive environmental benefits such as lower carbon emissions will arise from the better management of road traffic and lessening of congestion through the use of intelligent transport systems.

Security standardisation and privacy protocols are also important for economic considerations. One of the main economic challenges for secure applications in the transportation domain is obviously the expense factor of deployment in security concerns. Furthermore, it is important to consider scalability aspects for security components in the infrastructure. Security stays unrecognised when implemented in a good manner, and in order to avoid unnecessary implementation and operation of security and privacy measurements a common denominator is necessary.

A view

In the area of Transport, there are a number of bodies that have been looking into its future, and its relationship with ICT in general, and with M&WCs in particular.

ECTP [ECTP07] states that ICT can be used for fully integrated process optimisation and automated equipment. The main development issues and targets are technologies to monitor, to reduce and manage risks.

Artemis [Arte06] states that embedded systems are everywhere, being part of the future. They are interconnected into networks of many devices – the car to the fixed road infrastructure, the smart card to the banking systems. Nano-scale electronics and the increasing system complexity will need the modularisation of device construction (a device being, e.g., a mobile terminal) simply to keep the design effort manageable and successful.

EPoSS [EPOS07] has a roadmap on the major automotive R&D challenges from a functions perspective Figure 3.3, stating that up to 2015 it will be driven by customer, legislative and competitive requirements. The underlying technologies are sensors to characterise the situation completely (traffic, vehicle and driver), computational networks to analyse and obtain decisions, communications protocols and infrastructure for interaction and smart actuators, and human-machine interfaces to act in a proper way. The objective is to develop personalised vehicles – adapted to the driver and changing their attributes to personal and situation-specific needs.

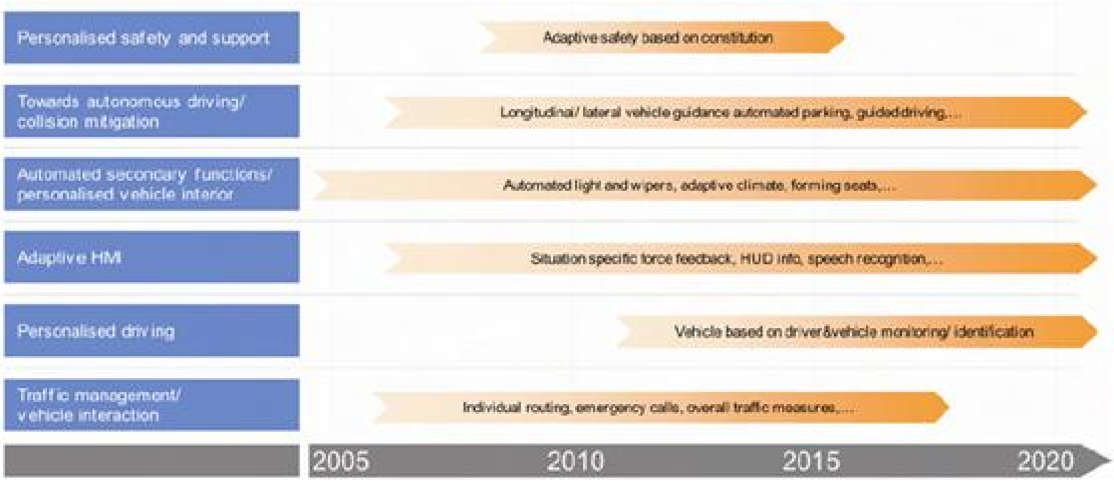

Figure 3.3 – Research priorities for automotive technologies (extracted from [EPOS07]).

ERRAC [ERRA07] states that for the next decade:

- A European-wide Intelligent Infrastructure is needed to support customer information systems offering a higher quality of service through seamless transport technologies between Member States and across transport modes.
- High-performance Telematics systems to better manage passenger and freight traffic will demand better interface protocols to safeguard existing national investments while offering greater cross border utilisation.
- The secure transmission of passenger information will need to balance civil liberties and security needs.
- Future traffic management systems will include train positioning and related traffic management.
- Independent databases will be developed with the ability to pool relevant information for operations management and logistical planning.
- Innovative Communications Technologies, will exploit Galileo and mobile broadband to deliver all the above at affordable cost.

A joint work among ERRAC, EPOSS and SmartGrids [EESG09] (European Green Cars Initiative) has addressed milestones for the next ten years, related to multi-annual implementation of the European Green Cars Initiative, Figure 3.4. Six major technology areas are identified: Energy Storage Systems, Drive Train Technologies, System Integration, Grid Integration, Integration into the Transport System, Safety. Some of these areas are in direct relationship with M&WCs, e.g., System Integration, Integration into the Transport System and Safety; in particular, in Milestone 3, the following goals are identified: novel platform based on overall system integration, automated driving based on active safety systems and car-to-x communications, and maximum exploitation of active safety measures for electric vehicles.

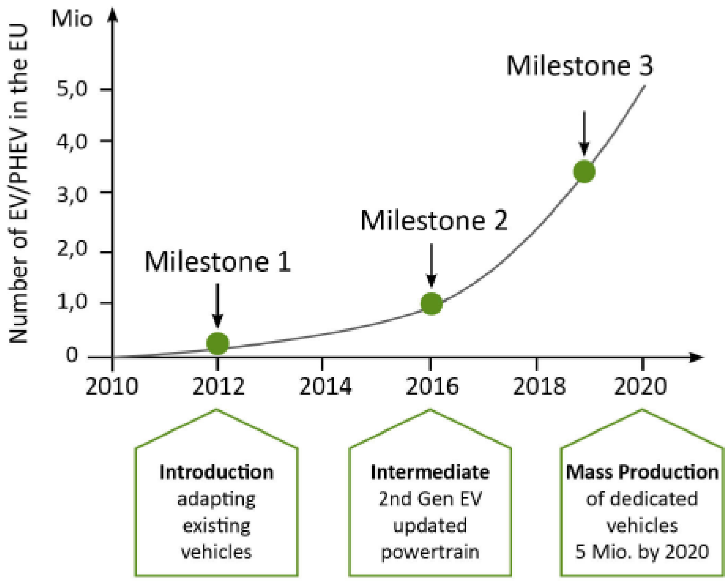

Figure 3.4 – Milestones of the European Industry Roadmap for Electrification of Road Transport (extracted from [EESG09]).

The particular goals within Safety and Transport System Integration clearly show the interaction with M&WCs, Figure 3.5.

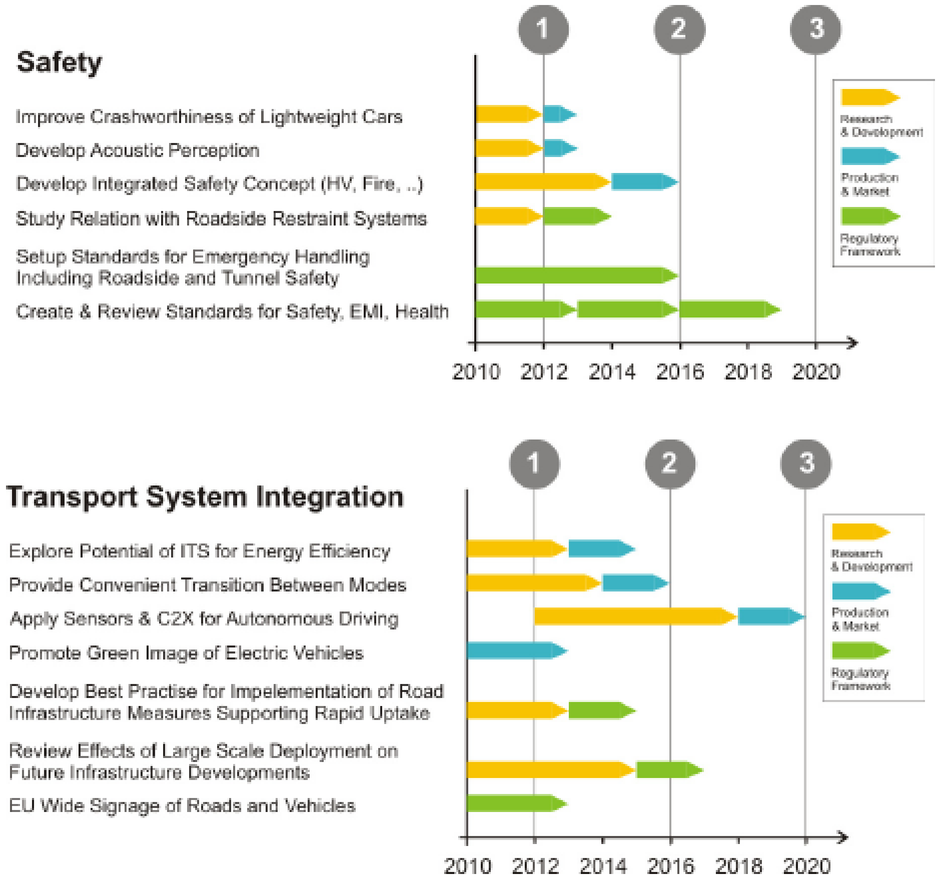

Figure 3.5 – Goals in Safety and Transport System Integration (extracted from [EESG09]).

The European Green Cars Initiative has recently established Recommendations for a Strategy on Clean and Energy Efficient Vehicles [EGCI10], which include objectives that require the intensive use to ICT, namely: the electrification of mobility has to be made viable at the earliest possible opportunity by carrying out R&D and delivering the world's most advanced plug-in hybrid and full electric vehicle technologies and services; standardised charging infrastructures and billing systems need to be made available in a timely and coherent manner; innovative services as well as optimization of existing transport modes and logistics is generally needed.

Last, but not least, concerning the deployment of ITS in Europe, one has to consider the action plan from the EC [ECIT08], where several objectives are established to be achieved until 2014.

3.3 The future of Environment

The environment is a constant consideration in our lives, including the development of technologies and their associated impact on the environment. Given the increased concern with energy and other environmental issues in nowadays society, it comes as no surprise that environment is one of the focuses of *e*Mobility's SAA [eMob10]. In this document four domains were identified and are shortly described in next subsection, more information can be found at the SAA [eMob10].

The core vision in the area of Environment is "*Natural and man made hazards can be monitored, in order to provide the necessary alerts, and efficient solutions are required, so that we can live in a cleaner and safer environment.*"

3.3.1 Domains according to the SAA

The areas in environment area where mobile and wireless communications were considered to have an important role were:

Monitoring
Our planet is constantly changing, and one of the major issues that exist is how to be able to predict events that may impact on the people's lives. Through the monitoring of some environmental parameters, it is possible to study their behaviour and evolution, enabling to take the necessary measures to prevent catastrophes. There are parameters strictly of natural origin (e.g., geographic) and others were society and people may contribute significantly or even be the sole responsible for (e.g., radiation, pollution).

The impact of using ICTs in this area is huge. The ability to collect data and disseminate information, allowing a wider knowledge data base and efficient means of monitorisation of people's quality of live is of extreme importance.

Alarms
When considering the environment one of the major issues that we have is how quickly it can change around us. These changes can be quite harmful to the people that are affected by such changes. So it is important to have means of sounding alarms to the changes that are occurring, in order to take the necessary measures to decrease the impact of these events in the populations and regions.

There are several areas were the usage of a sensor networks in order to monitor and give alarms to an event is extremely helpful, for instance, to detect floods, fires, volcanoes eruption at the surface, and many others.

Efficient resources management
Now days, one of the major issues that we are facing regarding the environment are the limitations that we have in terms of the natural resources usage. The natural sources of

energy (e.g., oil) and also the impact that their exploration has on the planet and economy is becoming an unavoidable and very important topic. As such, the different applications that can contribute to have a more efficient management of the planets natural resources are on the spotlight.

Technology waste
Our society is more and more a consumption society, moreover a disposable consumption society that produces large quantities of waste. A large quantity of this waste is coming from the technology usage, e.g., PCs and mobile phones. So, when considering the environment it is inevitable to consider the impact that the amount of waste produced has on the planet, and consideration regarding this has to be given in the near future.

3.3.2 Challenges

Considering the four key areas – Alarms Monitoring, Efficient resource management and Technology waste – there are events and phenomena raising awareness for new needs and requirements. These key areas are increasingly important, given global drivers such as public safety and sustainable growth. All the solutions require investment and must show results which are measurable and economically viable in the long term. The mix of solutions can potentially address a large commercial market on a global scale. The drivers for the various solutions derive their specifications from risks caused by natural phenomena (e.g., volcanic activity, earthquakes), those caused by human activity (e.g., production methods, handling of waste, choice of materials and components) or an unforeseen hazardous deviation causing a serious risk to human life (e.g., chemicals used in food substances, issues with safety in public places).

So when we look at the challenges that are being faced one must look not at the individual areas identified, but at the whole chain, because of the intertwining between the different domains.

Monitoring & Alarms
Alarms per se are currently isolated systems, triggered by set limit values. They provide a warning signal once a risk has already been identified. Future opportunities lie in combining monitoring and alarm solutions. The terminals lifespan will also be extended in the future, as solutions and applications are increasingly becoming software driven, such as:

- Recognition and prevention using learning systems (pervasive computing, data mining, neural network applications able to process and analyse data).
- Linking servers through robust and reliable transmission channels to multiple kinds of terminals (such as, positioning-enabled terminals receiving warnings based on direct satellite signal, also A-GPS, mobile network station, DVB-H, WLAN/Wi-Fi, and short range sensors and transmitters connected to a remote server storing and packing the data for later use).

Globally distributed and interconnected systems could transfer an alarm at one location to a pre-warning signal in the surrounding areas and countries, such as forest fires or other sources of hazardous or harmful chemicals spreading over wind or water. The challenge lies in setting standards and conventions surpassing national and language boundaries, but also political and legal issues. Product reliability, other legal issues as well as prevention of malicious attacks and viruses are also major considerations for such critical systems.

An example that focuses on some of these issues is meteor burst technology. There are some legal, regulatory and institutional challenges. The authorisation of the communications solution chosen for water quality and air quality monitoring is left to the utilities and environmental sector to decide. Usually the most cost effective approach would be the most preferred solution. However there are some factors which contribute to the decision for a less cost effective but more practical solution, such as, remoteness of deployment and specialist monitoring equipment used.

Meteor Burst is a technology predominantly deployed within the UK and the US that is used to monitor different types of applications with environmental monitoring a large proportion of its use. The technology operates within an internationally recognised spectrum band allocated for fixed and mobile by the ITU in region 1 at 46/47 MHz and 49 MHz. European countries use this spectrum for many different applications, which presents some distinct difficulties for expansion across Europe, so any foreseeable challenges may emerge in the regulatory spectrum area.

Two key challenges surrounding this technology are mainly its low density of usage, and difficulty to become more widespread which thus negates any possibility of economies of scale, enjoyed by more popular technologies such as GSM and GPRS.

Meteor Burst technology has a limited user base and small target market. However, it is considered to be a cost effective solution compared to other wireless technologies and there are some benefits to using it, namely, it as a long range communications, very good coverage area in remote regions, and is cheap to maintain, service and operate.

The benefits are only realised in very rural hard to cover areas of the country where most cellular or even broadcasting coverage is not served. It is therefore mainly found in industries where this application is most suitable like environmental, water treatment and system processing.

The main economic challenges are cost of deployment and widespread deployment of equipment.

The technology would require some major investment for further development that would help reduce costs of components and the improvement of the integrated system design.

Meteor Burst does not cope well in real time related environments, and it may be susceptible to interference from noisy, heavy plant machinery. This type of system could be worthwhile from a wider European perspective where more remote regions could use this system for very wide area remote data collection.

Efficient resources management & Technology waste

Efficient resource management is measurable through assessing the ecological footprint and life cycle management. For example there are increasing amounts of hazardous waste resulting from manufacturing processes and discarding devices such as mobile phones. The proactive solution focuses on designing for ecological sustainability taking into account battery life and reusable materials.

One of the main issues regarding environmental monitoring is to provide guidelines that facilitate critical information availability, as well as the way the information is computed, transmitted and delivered. Usability and reliability play a key role in new solution design and implementation. It is also important to increase the collaboration between environmental organisations, the public sector and industry in order to focus on the most imminent risks, allowing the technology to improve the security of the professionals involved and the way it affects their lives and work.

With the current focus on energy production and consumption (e.g., oil), there is great concern to improve and find new and more efficient ways of producing energy and produce/recycle electronic components in an environmentally friendly way.

A statement that it is generally accepted is that Energy Efficiency is one of the key issues to be considered when addressing global warming and climate changes. It is, in fact, the key factor for a sustainable economy. The ICT sector is well positioned to assume a leading role on promoting energy efficiency across all energy-use sectors. Despite ICT sector being responsible for about 2% of carbon emissions, it can contribute to cutbacks of about 15% by enabling technological improvements in other sectors [eMob10].

The EU aims at promoting the cooperation of the ICT with other sectors in order to ease the transition to an energy-efficient, low carbon economy, and the ICT sector should be committed on promoting a measurable and verifiable reduction in carbon emissions of its own processes, in close cooperation with the buildings and construction sector, identify solutions to improve energy efficiency of new and existing buildings and constructions, and in close cooperation with the transport and logistics sector, identify ICT solutions to improve the environmental and energy performance of their services

Buildings and construction, transport and logistics, together with power transmission and distribution have been identified as the sectors were ICTs can deliver greater improvements. Quantifying this untapped potential, recent studies estimate that ICTs can be exploited to reduce energy consumption of buildings in the EU by up to 17% and to reduce carbon emissions in transport logistics by up to 27% [eMob10]. The energy consumption must look at the entire chain, from primary energy up to the end user/equipment, so one can say that ICT is to balance the areas of consumption and emissions [CoLa10].

When discussing energy efficiency in the power transmission and distribution sector, the focus should be on the implementation of the so-called smart grids. A smart grid is defined as a set of tools designed to improve efficiency, reduce the need for excess capacity and allow two-way real time information exchange within power distribution networks. The two main topics that must be considered are energy production (with focus on distributed energy resources) and advanced metering infrastructure (smart metering).

ICTs role in applications and services, that can be developed and disseminated, can be for instance, in enabling advanced telecommunications to allow distributed energy production (the deployment of a network that connects all relevant nodes to collect information on grid conditions will beneficiate from the flexibility that wireless communication technologies can deliver, which allow data collection even in the most remote sites), and in quantifying the real cost of energy being consumed at any given time by having advanced metering infrastructure (replacing traditional mechanical electrical meters with smart meters, enabling the development of demand-response programs). It can also have a big impact on the working practices, by allowing, for instance, home working, enabling a reduction in the overall chain of energy consumption and carbon emissions.

The legal and regulatory barriers for the deployment of smart meters are very much dependent on the status of regulation in the different Member States. In countries where there is no competition to motivate innovation, there is no motivation to move towards a common European approach.

In most cases explicit governmental policy goals to promote smart grids/meter implementation should lead to the deployment of smart meters more rapidly. Indeed, it is evident from countries like Italy that mandating the implementation of smart meters can be a significant factor to rapid deployment.

The protection of consumers and businesses is vital with any change to collection of data from the premises. The legal framework currently does not encompass sufficient protection for consumers so this is a future issue to be addressed.

There is still some debate in the industry regarding what spectrum the remote meter readers should use. This basic conundrum can only be resolved by in-depth analysis and understanding the costs and benefits to make an informed decision, which informs part of the overall business case. This uncertainty may prove to be more of a barrier to mass deployment.

There are challenges, however, when introducing new technologies as some social groups, such as the elderly, may not necessarily appreciate or understand the benefits.

A significant factor for many of those adopting remote meter reading and enabling energy efficiency is cost.

Any proposed project would require significant project management, time and resources for an effective national roll out of smart meters.

There is also the challenge of maturity of equipment, and therefore the challenge lies with the manufacturers and vendors to ensure up to date equipment is released to market early. They will also need to create strategies for upgrades and swap outs of equipment which will mean have a significant timeline for technology advancements to be realised.

In liberalised energy and utility metering markets there is a risk that some smart meters may not be interoperable with domestic supply systems. It will be important that the basic functionalities are in place in order for any smart metering equipment to be installed into the customers' existing supply systems.

The different deployment of the technologies in different countries will cause a disparity between countries and compound the challenges of interoperability.

Decisions on the communication between the smart meters and the meter readers are proving to be the biggest challenge, since the frequency band being used at the moment such as 900 MHz band is exempt from licensing in some countries and therefore can suffer from interference. In addition it is likely there will be millions of deployments for smart meter devices and there may be a requirement for additional coordination to avoid these circumstances.

The requirement of energy efficiency must also be present in the design, construction and operation of buildings.

An analysis of the available data shows that about 80% of the energy consumed during the entire life-cycle of a building is consumed during its service life (the remaining 20% are for materials, construction and demolition) [eMob10]. It is then apparent that the first priority should be the promotion of efficient buildings, with reduced energy demand during all stages of its lifetime, and if possible, integrating a distributed network of CO_2-free energy producers. These goals must be achieved not only for new buildings, but also for the existing ones. The challenge is, of course, different: while for the formers the focus should be on promoting eco design processes, where energy efficiency is considered from the beginning, for the latter the difficulty is on finding the best solutions to retrofit existing structures and systems to a higher level of energy efficiency.

In buildings its energy consumption is mainly related to heating, ventilation and air conditioning (HVAC) systems, and lighting systems. The ICT sector cannot save much energy on its own, but it can deliver several solutions and tools to enhance these systems. It is possible to outline two important functionalities that M&WCs technologies are able to provide connectivity (enabling automatic reactions to changing conditions) and transparency (possibility of remote transmission of useful sensor data to the system administrator or user).

The ICT sector can act as an enabler of processes and system optimisation, namely on the development of new applications to enable energy efficiency, reliable and transparent means to quantify and track energy and cost savings over time, and open standards for interoperability between different technologies and systems.

There are already several applications and solutions available on the market addressing some of these topics. An example of the type of applications that can be developed is described by a typical ICT-enhanced application to enable energy efficient buildings (temperature monitoring and heating control of a HVAC system). An efficient HVAC control system must connect all components of the system (e.g., indoor and outdoor sensors, radiators, air conditioners, ventilators) in a network, in order to exchange data and to have an adequate set-up of the system (condition dependent). The role of ICT is obvious; the network can be implemented using wireless technologies, which increase the flexibility of the system.

With the advent of globalisation and global economic growth, the Transport and Logistics sector has assumed a central role. In fact, there is an increasing need for global goods transport that must be met by this sector. Moreover, manufacturing is in several cases a distributed process over several locations, relying on the Transport sector to move parts to the final place of assembly.

There is a vast potential for optimisation in this sector that can be implemented with the help of ICT based applications, namely, traffic and freighter management, energy-efficient driving and stimulation of behavioural changes, controlling power train fuel efficiency, and co-modality.

An example of an application that can be developed with the contribution of mobile and wireless technologies is efficiency tracking, meaning the association of data recorders installed on each vehicle with wireless transmission devices creates an information system capable of providing real time information.

3.3.3 How to address the challenges

As stated in the previous subsection, there are several challenges in the environment area for ICT.

When introducing new technologies the industry should take into account the different social groups, such as the elderly, that may not necessarily appreciate or understand the benefits, so an effort should be made to provide proper information.

It is also important to increase the collaboration between environmental organisations, the public sector and industry in order to move towards a common goal, environment.

Buildings and construction, transport and logistics, together with power transmission and distribution have been identified as the sectors were ICTs can deliver greater improvements in energy efficiency.

Government policy and regulation

There are political and legal issues when considering standards and conventions in any technology. The different spectrum usage in different countries requires a convergence at the regulatory spectrum area in order to stimulate some applications and more widespread technologies. Also, there are legal and regulatory barriers for the deployment of some applications and services that is dependent on the status of regulation in the different Member States. There is a need to have a standardisation at an international level, to allow systems that facilitate different working practices. Additional coordination between regulators is required to face these issues.

The protection of consumers and businesses is vital with any change to collection of data from their premises, so the legal framework must address the issue of security and privacy.

The challenge in buildings and construction is different for new buildings and existing ones. While for the new ones the focus should be on promoting eco design processes, where energy efficiency is considered from the beginning, for the existing buildings the difficulty is on finding the best solutions to retrofit existing structures and systems to a higher level of energy efficiency. The governments should stimulate the sector to implement the necessary measures.

Economic aspects

In new technologies and applications there is always the economic aspect, were the challenges lie on the cost of deployment and widespread deployment of equipment.

In the transport and logistics sector M&WC can contribute to a vast number of applications, e.g., traffic and freighter management, energy-efficient driving and stimulation of behavioural changes, controlling power train fuel efficiency, and co-modality, here not only should there be stimulation from the government to implement these applications, but also the manufactures must be willing to allow these new applications in the vehicles.

Technical aspects

Then there are also the technical aspects, question of interference from other equipments and technologies, requirements of real-time data, interoperability issues between systems and taking into account the different deployments in different countries that must be addressed by industry and regulators.

When discussing energy efficiency in the power transmission and distribution sector, the focus should be on the implementation of the so-called smart grids.

There is also the challenge of maturity of equipment, and therefore the challenge lies with the manufacturers and vendors to ensure up to date equipment is released to market early. They will also need to create strategies for upgrades and swap outs of equipment which will mean have a significant timeline for technology advancements to be realised.

The ICT sector can act as an enabler of processes and system optimisation, namely on the development of new applications to enable energy efficiency, reliable and transparent means to quantify and track energy and cost savings over time, and open standards for interoperability between different technologies and systems.

A view

Common to most of the ETPs is the concern with energy efficiency, mostly not directly related with ICT, but it is expected that ICT will contribute to it. For instance, ECTP [ECTP07] envisions several targets for 2030 and 2050 all relating to energy efficiency in buildings and some regarding natural resources consumption and waste; there is no direct connection with ICT stated, but it is very likely that it will have an effect in these areas. Also, ERRAC [ERRA07] has identified in energy and environment some products and services that should be available by 2020, namely regarding energy efficiency, design and construction, and recycling. Artemis [Arte06] addresses the problem of power consumption as well, considering that minimum power consumption requirements are one of the constraints in the areas of communications, as well as sensors and actuators.

Several ETPs (ACARE [ACAR08], ARTEMIS [Arte06], EPoSS [EPOS07], ERRAC [ERRA07]) state that technological options offered by different alternative fuels need to be studied, since alternative fuel resources also have a big impact on energy efficiency and waste, so the ETP on Biofuels roadmap [Biof08]. should also be taken into account in order to be able to have a whole chain energy study. Concerning energy efficiency, EPoSS [EPOS07] has a roadmap on the automotive sector, Figure 3.6.

Figure 3.6 – Research priorities for automotive technologies regarding energy (extracted from [EPOS07]).

ERTRAC [ERTR06] considers that the sustainability and competitiveness of the European road transport sector depend heavily on the development of new materials and comprehensive design tools optimising processes over the entire chain and products over their entire lifetime. This requires new concepts for products and processes including recycling technologies for both vehicles and infrastructure. High levels of performance across the system require new methodologies and technologies for monitoring and maintenance, having established a roadmap on lifetime resources and use, Figure 3.6. The usage of ICT in general, and of M&WCS in particular, is apparent.

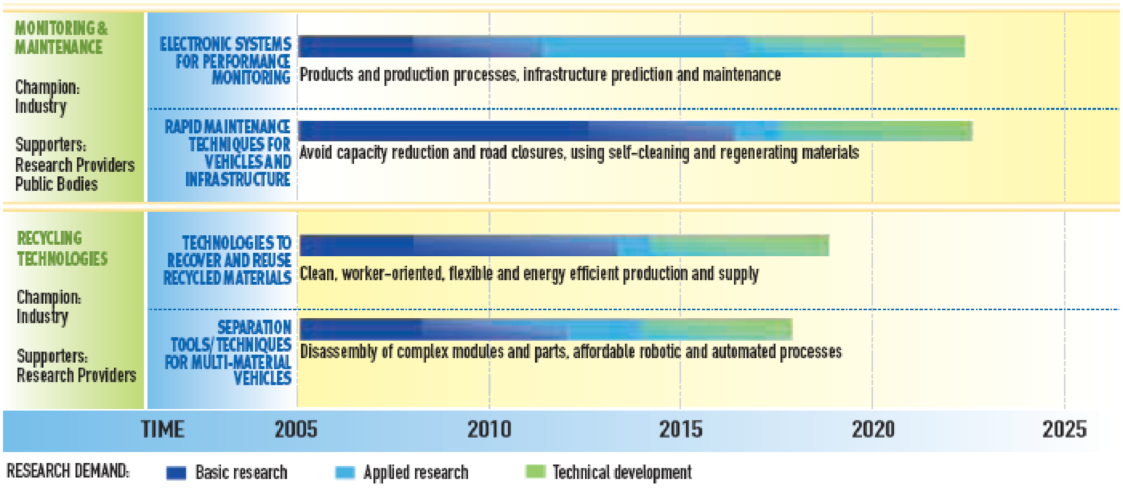

Figure 3.6 – Lifetime resources and use roadmap (extracted from [ERTR04]).

In WSSTP [WSST06], it is stated that tools for the detection and management of unaccounted for water (detectors, sensors, on-line models) have to be further developed and brought into operation, both in municipal and industrial water distribution networks, sewer systems and in agricultural irrigation systems. A major long term challenge for research (until 2030) is to halt the over-exploitation of groundwater resources and to minimise pollution threats (e.g., by salinisation, diffusive agrichemicals, exfiltration from sewers). Research is necessary to integrate groundwater management concepts and to provide incentives to increase water harvesting and groundwater recharge. Systems are needed for timely warning and information on chemicals and pathogens derived from natural sources, accidents or malicious attacks. These systems must include on-line and "at the site" monitoring and early-warning systems, as well as low cost, portable test kits for rapid and reliable determination of toxins, pathogens (including genomic and proteomic) and key contaminants. Early warning systems are necessary to enable better forecasting of extreme weather conditions and the subsequent impacts, using information from satellites and from earth based monitoring stations. Existing flood forecasting systems need to be further developed to model pollution incidents and guide emergency response and remediation. Risk management systems will also be developed to reduce the vulnerability of water quality during droughts. Such integrated forecasting systems are under development, but will need to be fully tested before widespread implementation and use will be possible (by 2015 at the latest). R&D into "intelligent sensors" will be very applicable in industrial water use, where fast sensors for in-process monitoring and control of relevant industrial components (e.g., dyes, stickies, and micro-organisms, including pathogens) are important. Also, by 2020 chemicals released to the natural environment will be biodegradable products that do not harm the environment (Technology Platform on Sustainable Chemistry), so tools need to be developed to allow immediate response if accidental pollution from trade or households enters the sewer system. These on-line measurement devices will be integrated to the new ICT tools, including next generation Earth Observation satellites, opening the way to real time spatial representation of water quality and correlation with other spatial data (human and animal health, industrial and agricultural activities, biodiversity, etc.), and better understanding of the links between land and marine water quality.

ZEP [ZEP06] provides an indication of what is required to prepare for future potential breakthroughs by 2050, via long-term R&D in terms of power plants CO_2 emissions, Figure 3.7.

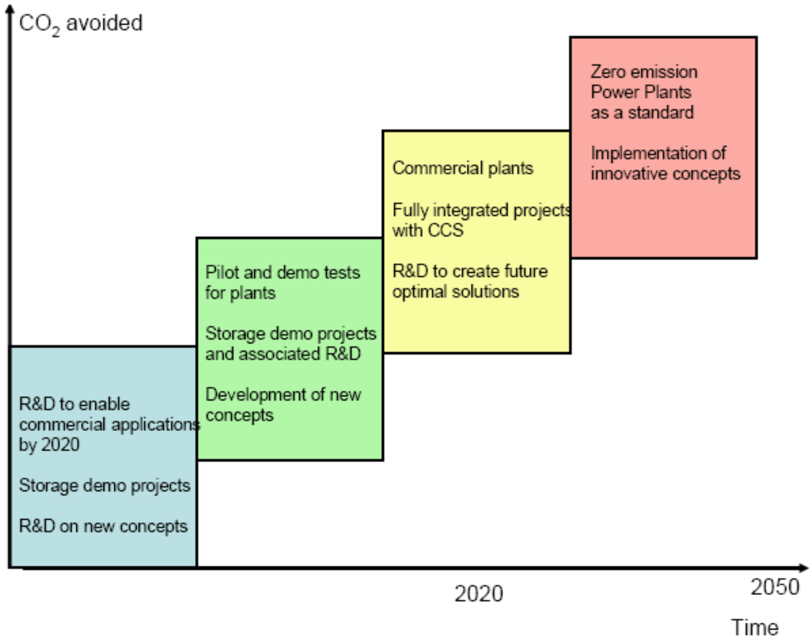

Figure 3.7 – Roadmap for zero emissions plants by 2020 and beyond (extracted from [ZEP06]).

Finally, SmartGrids [Smar10] has defined a roadmap, foreseeing that until 2016 different ICT technologies should be investigated and tested on site with the goal towards the introduction of ICT into the distribution level of electricity relying on the existing communication infrastructure (radio, power line, copper or fibre optics), applied in a cost effective way. ICT deployment is a key enabler for a range of functions and services of SmartGrids:

- Smart Metering.
- Online collection of customer data and support to customers' participation in the market.
- Aggregation of distributed generation into virtual power plants.
- Distribution automation (e.g., to enable self healing as the capability of the electricity grid to autonomously identify, localise, manage and repair an unforeseen disturbance or interruption).
- Consistent data management within and between the enterprises.

Finally, the European Commission has established a Technology Roadmap associated to the Strategic Energy Technology Plan (SET Plan), which clearly addresses the use of ICT [SETP09] in its objectives: engaging the active participation of customers in energy markets and energy efficiency through better information about their consumption, incentives such as dynamic pricing mechanisms and appropriate ICT tools; smart appliances (ICT, domestic appliances), lighting (in particular solid state lighting for street and indoor), and equipment (e.g. motor systems, water systems) in energy networks.

3.4 Requirements on The Future of Internet

Future Internet (FI) is a concept involving several technology areas that is receiving a great deal of attention in the research world. As of now there is no clear vision or agreement with regard to what such network of the future will allow and which capabilities it will offer.

Current Future Internet research deals with the technical capabilities and features such as personalisation, context-awareness, Internet of Things, cloud computing and content based networking. Lots of potential is seen in these advancements and lots of effort has been put into their development. However, these development efforts are in vain unless there are applications that use these newly developed capabilities.

While the technological advances open up new ideas for applications, visionary applications can identify new requirements for the Future Internet. Understanding the requirements for future applications and services may, in turn, drive research in the right direction revealing new opportunities and business potential.

This section takes a look at some vision for future applications through a single futuristic scenario. This scenario will show case the requirements that go beyond the capabilities of the current Internet. Some of the reasons why the applications presented are currently not reality and what are the needs from the Future Internet to make the realisation feasible will be described.

The core vision in the area of Future Internet is "*Applications and services have requirements that the Future Internet should fulfil, e.g., higher transmission rates, seamless connectivity, better reliability, and higher security.*"

3.4.1 Domains according to the SAA

The following scenario illustrates some of the applications of the future envisioned within the leading edge applications workgroup. The applications for this scenario have been selected to point out the requirements for the Future Internet and applications perspective for what are the main challenges that need to be solved. This scenario and applications in it are just a subset of the multiple ideas described at the SAA [eMob10].

John is walking in the city. His new intelligent wear is connected to the Internet and ready to provide multi-modal information to him whenever required. Today, John is looking for a bicycle repair man. He takes a few pictures with his camera of his broken bike. The camera connects to a service in the Internet to create a 3D image from the taken pictures. After that, *John turns on his microphone and says: "Where is the nearest bicycle repair shop?". The request is transformed into text and transmitted to an Internet search engine that returns the location of several suitable bicycle repair companies. The results are shown in his data glasses. Via his headset he is able to get additional information: "Abby's bicycle repair is nearest to you and in generally respected. Your friend Benny highly recommends Bike from Mike, which is only 100 meters further away. Based on the 3D image of your bicycle, both places have the capability to fix your bike. Do you want to hear Benny's story about his bike repair?" This information is enough for John this time and he selects Bike from Mike, after which he gets a guiding voice through his headset.*

While John is finding his way to Bike from Mike, textual information is added over the objects and buildings that John sees through his data glasses. When crossing streets he gets warnings about cars nearby. Suddenly his glasses point to a red dot on his left and at the same time his left hand data glove provides a slight pressure indicating danger to his left. There is a woman with her dog and John is very allergic to dogs, so he changes his walking route a bit to avoid problems. While walking, John passes by an advertisement board. The board realises that there is a hockey fan within its vicinity and promotes the possibility to access the latest results and in-depth analyses of the games from results'r'us. As John finally enters the store, his jacket turns off its internal warming and starts the cooling cycle so that John is not going to sweat while being in the store.

3.4.2 Challenges

For such a scenario to turn into reality, several technical advancements are required. The main realisation challenges for the Future Internet are described bellow. The challenges have been divided into three groups. The first group contains challenges related to the heterogeneous hardware that will be used in the FI. Next, we look at the connectivity and network services, focusing on the challenges that are related to the network usage and its services. Lastly, we point out the challenges related to security, privacy, and trust being an orthogonal layer.

Heterogeneous hardware
Current research in the area of the Internet of Things (IoT) focuses at connecting everyday objects to the net. This will make more information sources available for applications. For example, the intelligent clothing in the scenario above relies heavily on information it gained from the different sensors in the environment. Such sensors are already available, but have not been ubiquitously distributed, mainly due to the lack of incentives for providers. Supporting the ubiquitous distribution of a variety of information sources in the environment would allow for the further development of innovative applications.

In the scenario, John has several items connected to each other or to the Internet: intelligent wear fetches relevant information, cars transmit data to environment, the environment informs the jacket about the temperature and so on. These devices have differences in their capabilities like the amount of available processing power and memory depends on the size and cost of the particular device. Mobile devices have limitations due the available energy unless development in this field will bring new breakthroughs.

The heterogeneity of capabilities of different hardware means that rather than relying on single communication solutions such as TCP/IP the FI requires dynamic communication protocols that adapt to the devices taking part in the communication. For instance, enabling lightweight and simple communication free of the burden of metadata could reduce the hardware requirements of simple devices. This, in turn, would reduce the cost of such devices and would further help to ubiquitous distribution of variety of sensors and other information sources.

Besides the hardware capabilities, the quality and type of communication links will also affect the way the communication should be conducted between devices. For example, chatty protocols should be avoided when the network has a high latency.

From the usability perspective, efficient and simple interfaces are important. Multi-modal interfaces require additional hardware such as microphones. For each modality, like sound, a single source could be enough rather than implementing source e.g. microphone for every gadget. This will require more interoperability between the gadgets, so that the current user of information source like microphone can be agreed on.

Connectivity and Network services

Before the applications in the scenario can become feasible and real, the uses of the network and its services have to be simplified for both users and applications. In the scenario depicted above, John uses several networks and services. For the solutions to be feasible, the access to the network and network services should become invisible to the user. For the network connectivity, the current process for selecting a proper network technology (Bluetooth, Wi-Fi, 3G, etc.), finding devices/hotspots/networks, selecting a service provider, establishing the connection, and authenticating to the network is too cumbersome. There is no need to burden the user with connectivity issues, since it is not the connectivity but relevant information, useful applications and helpful services user is looking for. As the amount of information sources, applications, and services steadily grows, the task of finding meaningful ones without help becomes harder and harder. Indeed, it is unacceptable that users have to go through pages of text to find desired information. Hence, the FI needs to feature more descriptive data (metadata) about available things in the network easing the selection process. Properly described data is also important for applications that rely on external information sources, such as intelligent clothing, so that they can identify correct sensor and sensor information.

Also, the Future Internet should help users to not only be information consumers, but also producers. One way to support these prosumers in this respect is the automation of metadata inclusion rather than requiring the user to fill out complex input masks. For example, whenever a user publishes an image to the network, the camera that took the picture could automatically add location information to it and an image analysis software could detect the important patterns from the image adding relevant descriptive tags.

In the scenario, John gets a lot of local information while walking in the street. Cars are informing him about their arrival along with possible other information such as speed and efficiency of the brakes to stop the car. This kind of information is needed to quickly provide warnings in a timely manner. Thus, the connection should rather be local and direct than globally routed. This reduces the latency of information transfer as there are fewer nodes that the data has to pass. The Future Internet should be able to dynamically decide when local routing is to be used.

Similarly, the currently centralised solutions for searching services and content are comparably slow. Local search services provided by the local network can provide accurate results about services and content within its area in a faster way than globally centralised solutions due the lesser network latency and smaller databases.

With communication capability limited devices like Intelligent clothing and mobile phones can rely on the external resources provided by network. The current trend of cloud computing, where applications and data storage is in the network, will evolve further. One possible development path is to offer more services and application in the network that are targeted for other applications or devices like cameras. For example, in the scenario, 3D image construction and image analysis for the digital picture is not done by the camera itself, but by a specialised service in the network that the camera uses. Transfer of harder data processing from mobile device is especially beneficial to prolong the battery life.

Security and privacy

The Future Internet will consist of a variety of gadgets, applications, and services, which will interact with each other. Interactions and dependencies between network objects will make security an even more important issue. As applications will rely more and more on external information the accuracy, integrity, and steady availability of data is essential. The effects of wrong data will become more severe and risks will arise. In the scenario, for example, if the intelligent jacket receives false temperature data from a fake sensor, it warms up rather than cools down inside the building and thus, causes negative user experience.

As the applications and services may alter their behaviour based on the individual user needs and desires, they require more and more information about the user. In the scenario the warning application has to know about John's allergy towards dogs to warn him. The transmission and handling of personal data increase the risk of a breach of privacy. The opinion about what is considered to be private information varies between individuals. Also, everyone has their own view with whom to share personal data. A future challenge will be to find a solution that allows individuals to keep control of their private data and still use customised services.

Another trend is that users are more and more involved in content producing, which brings up the question about the reliability of provided content. Wrong reviews of services may be used to mislead customers to select particular service providers and avoid others. New trust models are needed that take personal relations and social group data into account. As user produced content becomes more and more important, the questions about protecting the rights of the content creator also becomes increasingly important. Models for user created content use and compensation from the use may open up new business opportunities.

Similar to the communication solutions, the security solutions should be dynamic, too. There is no single solution that fits for each case and each device. Approaches that consider sensors and tags using the computational power of other devices for security tasks are needed so that the best solution for a given situation can be selected.

3.4.3 How to address the challenges

Based on these scenarios and envisioned applications Table 3.1 summarises the challenges for the Future Internet, the current situation and where we could go. A number of example key words should provide hooks for further reading, but, indeed, the list does not claim to be complete.

Table 3.1 – Summary of the challenges for the Future Internet.

Challenge	Current situation	Possible FI situation	Example key words
Reliable and capable network; novel network architectures	Often limited bandwidth in mobile scenarios	Sophisticated real-time network applications; users are always connected; improved functionality (e.g., configuration, delivery speed)	Network protocols, content-based networking, network virtualisation
Connected everyday objects	Connected objects in specific application areas; detached smart devices, e.g., clothes	Communicating real world and virtual objects	Internet of Things (IoT), RFID
Enhancing interactivity, usability, and creating novel service front ends	Main interaction means is the (mobile) user device; emergence of gesture control, but mainly application specific (gaming) or in the research area	Multimodal interaction adapted to the user's environment, device or skills including natural language, gestures, object interaction, etc.	Service front ends, personalisation, natural language processing/ gesture recognition/ etc.
Seamless integration of context data or social network information	Location-based services; enhanced availability of context data mainly by means of the mobile phone; social communities and	Context data as inherent building block; multiple context sources available apart from the mobile user device; automated	Context-awareness, wireless sensor networks, recommender systems

	applications	integration of social data, e.g., recommendations	
Network services for applications	Increasing availability of cloud services, platforms, or infrastructures, e.g., for extensive computing tasks such as Amazon EC2	Services offered by the network and used by “dumb” devices; seamless outsourcing of complex computing tasks; improved usability and reduced costs	Cloud computing, Grid computing
Enhanced security models; privacy protection vs. personalisation	Often application-specific; use of personal information part of some business models	Inherent building block of the network; enhanced user control; anonymised data	Security and privacy models

A view

The Future Internet has a very wide scope concerning applications: on the one hand, this is an area that is being considered “only” by the sectors that are associated to ICT (networks, services, media, etc.), and on the other, it really encompasses all sectors of applications.

EPoSS [EPOS08] has a roadmap for Future Internet, focusing on the Internet of Things, stating that in the coming years, technologies necessary to achieve the ubiquitous network society are expected to enter the stage of practical use. It is widely expected that RFID technology will become mainstream in the retail industry around 2010. As this scenario will evolve, a vast amount of objects will be addressable, and could be connected to IP-based networks, to constitute the very first wave of the Internet of Things. There will be two major challenges in order to guarantee seamless network access: the first issue relates to the fact that today different networks coexist (e.g., mobile phone, fixed phone, broadcasting networks); the other issue is related to the sheer size of the Internet of Things. The IT industry has no experience in developing a system in which hundreds of millions of objects are connected to IP networks. Other current issues, such as address restriction, automatic address setup, security functions such as authentication and encryption, and multicast functions to deliver voice and video signals efficiently will probably be overcome by ongoing technological developments.

The following matrix captures the required technical and technologies for efficient implementation of the identified applications.

	Application Areas		
Technology Areas	**Health and Inclusion**	**Transportation**	**Environment**
Context and User Profiling	-Assisted living. -Personal records. - Environment context information (home, hospital, etc..)	-Road traffic condition (context). -Car (driver or passenger Context) -User profile (travel map, route planning: where, when, who, what) -status of mind and health)	-Environment context. -Face recognition -criminal profiling and tracking
Security Trust Dependability	-High integrity of information, -High dependability	-User privacy -user trust in system -dependability (very low system outage)	-Privacy (identify) -High integrity and reliability
M2M	Essential (wearable devices)	-Car-to-car -Automatic payment -In-vehicle context collection	-Essential technology -Machine-to-infrastructure
Cognitive Systems	No	-spectrum sensing -spectrum sharing -distributed control	-distributed monitoring, control, -data fusion
Broadband Communications	-High quality images, video and low latency	-car-to-car -car-to-infrastructure -In-vehicle networking	Yes
Optical Technology and RoF	-Not essential from technology requirements. -Potential impact on system cost reduction	-Not essential	-Potential impact on system roll out cost reduction
Mediation Bus	-Availability of services and user profiles across different heterogeneous networks. -Quality of Service	-In-car service platform	-Open access provisioning

Future Internet	Essential application and usage area	Essential application and usage area	Essential application and usage area
Green Wireless (Energy Efficient wireless communication systems)	Energy efficient and ---Long-life devices.	-Energy efficient communications	-Not critical

The technology trends foreseen for the next 20 years are outlined in Figure 3.8 and Figure 3.9. While Figure 3.8 concentrates on developments that can be foreseen within current research priorities, and can be seen as an evolution of the current technological advancements, Figure 3.9 focuses on more radical and ground breaking technology trends.

	Before 2010	2010-2015	2015-2020	Beyond 2020
Vision society	• Socially acceptable RFID	• Pervasive RFID	• Interacting objects	• Personalised objects
People	• Realising benefits (food safety, anti counterfeiting, health care) • Consumer concerns (privacy) • Changing ways to work	• Changing business (processes, models, ways to work) • Smart appliances • Ubiquitous readers • Access rights • New retail and Logistics	• Integrated appliances • Smart transportation • Energy & Resource conservation	• Mastered ambient intelligence • Interaction of physical and virtual worlds • Search the physical world (google of things) • Virtual Worlds
Politics & Governance	• De-facto governance • Privacy legislation • Address cultural barriers • Future Internet governance	• EU governance • Frequency spectrum Governance • Sustainable Energy Consumption guidelines	• Authentication, trust and verification • Security, social well-being	• Authentication, trust and verification • Security, social well-being
Standards	• RFID security and Privacy • Radio frequency use	• Sector specific standards	• Interaction Standards	• Behavioural Standards

	Before 2010	2010-2015	2015-2020	Beyond 2020
Vision technology	• Connecting objects	• Networked objects	• Executable objects /semi-intelligent objects	• Intelligent objects
Use	• RFID adoption in logistics, retail and pharmaceutics.	• Increased interoperability	• Decentralised code execution • Global applications	• Unified network that connects people, things and services • Integrated industries
Devices	• Smaller and cheaper tags, sensors and active systems	• Increasing memory and sensing capacities	• Ultra high speed	• Cheaper materials • New physical effects
Energy	• Low power chipsets • Reduced energy consumption	• Improved energy management • Better batteries	• Renewable energy • Multiple sources	• Elements of energy harvesting

Figure 3.8 – Extrapolation of technology trends and ongoing research (extracted from [EPOS08]).

	Before 2010	2010-2015	2015-2020	Beyond 2020
Vision society	• Wide take up of RFID	• Integration of objects	• Internet of things	• Unlocked full potential of the Internet of Things
People	• Socially acceptable RFID	• Ambient assisted living • Biometric IDs • Industrial ecosystems	• Smart living • In-vivo health • Security based living	• Mastered continuum of people, computers and things • Automated healthcare
Politics	• First global guidance • Standardisation	• First global governance • Unified open interoperability	• Authentication, trust and verification	• Inclusive Internet of Things
Standards	• Network security • Ad-hoc sensor networks • Protocols for distributed control and processing	• Interoperability protocols and frequencies • Power and fault resilient protocols	• Intelligent devices cooperation	• Health security

	Before 2010	2010-2015	2015-2020	Beyond 2020
Vision technology	• Low power and low cost	• Ubiquitous integration of tags and sensor networks	• Code in tags and objects	• Smart objects everywhere
Use	• Interoperability framework (protocols and frequencies)	• Distributed control and databases • Ad-hoc hybrid networks • Harsh Environments	• Global applications • Self-adaptive systems • Distributed memory and processing	• Heterogeneous systems
Devices	• Smart multi-band antennas • Smaller and cheaper tags • Higher frequency tags • Miniaturised and embedded readers	• Extended range of tags and readers and higher frequencies • Transmission speed • On-chip antennas • Integration with other materials	• Executable tags • Intelligent tags • Autonomous tags • Collaborative tags • New materials	• Biodegradable devices • Nano-power processing units
Energy	• Low power chip sets • Thin batteries • Power optimised systems (energy management)	• Energy harvesting (energy conversion, photovoltaic) • Printed batteries • Ultra low power chip sets	• Energy harvesting (biology, chemistry, induction) • Power generation in hash environments • Energy recycling	• Biodegradable batteries • Wireless power

Figure 3.9 – Topics requiring new or intensified research (extracted from [EPOS08]).

The Future Internet X-ETP Group has established a Research Agenda [FIXE09] that, although not begin devoted to applications, addresses a number of items that are directly related to the deployment of applications.

Finally, an integrated approach can be given concerning the foreseen evolution for Mobile and Wireless Communications on the one hand, and the application sectors on the other. Taking the roadmaps previously presented, one shows the applications that are closer to the area of Mobile and Wireless Communications, together with the foreseen evolution in communications, Figure 3.10. The area of Health & Inclusion seems to be the one that will pick earlier (or has already picked) communications technology for the deployment of a number of applications, while Transport is still on the way. A possible reason for this is that the Health sector is much more fragmented than the Transport one (which is quite standardised), hence, being much easier to apply new technologies in the former. Environment is somehow in parallel with Transport, one of the reasons being that they are related to each other, thus, being understandable that the deployment of some technologies is done "at the same time".

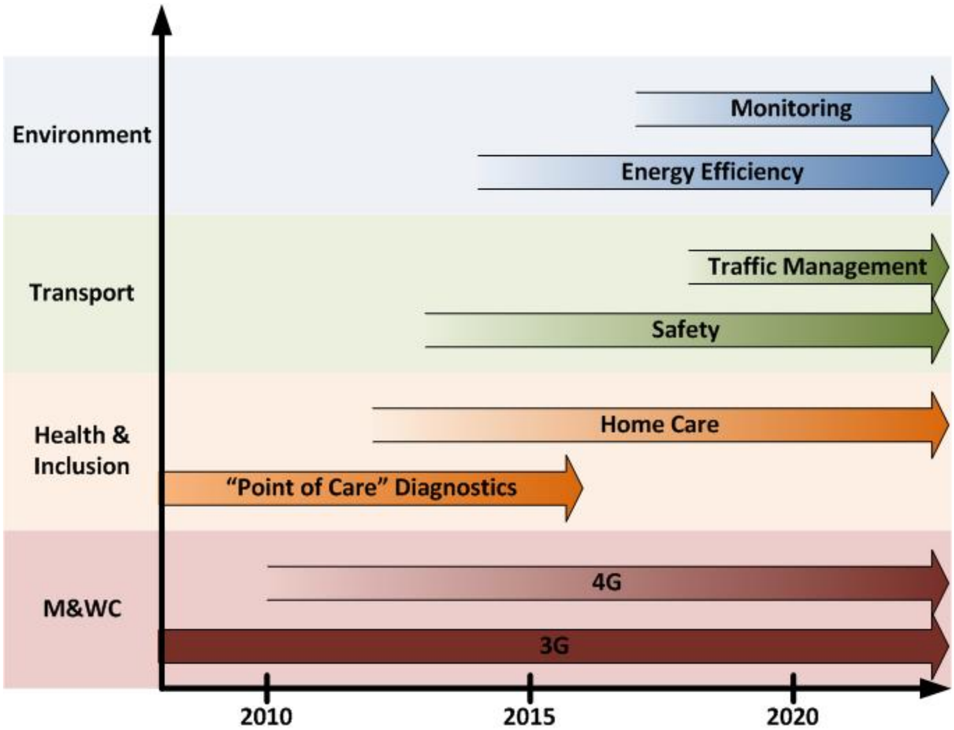

Figure 3.10 – Integrated roadmap.

In conclusion, the application of Mobile & Wireless Communications looks quite promising in the near to far future, not only because current usage will be increased, but also due to the increased exploration of new areas that are transversal to many sectors, like machine-to-machine communications.

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4. Context Provisioning and User Profiling for User-Centric Services

4.1 Rationale

Mobile Communication offers a user access to personal services anytime anywhere. However, sometimes the user feels flooded by irrelevant information or misses important messages. In times of growing communication spheres and data spaces, the users demand support to filter and adapt the information relevant to their current contexts and needs. If communication would be context aware, it could take over the job of a secretary and filter or forward messages and adapt the services to their current requirements.

In addition, mobile content provisioning and, in particular, advertisement is a growing market, but the target groups remain often unreachable due to a missing focusing mechanism. Advertisement companies are very interested in more information about the users' context to provide tailored advertisements. According to the Financial Times Germany, sales of € 13.5 billion are expected in 2012. Specific companies invest up to € 1.5 million for their mobile marketing. Thus, there is a strong demand for context-aware systems.

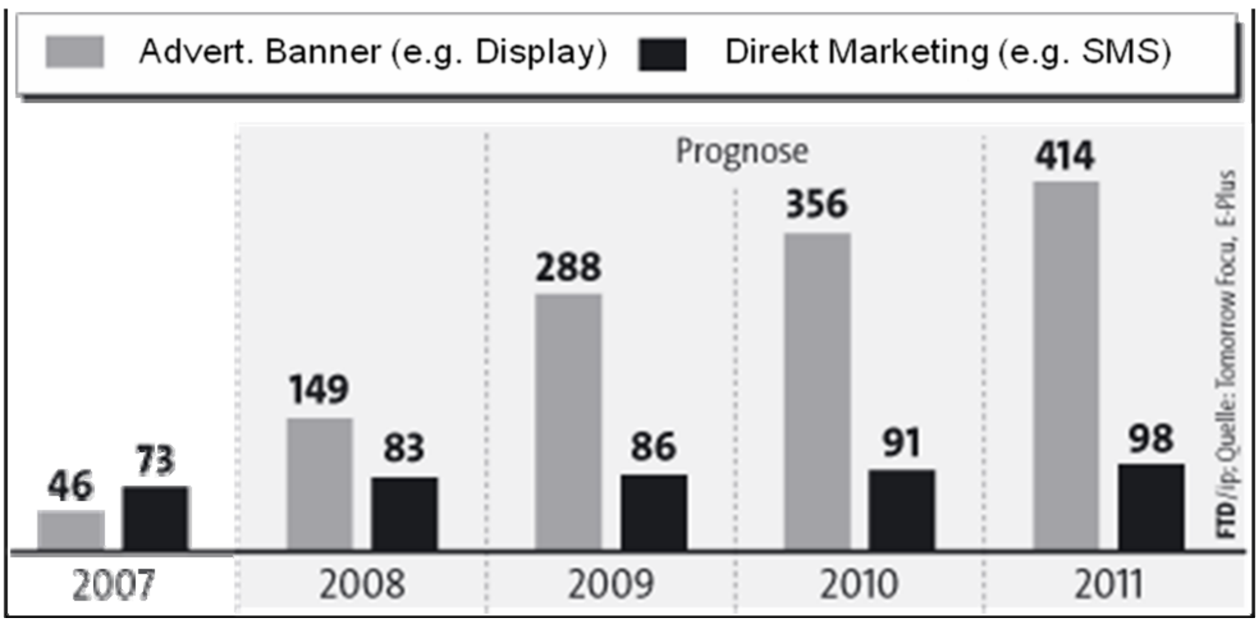


Figure 4.1 - Turnover of mobile advertisement in Germany in Mio € (Source: Financial Times Germany, Sep. 2008)

A system is defined to be context aware if it is able to assist its users without need for their explicit interactivity. Instead, the system is aware of the users' context. It is able to proactively support the identified user goals and reduce disruption. Contextual information may be inferred from physical sensors (e.g. acceleration, light intensity), virtual sensors (e.g. calendar, e-mail content) and logical sensors (e.g. databases). In the future, the number of context sources and sinks are expected to increase tremendously. At the same time, new applications and usage scenarios may arise, requiring a scalable, extendible context-provisioning framework, e.g. new context types/domains and evolving context models. In particular, social community services (cf. Facebook, LinkedIn) are emerging. Context-aware services provide a unique opportunity for mobile service providers that maintain, in contrast to other service providers, individual user profiles and can employ the mobile phone sensors (speaker, accelerator, compass, GPS etc.) to explore the user context.

4.1.1 Objective and Scope

The objective of this chapter is to analyse the prerequisites and enablers for context-aware services and to emphasise the challenges and the priorities for future research.

To make context-aware services a reality, the user perspective, the business perspective, as well as the required technological enablers, have to be understood. This paper aims at summarising briefly the current issues and prioritising future work to foster the evolution of user-centric services that adapt to changing context and, therefore, also to user needs. Hence, the scope of this paper includes user and business requirements and technological enablers for context-aware services.

The document is structured as follows: The next Section describes in detail the research priorities and concludes with a recommendation for future research priorities.

4.2 Research Priorities

This section discusses the research areas for context-aware services. It is structured as following: The next subsection defines the common terminology used here. The second and third subsections analyse the enablers for context-aware services: context provisioning (including context modelling, reasoning and management) and user profiling (i.e., profile management, user models, security trust and privacy, user acceptance), respectively. Subsection four discusses the envisioned user-centric services that employ the enablers to adapt to changing context and user needs. Subsequently, a holistic perspective is taken, addressing standardisation and regulatory needs and future roadmaps for business model evolution and evaluation methodology definition.

4.2.1 Definitions and Terminology

Context

According to one of the most popular definition used widely in literature context can be;

"any information that can be used to characterise the situation of an entity (person, place, physical or computational object) that is considered relevant to the interaction between entity and application."

This definition is by far the most cited in literature and also adopted here. Furthermore, relevant entities (EoI – Entity of Interest) are defined to be places, people and things, and four categories or characteristics of context information are introduced, namely; identity, location, status and time. Five fundamental categories of context information are proposed: time, location, activity, relations, and individuality. The term intentional context is sometimes used to describe what the user has been doing and what (s)he is planning to do next. The elements of mobile context are known to comprise the technical context, the physical context and the social context. Mobile applications can be used in various contexts that may even change in the middle of a usage session. In this chapter, the terms context provider and context consumer relate to the context source and context sink, respectively.

Situation

With regard to the definition of a situation in context-aware systems, different views exist in the research community. Zimmermann defines it as;

"the state of a context at a certain point (or region) in space at a certain point (or interval) in time, identified by a name".

Being a structured representation of a part of the reality, situation can be compared to a snapshot taken by a camera. Location and time can be used as spatio-temporal coordinates. With regard to situation-awareness, Billings defines a situation as;

"an abstraction that exists within our minds, describing phenomena that we observe in humans performing work in a rich and usually dynamic environment."

In summary, a situation may contain an infinite variety of contextual information. In this chapter, a situation describes the overall state at an instant of time comprising several entities with their respective contexts.

Context Awareness

In literature, the term context awareness was initially introduced by Schilit and Theimer in 1994. In the last decade, a lot of research dealt with the investigation of context-aware systems. The consideration of context enables the provision of personalised enriched services and increases user experience. The content (e.g. text, speech, videos), the way it is decoded (e.g. audio/video codec) and transmitted (e.g. network and device selection) autonomously adapts to the user situation and other recognised circumstances, such as availability of access networks, device capabilities, environmental conditions, and user preferences. From the user perspective, the communication itself is simplified and fades into the background by adding intelligence and autonomy to the communication system. The system improves usability by reducing explicit user actions and providing interactivity without need for user interaction. A context-aware system typically performs the following tasks: (1) Perception/Acquisition, i.e., collection of relevant data allowing conclusion to the context; (2) Reasoning/Inference, i.e., deduction of more abstract (so-called "higher level") information from the raw data; (3) Learning from and predicting based on historic context information and actions; (4) Context Representation, i.e., representation and modelling of context information in a machine-readable and understandable way; (5) Management and diffusion of context information; (6) Actuation, i.e., Triggering/Adapting the service execution or application behaviour based on the available context information. Context awareness is related to integrating ambient intelligence in pervasive computing.

User Profile

A user profile is a collection of long-term data associated to a (specific) user or group of users. Relative to dynamically changing context, the user profile is more static, changing not at all (e.g. date of birth) or less frequently (e.g. age). Context-aware applications adapt to profile and context. The actuation of an application may change the context (inner control loop), but not the profile of a user (outer control loop).

ETSI (European Telecommunications Standards Institute) describes a user profile as "The total set of user-related information, preferences, rules and settings, which affects the way in which a user experiences terminals, devices and services". In online forums, and, in particular, in social networks, user profiles are used to describe and present individuals; they greatly contribute to personalising interaction on the web. Related work describes a profile as a description of an individual - his or her personal taste, interests, expertise, and opinions. The term can refer to a group of users, in particular, when describing target groups and user needs while establishing business strategies.

4.2.2 Context Provisioning

Developing the abstraction of "awareness" in a context-aware system or application capable of adapting and acting on behalf of users is a complex endeavour. Context-aware applications must be supported by context information models and reasoning techniques which in turn all require access to quality context information. The models are an idealised representation of the real world for a certain objective, e.g. searching or reasoning. Making available both basic and higher-level context requires a context management system. Together these enablers provide a context-provisioning system which, for maintainability and evolutionary purposes, should be decoupled from the applications.

Context Provisioning involves the tasks of context management, context modelling and context reasoning as well as making it available for usage to the application or other functional infrastructure elements.

Context Management deals with

- Context Acquisition as a mechanism to obtain context from diverse sources;
- Context Discovery as a mechanism to locate and access context sources;
- Context Aggregation for merging correlated contextual information; and
- Context Dissemination for efficiently propagating the context while ensuring availability and reliability.

Context Modelling covers

- Abstraction of the reality that is relevant for context detection;
- Identification of an adequate context representation, incl. modelling of context meta-Information such as context quality; and
- Provision of a context query model and mechanisms for querying.

Context Reasoning includes

- Interpretation that assigns a semantic to the sensor data; and
- The inference that derives a new conclusion about the context or predicts future context from existing knowledge (e.g. a priori knowledge and context history).

4.2.3 Context Management

The main features of context management are context acquisition and storage, context aggregation and fusion, context dissemination, discovery and lookup. Context can be acquired from a diversity of sources from social websites, profiles, databases and physical sensors, and may be filtered and aggregated to form higher-level context. In most cases, context has a lifetime and, therefore, must be continuously refreshed, requiring lifecycle management functions. Context quality is a major issue with unreliable sources, uncertainty in measurements, conflicting information, time delays, accuracy and staleness.

Context Acquisition

Context acquisition is the process of capturing information concerning an Entity of Interest (EoI) that describes different facets of its state or situation in the real world. Entities can have living embodiments such as persons and animals or be objects such as buildings, cars, tools, production material or other organic and non-organic matter.

Before context acquisition takes place, a (context-aware) system must have identified the EoI and what contextual information associated to the EoI it requires. In many context-aware applications, such information is hardcoded as part of the service logic. Enabling a more dynamic selection of EoI and relevant contextual information at run-time is a major challenge, but promises more flexibility and reliability for applications in dynamic environments.

Context can be captured from context sources pro-actively by using pre-configured context models to maintain data in a system, which can be later queried by applications, or reactively upon explicit request of the application when context is required. As the number of possible EoI and context sources can be extremely large, scalability becomes a major concern, if context is captured proactively. If context is captured on-demand, the discovery of suitable context sources and interaction with those sources to obtain context can introduce delays that constrain the reactivity of the system. Therefore, context sources that employ event-based publish/subscribe mechanisms (i.e., trigger functionality) are a powerful alternative. Apart from the development of suitable mechanisms to handle the different cases, finding the right balance between them is a challenge on its own.

Context Discovery

Selection of context sources for the acquisition of context represents another difficulty, as it depends on a variety of factors that have to be considered holistically: the type of context required by a context-aware service/application and its quality, the context models utilised in the system, availability and accessibility of suitable context sources that can provide (parts of) the context at desired quality.

An obvious prerequisite for the selection of suitable context sources is their discoverability by the system. This requires representation formats to describe the characteristics and capabilities of the context sources and mechanisms for efficient lookup and discovery of context sources according to requirements. The sheer scale of possible context information sources and the existing heterogeneity of their description (if these exist) make efficient discovery a very challenging task.

The existing heterogeneity of context sources also makes access to these descriptions very difficult as applications are faced with a wide variety of interaction protocols and representation formats of information they deliver.

Some context sources can be statically associated with a specific EoI, e.g. the calendar of a person. Many context sources, such as sensors, however, are able to deliver information about a variety of EoIs, possibly simultaneously or at different instances. These associations between context sources and EoI are in reality often dynamic, as EoI and context sources are mobile with respect to each other, or context sources may become unsuitable due to system dynamics. Consider an exemplar room EoI which is related to various user EoI's staying within and suddenly leaving. Providing mechanisms that are able to establish and manage such dynamic associations in a reliable, scalable and automated way represents a major challenge that still needs to be solved.

Context Aggregation

Context aggregation addresses the task of merging correlated contextual information. Here, the quality of the context information has to be monitored and rated when quality of service requirements have to be guaranteed. When using aggregated context information, the parameters that quantify the quality of this information must be understood and mechanisms that monitor this quality must be provided. With its growing economic importance context information and, in particular, context sources might soon become target of intentional and unintentional manipulation. Potential quality parameters are accuracy, timeliness/up-to-dateness and authenticity. Potential context source parameters are battery status, sensor aging, and estimation algorithm variance.

Context Dissemination

Context dissemination is related to the distribution of context information. It encompasses context querying models and mechanisms, based on ContextML, which should allow for an efficient search and query access and for scalability. It provides communication mechanisms between context broker, context provider and context consumer, where context information and/or context meta-information is transmitted between these partners. Examples are publish, advertise, announce, subscribe, query, etc.

Efficient searching, powerful query mechanisms, combined with scalability are key factors that need to be addressed.

Research Issues

- Architectures for heterogeneous and scalable Context Management, also across different administrative system boundaries, based on principles of centralized and / or decentralised governance and open and standardised interfaces;
- Preserving the privacy of entities, the context relates to unified representation formats for context sources and their respective capabilities;

- Semantic enrichment of context sources and context processing entities, in order to facilitate efficient discovery and selections of unified interaction protocols for accessing context sources and encoding format;
- Efficient mechanisms to cope with the temporary validity of context, in particular in distributed systems.

4.2.4 Context Modelling

Context modelling concerns representing the knowledge about the real world in a machine readable form. In order to manipulate context information it must be represented and stored in some form that can be used by machines to derive higher-level context, is searchable, can be communicated and modelled. Context is just a special type of metadata so is open to all the techniques used in meta-modelling. Since higher-level context is derived from relationships between more primitive context, storing context in a relational database and querying to derive this higher-level context is a common approach. Other context and model representations could be object-orientated, knowledge-based, ontological, rule-based, logic-based, based on semantic graphs or fuzzy logic sets and many more approaches. Expressing context using just one representation is almost impossible since the range is from the most specific, for example a temperature reading, to the most abstract, the state of happiness. Furthermore, the representation must lend itself to machine learning, reasoning and inference techniques to be used such as classification, taxonomies, data mining, clustering and pattern recognition. Finally, it must be possible to query context models and context repositories in order match the spontaneous needs of context-aware applications. Taken to the software engineering extreme context modelling is about building a computational model of the world where fresh context is used to synchronise this world model with the real world.

More work is to be done on behavioural modelling. Humans are the target for most context-aware applications. This also includes social research on detecting behavioural patterns. There is a need for a set of standard context representations and for researching ways of mapping between representations. We have to come up with a mechanism allowing scalable maintenance of associations between EoI and context sources, despite mobility of system entities and other system dynamics. This requires a system providing support for modelling quality of context, with (1) an adaptive mechanism to monitor and maintain quality of context in the system, despite mobility and other system dynamics; (2) an identification of parameters describing quality of context; and (3) a mechanism for quality of context monitoring / rating.

Research Issues

- Need for common models (always a problem in information modelling);
- Support for progressive extension and modification of the context model, i.e., its adaptation to new applications, services or usage scenarios;
- Ontology to describe and interrelate heterogeneous EoI and context models.

4.2.5 Context Reasoning

Reasoning is the process of deriving abstract high-level context information (e.g. user is in meeting) from low-level primitive context (e.g. GPS longitude, light intensity). Reasoning is also used to verify the consistency of context and context models or to derive future context (context prediction). Context reasoning could employ, for example, rule-based inference, predicate logic or Probabilistic Reasoning (e.g. Bayesian networks). It is a challenge to deal with the dynamics in a mobile communication system where user, network and environment context change rapidly. High-level context may depend on low-level context information processed at distributed network entities. Due to constrained resources of mobile handheld devices, complex reasoning tasks have to be executed on high-performance infrastructure entities. The question is how and where to distribute knowledge and the inference process itself. Robust reasoning and inference mechanisms also need to compensate incomplete knowledge, uncertain and imprecise contextual and sensor data by incorporating context meta-information, such as the degree of uncertainty or accuracy. Moreover, the connectivity of a mobile device is not necessarily given, i.e., the context provisioning network is frequently changing and loss of contextual knowledge needs to be prevented. The processing of contextual information by means of inference and reasoning must not be understood as a static and unidirectional process. Instead, reasoning is accomplished in an iterative manner: A priori and derived knowledge constrains and adapts successively the context. The system needs to learn (either supervised or autonomously) from (in-) direct user feedback and from previous user actions, i.e., by taking historic context information into account adapt to existing context models and available system knowledge.

Research Issues

- Efficient methods to include and use a priori knowledge to enhance reasoning capabilities;
- Reliable methods for reasoning to deal with incomplete, imprecise and uncertain information, including also the use of meta-information on sources with varying reliability;
- Reasoning architectures that can be optimised for distributed information sources and information aggregation with different communication capabilities between the different entities;
- Use of historic data;
- Machine learning to improve the reasoning mechanisms continuously.

4.3 User Profiling

User profiling is the process of building a profile based on a set of data. A profile is defined by the individual that it describes with the expressed purpose of sharing this information with others, friends as well as colleagues and strangers. Online forums provide efficient means for user profile collection. After joining a social network service (SNS), an individual is asked to fill out forms containing a series of questions. The profile is generated using the answers to these questions which typically include descriptors such as age, location, interests, and an "about me" section. Most sites also encourage users to upload a profile photo.

Different circumstances trigger a different user behaviour as to device and its services and applications. According to ETSI (European Telecommunications Standards Institute), each situation-dependent profile will identify which devices and settings are needed in the situation and what device and specific settings will be required. These situation-dependent profiles contain settings and rules, which need to be activated when the defined situation occurs, for example: when the user is in a meeting, the mobile phone is put into silent mode; when the user is in a car, the fixed phone is transferred to the mobile phone.

Thus, in addition to a “basic user profile”, we also have an “extended profile”. The basic profile reveals the user’s identity, containing objective data, e.g. name, address, gender, phone numbers, e-mail address, etc. The extended profile, on the other hand, contains context-dependent data and preferences, such as music, movies, media formats, price, food, sports, health, etc. This category is situation-dependent, or perhaps even mood-dependent (relating to emotional factors). Also included in the extended profile are device profiles, where the pre-set default device profile is changed according to user preferences; and service profiles, which are predefined, but can be amended based on user settings. Device-driven user profiles, for instance, allow the use of private or professional networks based on geographical location.

User profiling requires a profile management system and user models. In particular, privacy is a major issue for user acceptance. These topics are discussed below.

4.3.1 Profile Management

It is recommended that overall (and often technical-oriented) user profiling is enhanced with situation-dependent user preferences and user behaviour. Therefore, such situation-dependent user preferences also need to be incorporated into the profile management.

If the user profile also contains situation-dependent subprofiles, setting situation-dependent user preferences, such context preferences can be used to find a match when the situation (context) changes, resulting in a more effective match. Therefore, user profiles, context information, security and privacy should all be managed by one and the same framework. Privacy is, of course, a major issue. It should be guaranteed at all times and all profiles should be managed and handled in a trustworthy manner, for example by a trusted profile manager, specialising in personalisation of information.

A person should have access to more than one profile. And, if the user has different profiles, it should be possible to have a single integrated view of the different profiles. Standardisation in profile management is a key issue, as users are currently confronted with a high number of different systems, with each their own characteristics, procedures and specifications. It should support the major popular sites, e.g. Facebook, Hi5, LinkedIn, etc., be user-friendly, transparent and, yet, efficient for matching purposes.

There is a need for updating profiles regularly and efficiently in order to adapt to changing situations, user preferences, new services, etc. The system should extract the maximum of data from other sources, without intervention from the user and at the same time limit the effort by the user in defining the profile. Thus, automation and profile entry efficiency should be maximised. The user should not have to be concerned with the technical applications or underlying technologies when using the devices and access profiles for such devices. User-friendliness, usability and convenience are priorities.

According to ETSI, the following properties have to be defined for each user profile:

- Profile name;
- Core functional data (preferences, settings and rules);
- Activation criteria;
- Deactivation criteria;
- Mandatory user confirmation for activation & deactivation of profiles.

In addition, other elements can optionally be included, such as:

- Free-text comment;
- Profile hierarchy;
- Association to a live template ;
- Lifetime.

Research Issues

- Enhancing the overall user profile system with situation-dependent subprofiles;
- Complementing the technical-oriented profile with a more personal perspective;
- Need for standardisation in online user profile structures and procedures;
- Need for privacy guarantee and trustworthiness at all times;
- Need for user-friendliness and simplification.

4.3.2 User and Social Networking Models

Various models can be used to represent the different aspects of the user profile. However, it is essential to consider the aforementioned factors and context elements, such as location, social contacts, availability, etc.

Situation-Aware User Model

The situation-aware user model sets preferences for the user for a given context and has typically the elements (1) social network preferences, (2) situational preferences, (3) physical context, (4) user-activity context, as depicted below in Figure .

Figure 4.2 - Situation-Aware User Model

Social Networking

Context information describing social relations has not been covered as widely in literature as context with respect to location or personal interest. The availability of social network information in sites like Facebook, Hi5, MySpace, and the like, as well as their popularity, inspired concepts of how to use social network information as part of the user context. Given that social network services (SNS) are used to articulate and manage relationships to personally known people, it is expected that a recommendation or information sent by one of the social network contacts is perceived as highly relevant for the user.

Based on an online survey, addressing users of online social networks, first, the relevance of social network information for users has been analysed based on a survey and then, based on the results, a concept for inclusion of social network information as context information is developed. The survey and hypotheses testing revealed also the preferences of users with regard to the specific way in which and how social network information might be included as context. Based on that, the following two-sided concept for inclusion of social network information as context is proposed:

Enhancement of the user context and profile information with social network information;

Enhancement of metadata of information and recommendation provided to users with social network information.

The minimum of social network information necessary as part of the user profile is the information in which social networks (s)he participates. A better match with available information can be made if also information about the first order contacts of the user is stored or is accessible as part of his profile (preferences). Enhancing the user's profile with this social network information would allow to filter as relevant information that has been provided or reviewed by others from the same social networks or even by the contacts of the users.

Besides the user profile itself, also metadata of information needs to be extended with social network information. In this context, the minimum of additional metadata needed is the link to the social network information from which the information was provided or revised. For a more detailed matching, it is furthermore necessary to provide the link to the profile of the person providing or having assessed the information. According to the results of the survey, the trustworthiness of the information sent to the user would increase if the person providing it is related to his contact hierarchy. The closer to the first-grade contacts of the user, the higher the probability that the user sending the information will be recognised as known and the information sent by the sender will be considered as relevant.

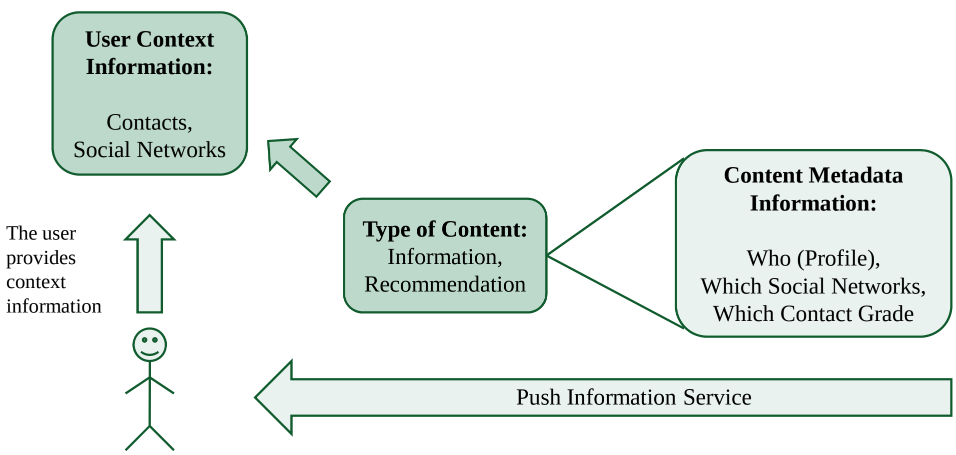


Figure 4.3 - Concept for inclusion of social network information as context

Research Issues

Enhancement of the user context and profile information with social network information;

Enhancement of metadata of information and recommendation provided to users with social network information.

4.3.3 Security, Trust and Privacy

A context provider essentially does not want the advertised context information to compromise its anonymity. On the other hand, a context consumer will have to make sure that it can trust the incoming context information (at least trust its sender and completeness), especially if this information should automatically trigger a specific action (maybe even a security action).

The following aspects concerning privacy and trust are to be addressed:

- Architecture for secured upload of context information
- Proposed solutions for advertising context information typically exist under a centralised form (a central server collects context information from the nodes it serves) or a peer-to-peer form.

Centralised exchange of context information should include anonymisation techniques, e.g. having collecting entities that perform aggregation over the received context reports, so as to preserve users' privacy. The central server (including the communications it manages) has to be designed so that it may not be a single point of failure for the system.

Peer-to-peer exchange of context information raises new security issues, making it more difficult for a user to control the dissemination of its context data. Solutions allowing for secure/limited dissemination should be investigated. Adequate means for providing true anonymity to the context provider should be developed as well. Both would typically emphasise the need for collaborative action between a set of nodes.

- Need for novel privacy/trust metrics and interfaces

Metrics should be designed to help the user quantify the trust he puts in various entities he interacts with, his privacy level and the sensitivity of the context data he is sharing, as well as to help his gaining visibility over the whole security level provided by the entire neighbouring topology (as opposed to the classically well-known one-hop distant peers). This also includes methods to constrain the visibility scope of personal context information to certain groups (e.g. friends, family, communities), avoid forwarding and limiting the life time of personal information.

Context-based security policies

Using context information to determine which security / privacy policy is to be applied (adaptive security) puts additional emphasis on the context characterisation, in that a badly identified context may lead to a critically inappropriate choice. This requires that intelligent control be performed over user-defined context-triggered security decisions, which may not achieve their intended goals. More importantly, an adaptive security scheme should be carefully designed, so as to prevent attacks where the actual context adaptation behaviour is targeted.

Research Issues

- Architecture for secure centralised or a peer-to-peer exchange of context information;
- Need for novel privacy & trust metrics and interfaces.

4.3.4 User Acceptance

Technology acceptance models aim at studying how individual perceptions affect the intentions to use Information and Communication Technologies (ICT). Aspects such as the ease of use, value, trust and adoption affect the intention to use a mobile service. To this end, context awareness may introduce additional difficulties to users if it requires complex configuration operations. From the user acceptance perspective, these complex operations should remain hidden; the user remains oblivious to any operation beyond the pure enjoyment of the services (simplicity and transparency). On the other hand, context awareness requires very detailed information of users, so any process should guarantee the highest privacy and trust level in order to encourage collaboration and acceptance.

The role of the users is evolving to a more creative role, providing content and services by their own, so the context-aware concept should also consider these new creative aspects in the ICT area and expect the user to provide content on himself, his context and his social relations by their own motivation, without being requested by the network. Instead of requesting information from the user, the whole process would be much more accepted if the user feels part of it, willing to participate in it.

Research Issues

- Simplicity:
    - Auto-configuration properties;
    - Context awareness: adaptability to situations;
    - User awareness: recognition and adaptation to the specific user.
- Transparency:
    - Isolation: spare the user of the complex network processes, even those where the user plays a key role, such as “user profiling”.
- Human role:

- Prosumer concept: beyond the user role -- the more implication, the more acceptance -- produce and provide content and services; user defining and sharing contexts.

4.4 User-Centric Services

An efficient way of improving the usability of mobile services and applications is to adapt the content and presentation of the service to each individual user and his/her current context of use. In this way, the amount of user interaction will be minimised: The user has quick access to the information or services that (s)he needs in his/her current context of use. The services can even be invoked and the information provided to the user automatically. A system is context aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task. The main challenge with context adaptation is that the context cannot be easily identified or measured. Some elements of context, e.g. social and intentional context, are almost impossible to recognise, so context recognition always includes some uncertainty. Even if the context was recognised, there are personal differences in user needs in different contexts of use and even with the same person the needs may vary.

Context awareness in mobile services has been studied a lot, but actual implementations are still rare. Currently, time and location data are well available for context-aware services, but the other elements of context may be more difficult to measure. Context awareness targets user experience having ready access to relevant information and services. Since context recognition and knowledge of user needs in a certain context include a high degree of uncertainty, user experience can easily be disappointing if the user gets irrelevant information or if the context is continuously changing, thus causing liability in the application. Users also have a role in context recognition: They can teach context recognition systems and they can themselves define and share context data, e.g. context data related to a social situation or user mode.

Thus, user perception of context-aware behaviour is an important area of research. What kinds of behaviour should be targeted for successful user experience? It should cover individual, application and context-related differences in user experience.

4.4.1 Service Ecosystem

Context-aware behaviour is often introduced as an application-specific feature. However, from user and also service provider point of view it would be beneficial to utilise the same context information in different services. That would ease taking context awareness into use as people could use the same profiles with different services. Cooperation of different technology and service providers as well as end users is required to create a whole context-aware ecosystem of services. The service ecosystem consists of interactions and relationships between service providers, content providers, content aggregators, network operators and users. A single service is connected to the whole ecosystem. Context awareness complements this ecosystem with context providers and context aggregators as illustrated in Figure below. The different major players that are involved in the future internet ecosystem can be allocated to different separate value networks. Such separate value networks are heterogeneous from each other. Linked players within the value network, are summarized in several clusters which are coloured in grey. These clusters e.g. show the content-related relationships between the stakeholders, or e.g. the context-related relationships.

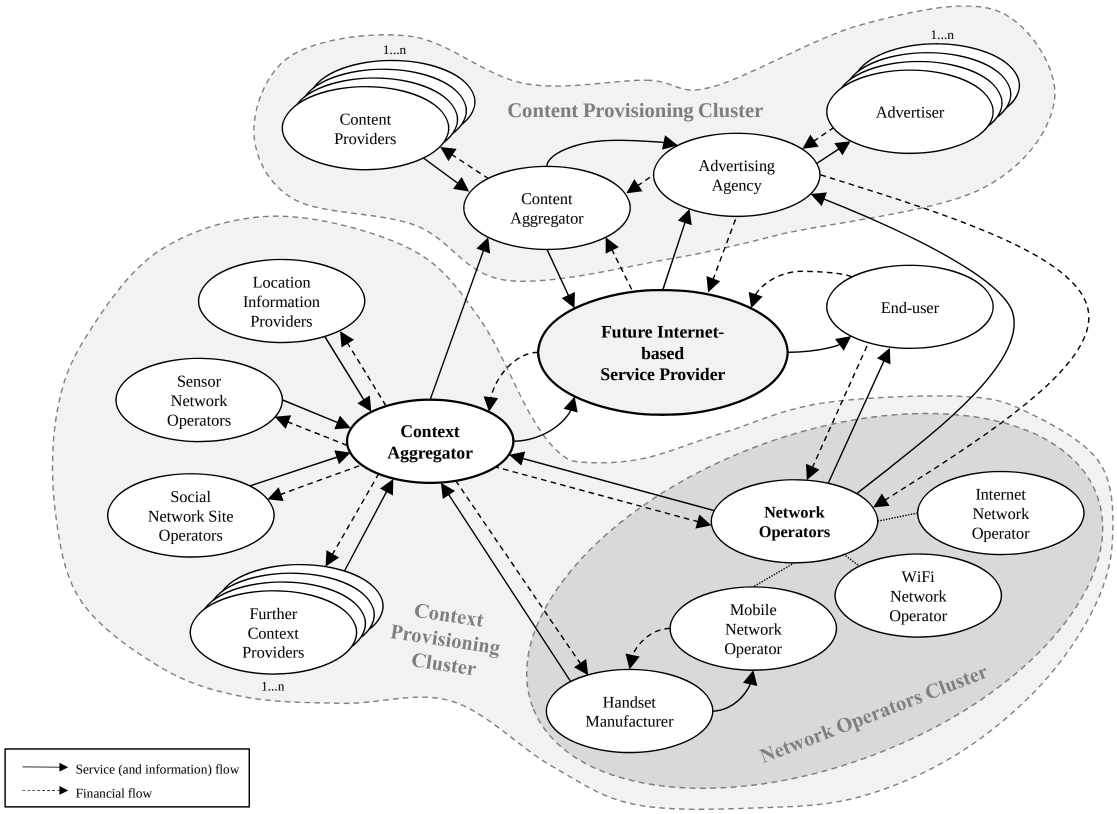


Figure 4.4 - Outline of the Value Network

Context awareness is not only about context-aware features in individual services. Context awareness is also extremely useful in activating contextually relevant applications and services. Universal context recognition is extremely challenging. That is why it can be expected that context awareness within service ecosystems will start from specific environments or application areas such as an ecosystem of services related to guiding visitors in a city or an ecosystem of services related to traffic guidance.

In the framework of these context-aware service ecosystems, it is important to study how services share context information and user profiles. Research should deal with its elements of context and user profile, which are (1) generic, (2) application field specific, or (3) application specific.

Research Issues

The service ecosystem with context providers and context aggregators needs to be studied. It has to be investigated how context aggregators have to be designed for provisioning of the necessary context information to the different services. The major research issues are:

- Context-aware service ecosystems with context providers and context aggregators;
- Users and user communities participating in defining, utilising and sharing contexts;
- Cooperation models for actors of service ecosystems.

4.4.2 Context-Aware Services

A diversified group of applications and services can be listed here. More and more information about users is being recorded and used to model and change the user experience when browsing the Internet, e.g. information used by online shops to show products more tailored to a given user. However, this can be pushed a step forward, as the network can start to use other information about the user in order to increase user experience and services. For instance, it can use the user location not only to give him/her location-based services, but also to show the user the location of nearby friends. There are many other examples of involving communities in general, not only friends, but also colleagues, relatives, professional relations, etc.

Context awareness can be provided at a large scale, as user profiles can be more or less known as a whole, not only involving connection usage (e.g. type of services or time of connection), but also other users' personal information not directly related to the network (e.g. daily commuting between home and work location, or type of food for restaurants). Additionally, a break into users' daily routine can also be used by networks, since this can be seen as unexpected events, e.g. if users start stopping in a highway, this may mean that there is an accident, and other users can be warned about it. Even the network can take advantage of this information, in order to allocate capacity to a given area, or to increase capacity for communication to a given centre.

Health care applications intend to assist elderly and other persons in need of care. By monitoring their health status (e.g. motion, blood pressure, pulse rate) and location, their everyday life is secured and eased. Context-aware systems facilitate communication to doctors, family members and friends in a convenient way when and wherever desired or needed, e.g. in case of accidents or emergency. The success of (e-) learning, collaboration and supervision of students and pupils can be increased by offering a smart campus. The integrated context-aware e-learning system may be able to deduce student experiences based on their profile, i.e. based on taken courses and modules. This way, course material can be filtered and tailored to the individual level of current knowledge. By using RFID (Radio Frequency identification) tags, other indoor location sensors and lecture schedule appointments with professors and supervisors can be easily managed. In addition, virtual notes could be left behind at office doors.

E-tourism and travelling are amongst the most obvious applications, though limited or at least focussing on location awareness as a rather simple type of contextual information. A context-aware travelling assistance service may filter the bus schedules and display the connections going in the right direction on the user's device - given the system is aware of the geographic and time goal. Delays can be considered and also train and flight bookings could be made and modified on the fly. Pedestrian ways between bus and train stations could be guided with the help of outdoor and indoor navigation. As a further type of contextual information, E-tourism may, moreover, involve the user profile (e.g. gender, age and spoken languages) to identify interesting sightseeing sites, adapt and display their description, accordingly. A public piazza may indicate places and actions of interest with regard to known preferences of the visitor. Multimedia content (videos, pictures) of other tourists - tagged with valuable information such as location and time of creation - may be accessible.

From the business point of view, context-aware advertising and other e-commerce applications are promising scenarios. Advertisements may be adapted to identified situations (party, meeting, hot weather, traffic jam) and to user profiles. The amount of ads can be reduced while maximising the hit ratio. Entertainment-oriented online applications aim at offering interesting multimedia content (movies, video clips, music tracks, ring tones) selected by a matching process based on user interests.

Various other different applications can be included as well, e.g. augmented reality and 3D Internet. Although not specific to context awareness, these applications can surely take advantage of the users' context to give him/her a better interface and experience with the network, with other people, and even with physical objects. Furthermore, context awareness can also be viewed from two different perspectives: a "physical" one, where context relates to the user situation in terms of the surrounding environment (location, types of available networks, etc.), and a "social" one, where context refers to the user profile (activities (s)he is engaged in, information on his/her friends and colleagues, etc.). The key factor beyond context awareness is that services can be tailored according to the user's physical and social context. Moreover, adding some sort of context prediction can further enhance users' experience; in fact, being able to predict the future context of a user or device can be useful to enhance services and the way they are being provided. An additional example can be considered for the interaction of a user with the surrounding environment, as it is the case of interactive context-aware games, i.e., games based on the user context: a user can play around in the environment where (s)he is located (which is automatically "absorbed" by the game), and the game adapts itself to it; context-aware games take the user and the environment inside the game.

Another important application and wide research area in itself are smart spaces. A smart space defines a limited geographic area that is equipped with numerous sensors, processing devices and actuators, e.g. smart homes and offices. The environment acts intelligently and assists users within this environment by adapting to their demands based on acquiring and applying knowledge. The combination of context awareness and mobile communication systems offers great opportunities for realising urban smart spaces at a large scale.

Research Issues

- Robust service adaptation framework for incomplete and erroneous context information;
- Efficient storage and distribution of user information for given applications;
- Profiling of users and communities for given applications;
- Meta-models for the description of context-aware applications to select and adapt the application according to the context.

4.5 Standardisation, Regulatory and Technology Roadmaps

Being a service enabler rather than a holistic service, context awareness adopts and supports all the business models already discovered and applied in the telecommunication world with multiplayer revenue sharing, complex values chains and multichannel value chains, etc. Therefore, no pioneering contribution is expected in the business model perspective by providing context-aware services. However, the business development; i.e., the way to build new businesses through new context-awareness-enabled services is of very high potential as far as context awareness opens a new dimension widely unknown to the classic communication service providers. The standardisation effort focuses on the creation of the technological and technical awareness, which will support features that shall be respected by all industrial partners in the end-to-end mobile market from terminal and service node manufacturers to the service providers and their customers.

Context awareness should be considered as a promising service enabler for providing a variety of adaptive services. Therefore, the right place to consider it for future business models and business evolution for ICT (Information and Communication) operators, as well as for IT (Information Technology) companies, is industrial standardisation rather than best practices. The concept and the technology underlying context awareness is pretty innovative for the ICT and IT industries and is not yet considered in a consistent service-enabling way in world-leading standardisation bodies. However, initial standardisation efforts have already been made in a number of standardisation working groups, such as OMA (Open Mobile Alliance) and W3C (WWW Consortium).

The next sections review the current state, the roadmaps and research issues for standardisation and evaluation methodology for context-aware technologies.

4.5.1 Standardisation and Regulatory Issues

As mentioned above, context awareness is neither a service, nor a technological solution, but a service-enabling class of features – a new service dimension. This pretty much predefines the choice of the standardisation body. Major efforts can be identified within the following standardisation bodies and their respective Working Groups (WG):

- OMA (Open Mobile Alliance):
    - Mobile Advertisement WG, which allows and considers a mobile-based service – advertising – to be customised according to user preferences;
    - Mobile Search Framework, defining a context-aware search results visualisation at the customer side;
    - Moreover, context awareness is also considered within requirements formulated in the Next-Generation Service Interfaces requirements draft document.

However, there are already some service enablers within OMA, such as the Proximity and Location Service Enablers that already rely on the context of the user, its presence status or the user's location in their respective cases.

- W3C (WWW Consortium):
    - Context Awareness and Personalisation Working Group that has just been started as a recent proposal to be brought into the W3C and as yet little effort has been made in the area of standardisation. However, within this group, its standardisation mission, even if at idea level, is in a good definition way.

There are a number of other standardisation initiatives that treat or consider context in some way, such as 3GPP (3rd Generation Partnership Project) or the IPTV (Internet Protocol Television) forum, but these efforts and their respective CA service features are not of an integrative character as the two initiatives mentioned before. In the case of 3GPP and IPTV, only network availability and quality evaluation embedded into a mobile terminal, which is not available for any service except the network monitoring and management, or only explicitly assigned user preferences in their respective cases, apply and hence may not be considered as technology enablers for context awareness.

The regulatory situation regarding privacy and in particular commercial use of personalised data is heterogeneous in Europe. This has to be taken into consideration by the service logic. An effort towards harmonisation of the different legal frameworks is recommended.

Research Issues

- Integrating standardisation initiatives;
- Harmonising different legal frameworks;
- Defining integrated standardised required technology enablers for context awareness;
- Establishing mobile search framework: defining context-aware search results, visualising at customer side**.**

4.5.2 Design and Evaluation Methodologies and Metrics

User evaluation is needed throughout the design process to identify the different elements of context and user preferences in different contexts. The main challenge in evaluating context-aware behaviour in services is that there are several different contexts, and different users have different preferences in the contexts. Thus, testing all possible combinations and alternatives may become quite time-consuming. Methodological development will be needed in order to get efficient and cost-effective methods to illustrate design decisions and gather user feedback throughout the design process.

Research Issues

- Methodological research and development is needed in user research, design and evaluation methods to identify user needs for context-aware behaviour and to assess the success of context awareness.
- Methods for human-centred design of context-aware behaviour;
- User research methods to identify key contexts and their elements;
- Measurement tools to assess the accuracy of context recognition.

4.6 Recommendations

Summarising the analysis conducted in this chapter for Context Provisioning and User Profiling for User-Centric Services leads to a set of key high-level recommendations to future European and National programmes to be considered in the initiatives for future funding of research on the next generation of user-centric services including context awareness with the emphasis on mobilisation of resources towards a common goal, thereby enforcing and consolidating Europe's position in user-centric services.

R1: Enhanced support of privacy: as a key issue for user acceptance;

R2: Reference metrices: to monitor and compare progress of different approaches;

R3: Standardised Interfaces for context provisioning and user profiling enablers: from hidden context-aware services to common reusable context-awareness components;

R4: User-centric services with explicit use of context information: from any services at any time anywhere to the right service in the right context (including meta-models for service description to select and adapt the service according to the context);

R5: Standardised structure for user profiles and situation-dependent subprofiles, including social network information and supporting aging and evolving demands of users.

R6: Algorithms that support fault tolerant selection and adaptation of services based on uncertain and incomplete context information.

R7: Service ecosystem for the cooperation of the different actors in heterogeneous administrative domains, allowing for centralized and decentralized context-aware services.

5. Trust, Security, Dependability and Privacy

In this chapter, the concepts of security, trust, dependability and privacy are briefly discussed from the point of view of mobile and wireless communications. These abstract concepts set objectives that should be reflected to actual technical STDP solutions to be developed.

5.1 Trust

The concept of trust will become more essential in the near future. Trust is a complex concept that is composed of many different attributes, such as reliability, dependability, honesty, truthfulness, security, competence and timeliness, which may have to be considered depending on the actual environment. It must be noted that trust is directed, highly subjective, context-dependent, dynamic and conditionally transferable. It also depends on history. Trust is usually non-monotonically changed with time, and may be refreshed periodically or may be revoked, and must be able to adapt to the changing conditions of the environment in which the trust decision was made. Trust can no longer be assumed in the emerging and future wireless and mobile communications. There is a need to differentiate between trust and other security-related concepts and understand trust relationships better. Trust should be obtained, perceived, assessed, measured, ensured and communicated.

User trust in technology and mobile services includes perceived reliability of the technology and the information and functions provided, reliance on the service in planned usage situations, the user's confidence that (s)he can keep the service under control and that the service will not misuse his/her personal data. The users may have unrealistic expectations that may cause unfounded trust or mistrust. User trust and the actual trustworthiness of the mobile solutions need to be in balance. Usability problems are often related to missing information on the available services and how to deploy them. The user population of mobile devices and services is growing, both in the consumer market and in professional use. User abilities and skills vary, and many users in the developing countries may even be illiterate. This poses increasing challenges for usability and user trust.

We should be able to build trusted systems, Trusted Computing Platforms (TCP), trusted devices and the communication itself has to be trustworthy. There is a need for solutions that provide justifiable trust that the system or device will function according to its specification.

5.2 Security

The security of mobile communications has, and will continue to be, a core issue of high practical relevance. Without adequate protection devices, networks, applications, services and personal data, trust and confidence in mobile systems would quickly vanish, as has been the case with so many Internet-based services. With the fourth generation of mobile systems envisaged as resulting in a full merger of traditional mobile systems with VoIP and data services and a full integration with many other Internet-based services, the traditional Internet-based threats will become highly relevant for mobile systems. A seamless transition between heterogeneous networks and services that have so far been kept separate also means that perimeter- and gateway-oriented security paradigms will have to be supported and eventually even be replaced by a new generation of security mechanisms. User-managed and system-controlled security elements will have to work hand in hand. From the application layer down to the physical layer of network infrastructures and from the basic operating system to the applications run on future mobile devices, security will have to be ensured in an end-to-end mode.

5.3 Dependability

Dependability can be defined, e.g., a system property that addresses many attributes such as availability, reliability, safety, confidentiality, integrity and maintainability. As the dimensions of security are confidentiality, integrity and availability, it is a sub-dimension within dependability. In addition, dependability has overlapping objectives with trust and privacy.

The performance and compatibility of protection systems for mobile devices is still defective and perception of the whole environment is important in the design of security solutions. One cannot assume that inputs to mobile devices are well defined, correct and harmless. The dependability of the software is becoming more and more critical, as well as its ability to filter out deficient data coming from its environment.

Nowadays the market sets tight time schedule requirements on R&D, in many cases resulting in a low quality of implementation. Poor quality increases the number of vulnerabilities and other dependability problems. Threats include the great number of different software versions, unsatisfactory maintenance of software (e.g. updating anti-virus software and backup of information) and the more risk-prone open programming interface of new mobile operating systems.

5.4 Privacy

Privacy is an inherently important part of the user's trust in mobile services.

Information processing and storage capacity have increased remarkably and will continue to increase in the future. It is possible to collect a lot of personal information from the Internet and other electronic sources. While a single source of information may not be a threat to privacy, combined information from different sources can be. The lifespan of information is vastly different in the ubiquitous environment, and it becomes less controllable as it is recorded and mediated. Thus, it is becoming far easier to automate the collection and processing of information, and the users are interacting with a multitude of other users and entities without always realising that.

Privacy protection should cover storing, collecting, using and transferring personal data. From the service providers' point of view, their customers' privacy is one of the core business assets. A correct and careful response to the privacy requirements is imperative: inadequate privacy solutions will lead to lost opportunities and serious financial implications. However, the providers also have incentives to gather information on their customers' behaviour in order to keep up with the current trends and maximise the cost-efficiency of their offerings. Naturally, the providers still need enough identity information for billing purposes. In addition, the regulators and authorities set their own requirements for the identification of users. The user should be given the possibility to control the usage of their own personal information. One possible approach is the user centric identity management that gives the users the keys to dictate the level of information disclosure. However, the usability issues become critical when the users wish to use the services in an unobtrusive manner and do not want to have to make a privacy decision at every step. User centric identity management can be seen as one of the Privacy Enhancing Technologies (PET) that are providing a research direction for privacy solutions in the ubiquitous environment.

A challenge for privacy in telecommunications will be to find a balance between two often opposite demands, traceability and anonymity. This balance cannot be implemented using technical solutions alone – legislative guidelines and regulation are also needed. Privacy management and enforcement cannot be done without technology, but technology alone cannot solve all the issues.

5.5 Some Threat Trends in Mobile and Wireless Communication

5.5.1 Increased Complexity

Because of the digital convergence, the complexity and number of interfaces in devices is increasing, resulting in an increased need for management of the system as a whole. New security threats are introduced when mobile devices become more versatile and more complex. A great number of conventional PC threats already concern mobile devices too. Cross-layer, cross-spectrum and cross-network operation is becoming more and more common. Data services with a connection to networks such as the Internet are especially plentiful. At the same time, the user has more responsibility for his/her device, which could be difficult to follow. The users are likely to have many devices, both single and multipurpose, and there is a lot of device-to-device communication. One should also take into account that not all devices are for personal use only – some are in shared use by a group of people.

One can learn from the history of technological development that architectures and platforms (or at least parts of them) such as communication networks and user devices are often re-used for purposes for which they were not originally developed, causing major security problems in many cases.

Simple and unambiguous architectural solutions could increase security. In addition, they should be designed to answer the security, trust, dependability and privacy needs of the target use scenarios. A remarkable challenge is that smart phones are being used as platforms for applications and services that cannot be foreseen during the platform design.

5.5.2 Increased Connectivity

The expanding wireless connectivity to individual devices and networks, which increases their exposure to attack, is one of the key areas of concern. In dynamic, hybrid or all-wireless network environments, the traditional defensive approach of securing the perimeter is ineffective because it is increasingly difficult to determine the physical and logical boundaries of such networks.

5.5.3 Wirelessness

Wireless networks share common security threats; however, some of them are more pronounced than others. From the service providers' point of view, fraud and theft of services, malware, business image problems and bad publicity relating to information security incidents, and loss of privacy of their customers are the main causes of worry. The end users are concerned with hijacking of connections or capturing of credentials, loss of integrity in the terminal, and eavesdropping. Wireless networks also have other kinds of threats – they are not protected or bound by the natural physical access control in fixed networks. Malicious users and radio interference are weakly traceable, and tracing them often requires special hardware and surveillance.

5.5.4 User Devices

The physical device itself must be well protected in order to avoid loss of stored data and to ensure that confidential data cannot be accessed even if the device gets into the wrong hands. Mobile device security includes physical protection, platform security, device access control, storage protection and protection of connections. Threats targeted at the user have increased due to the increase in mobile device use and their increased multiformity. For example, the use of mobile devices as tools, as personal information repositories and as a channel to access services is causing mobile users to puzzle over many practices familiar from the Internet world, such as certificates, passwords and configuration settings. Incidents involving spamming, Denial-of-Service, virus attacks, content privacy and other malicious attacks have become a growing problem. Consequently, security needs to be built into the platform instead of dealing with various separate add-on features. New platform security solutions for user devices should support device STDP management, reduce the complexity and offer means to manage add-on components and applications from STDP point-of-view.

The impossibility of physically protecting the devices in a wireless network, as well as the still limited processing and storage capacity of battery-driven mobile devices, are challenges for the implementation of STDP solutions. The traditional approach of securing the network perimeter must be replaced by securing the network connectivity, network nodes and network services, since no fixed perimeters exist. New threat models for mobile devices are constantly evolving.

The storage capacity, performance and applications of mobile devices increasingly resemble those in a personal computer environment. Smart phones contain a lot of personal and business-critical information and they easily get lost or stolen. This poses new challenges for trustworthy data storage and backup, as well as protection of data if the device gets into the wrong hands. Storage protection of a user device should include online integrity control of all stored program code and data, confidentiality of stored user data and protection against unauthorized tampering of stored content.

In addition, it is very difficult for the user to realise the differences between professional and personal use of the mobile device. The information security needs for these two ways of use are different. In the PC world it has long been common practice to utilise a separate device to protect information meant for professional use.

Some novel technologies and local communication solutions, integrated to user devices, may create special security and privacy threats if not properly integrated to the threat analysis and use scenarios of the device. These technologies include biometrics, Near Field Communication (e.g. RFID) and device-to-device communication solutions. Traditional security solutions are too heavy to be implemented at reasonable cost to the cheap and simple RFID tags. Unprotected RFID tags are seen as a privacy risk. Ignoring these risks can slow down the adoption of the technology from plain industry use to everyday life.

Availability is very poorly addressed by security solutions in devices today. Most devices with security monitoring have a definitive reaction after detection of a problem, such as clearing memory, erasing cryptographic keys, etc. These kind of reactions could be used, e.g., for Denial-of-Service type of attacks. More attention should be paid on availability and survivability of devices, services and applications.

Identity management is a major challenge in current and future devices and networks. For instance, usability of IP addresses depends highly on the application. For instance, the IP end point model is clearly not suitable for sensors or RFID carrying out environmental monitoring.

5.5.5 Network Management, Roaming and Routing

Operator networks are incorporating many features similar to the Internet network. They can be compared with companies' intranets, accepting only desirable traffic. At the same time, operator networks inherit threats from Internet networks. The servers in operator networks are targeted by unsuitable and malicious network traffic, both from the Internet and from the mobile users. It must be noted that in the future, in addition to operators small "mini-operators" can be involved in the business. Non-repudiation will be more important in this kind of dynamical environment. Management of roaming security, e.g., mutual authentication of a user device and the access network is an important challenge. The unpredictable and dynamic topology of mobile networks is not only a source of routing complexity but also a routing security problem. Secure routing starts with route discovery protection and requires a secure routing protocol in the presence of malicious network nodes. In addition, a secure and fault-tolerant data forwarding scheme is needed.

5.5.6 Automated Operations in Applications and Services

Applications and services are using more automation to provide better user experience. Applications may establish automated connections to a variety of information sources from where the desired data will be fetched. This automation can cause surprising costs to the customer when, e.g., the mobile device decides to fetch incoming emails over 3G connection when the user is travelling abroad. Consequently, it is important to validate the target of such automated operations. Context-aware applications can also require connection to external sources for acquiring context information. The authenticity of the source and the validity of the data should be verified prior its use.

5.6 Research Priorities

In the following, we introduce research topics that we think are important in mitigating the near future threats and answering to the security, trust, dependability and privacy challenges introduced earlier.

5.6.1 Proactive STDP Solutions

Security, trust, dependability and privacy issues should be analysed and built in to the system starting from the very early stages of its development in order to be able to develop proactive architectural, technology selection and system-level solutions.

The Internet has become a crucial element of our economy and society. Its evolution and how it has to respond to future challenges is at the core of continuous global discussions. Today is the correct time to affect the Future Internet architectural and technological choices from the point of view of security, trust and dependability in a proactive way.

An important cross-discipline task is to establish a generic, widely accepted and unambiguous trust model that can be implemented in technical architectures and design. The trust model should define the trust relationships and liability issues, and ensure enough security and privacy.

In the current communication architectures, attackers often have many asymmetric advantages over defenders, such as powerful tools and readily available resources. If security is not taken into account in some of the layers of the communication architecture, attackers can easily take advantage of it. The current security, trust and dependability solutions are not multi-level enough. Classical paradigms for security use the multistage or multiple barrier idea. Information and communication technology based systems should follow the same philosophy. It must be noted though, that non-malicious threats will continue to account for the biggest business impacts.

Complementary to the protection provided by the affirmative security mechanisms, defensive mechanisms and processes are needed for the detection of and response to certain attacks and malfunctions. Nowadays there is ongoing provision of protection against malicious agents –

such as viruses, worms, Trojan horses – and Denial-of-Service (DoS) attacks. Most malicious agents are dependent on inadequacies in widely used components. In addition, defensive measures are required to detect and counter intrusion and disruption attempts and other emerging threats, as well as unforeseen and unauthorised by-products of otherwise legitimate functionality. The design of the protection of the system's operation and services must also include attack-resistance and fault-tolerance.

5.6.2 Usable, Scalable and Built-in Security, Trust, Dependability and Privacy for Mobile Communications

Security, trust, dependability and privacy are clearly system-level problems. Most of the requirements for these characteristics arise from the mobile services that utilise the system-level features. Consequently, one cannot accurately determine the STDP requirements outside the context and environment of the system and use scenarios. Building STDP requirements is often a process of making trade-off decisions between high STDP, high usability and low cost. The STDP solutions should be as usable as possible. They should respond to the requirements of future services that may be critical. From the user point of view, STDP solutions need to be easy to understand, easy to take into use and easy to monitor and control. Poor usability may actually turn the solution into a threat as the users either refuse to use the solutions or use them in the wrong way. The current security solutions in telecommunications often suffer from poor usability. A specific problem is that the users do not understand the solutions and often just choose to rely on them.

An important part of the low usability of the current security solutions is that they are not scalable enough. Scalable and reconfigurable security solutions are needed to answer the needs of actual use cases. STDP solutions should not be designed as separate services or add-ons. They should be built into the actual architectures and should be addressed from the very first phases of the development. A holistic perspective on the system and STDP design that integrates the set of common and interoperable technological solutions is clearly needed.

Further development of hardware support for cryptographic algorithms and for the key management, required by these algorithms, is needed because of the capacity limitations of mobile devices. The potential of the emerging cryptographic technologies for wireless and mobile networking should be explored and deployed. The current algorithms are robust (from the point of view of current needs) and have been thoroughly explored by mathematicians, cryptographers and other computer scientists. Security solutions based on cryptography are therefore attacked with phishing, other social engineering techniques, and through vulnerabilities in the key management. Widely diffused systems, with the user (and the attacker) having physical access to it, cannot be considered as fully secure. The key management can be improved by proactive avoidance of implementation vulnerabilities and by improved key management functions. A number of cryptography research topics are relevant to the entire digital environment. They include fundamentals such as ongoing cryptographic research, including flexible and scalable low-cost cryptographic protocols and STDP mechanisms for low power devices, the general issues relating to identity and privacy provision and management.

Development of suitable security policies for wireless and mobile communications is needed. Security is formalized using “security policies” paradigm. There is a lot of work dedicated to the development of methods and tools to express analyse and prove security policies. However, security policies formalize normal behaviour (protocols, access rights, etc) and do not take into account attacks based on a physical access to the device (side channel attacks, fault generation, modifying the environment). Detection of attacks and effectiveness of security reactions depend only on the competence of the developers. Modelling physical attacks, attack detection capabilities and security reactions, developing integrated tools to express, analyse and prove security policies integrating these features are key elements of the future. Security solutions implementing policies should incorporate sensing and reaction capabilities, evolving from crypto-processor to a security system. Particular challenges are raised by the ubiquitous, pervasive mobile environment: the dynamics, fluidity, and mobility; the polymorphism and heterogeneity; the need for automatic negotiation and agreement on security policies and implementation to enable co-operation and collaboration of domains.

The end-user device will have an essential role due to the direct user interaction, the support of application software and the connectivity it will provide to various access networks. The ubiquitous, self-organising and heterogeneous environment brings many new STDP concerns into the picture, and new measures are needed to protect the devices and data stored in them or accessed through them. Multimodal and context-aware authentication and context-aware authorisation can be used. There is a need to move up from the current paradigm of authenticating the device in the system into actually authenticating the user. Secure and trusted application integration mechanisms, as well as trusted execution environments, are important areas for development. Protection of security devices (such as smartcards and dedicated circuits) has to be improved. During the last 10 years, there has been permanent and fast evolution of attack methods targeted at them, resulting to a reduction of their life time.

5.6.3 Industrial Strength Methods, Metrics and Tools for Security Assurance, Forensics and Vulnerability Discovery and Management

The increasing complexity of telecommunication and software-intensive products, together with digital convergence, is increasing the need for adequately validated STDP solutions. Different security assurance methods are needed, such as testing, monitoring and evaluation. Testing is not enough in itself, nor is evaluation. Definition of STDP requirements at a suitable level based on threat and vulnerability analysis is a vital stage in security engineering – the requirements guide and control the security assurance activities.

How secure is a software product or a telecommunication connection, or their fusion? And how secure does it need to be in order to be secure enough? Even though appropriate security solutions can be found, their resulting security strength often remains unknown. If appropriate security, trust and dependability metrics (or indicators) can offer a quantitative and close-to-objective basis for security assurance, it would be easier to make business and engineering decisions concerning security, trust and dependability.

The field of defining security metrics systematically is young. The problem behind the immaturity of security metrics is that the current practice of security is still a highly diverse field, and holistic and widely accepted approaches are still missing. If the research community is able to develop intelligent and feasible mechanisms for the measurement and information gathering, we might even learn more about the nature of security, trust and dependability. The current limited knowledge of the nature of security-related concepts is hindering us from finding rigorous solutions to the aspects of overall security. Overall, metrics provide four fundamental benefits – to characterize, to evaluate, to predict and to improve.

Even with the best precaution, there will be misuse of the devices and networks in one form or another. In order to resolve the incidents, forensic analysis is required. Gathering a variety of logs and traces can help the forensics process. On the other hand, they can be a threat to privacy. Live monitoring of systems like intrusion detection and intrusion prevention systems can be used to analyse the attacks while they are happening. As the systems get larger and consist of devices from different manufacturers intended for a variety of purposes, security information and event management systems are required. These systems can combine information from different sources and provide a centralized view of what is going on or what has happened in the system. Such systems should be further developed so that enough information is provided for analysis but at the same time the information should not overwhelm the system analyst.

It must be noted that the perceived security level is often more important than the “real one”, justifying a higher level of security.

5.6.4 Special Emphasis on Security, Trust, Dependability and Privacy in the Future Internet Architecture

The basis of the current Internet was developed in a closed environment, and its implementation still assumes a domain of mutual trust. Since then, the Internet has grown remarkably and changed its role. The demands for security, trust and dependability are today higher than from the initial environment. Furthermore, more and more components of societal critical infrastructures depend on global communications like the Internet. There are security, trust, dependability and privacy challenges for the Future Internet on many levels: architectural, service, user and various technical levels.

As individuals rely progressively more and more on Internet of Things applications, a new level of trust will emerge in the system. The applications, regularly processing personal data, will have to be (and be perceived as) secure enough to prevent identity theft and disclosure of critical information. In particular, exchange of secure information between different systems has to include new aspects of privacy control. Different schemes for reputations are also needed.

The role of security, trust, dependability and privacy is essential in all parts of the future network architecture. STDP should be integrated into the operation of the terminal, the radio access network, the core network and the service platform and in all relevant layers including hardware, operating systems and protocol stacks. Secure and dependable end-to-end protocols should be developed to meet the changed requirements. The level of STDP offered should be adapted to the needs in terms of user authentication, authorisation, confidentiality, integrity, non-repudiation, privacy, anonymity, global identity management, and content protection. The overall challenge is to maintain seamless, context-aware and transparent end-to-end STDP with an array of different technologies combined in a multitude of combinations in order to provide a flexible and efficient framework for the users to securely and privately enjoy their applications in comfort, while ensuring the trustworthiness of all services.

The STDP solutions in the Future Internet should be context-aware, scalable and designed for change, evolution and adaptation to combat unpredicted threats. The user’s identity and credentials needs to be protected and there should be better means to protect devices and networks against the malicious intentions of current and future malware. The generation and distribution of information content in the Future Internet should be re-thought with reference to the current philosophy where data is not often distributed in a desirable way.

Secure self-configuration, self-organisation and survivability (self-healing) are important functional requirements in the future network architecture. Dynamic transition and reconfiguration of devices and services set challenges for STDP management.

6. Machine-to-Machine (M2M) Communications

6.1 Rationale

Machine-to-Machine (M2M) communications represent technological solutions and deployments allowing Machines, Devices or Objects to communicate with each other, without any human interventions. The M2M market generated by usages, applications and services is promised to experience an annual growth of 49%, and exceeding 220billions euros in the coming years.

This represents one of the most attractive emerging market, with applications such as Fleet Management, Smart Metering, eHealth, and many others facilitating daily life of the citizens, whilst truly transforming our usages in the coming years.

Due to this massive potential both in terms of business and transforming usages, many manufacturers, industries, governments, governance bodies and thus standards are currently preparing the adequate frameworks from legal, technological and services point of view.

Finally, since Interoperability is the keystone of M2M, a review of the state-of-Art (SoA) is presented on the whole M2M ecosystem, including worldwide standards (3GPP, ETSI M2M, IEEE 802.16, IETF…) and industry forums currently trying to push for both solutions and usages.

6.2 Total Achievable Market

Defining the addressable market for wireless M2M is a highly complex task. 100 billion communicating objects are expected to be in use worldwide in 2010 according to ABI Research. Is that the size of the M2M market? Of course not. We should rather consider it as the size of the potential M2M markets, which can be valued very differently depending on the technology in use and the depth of the value chain in each market. As a matter of fact, most of these 100 billion objects communicate with simple RFID technology, and very few with enhanced wireless technologies, which are able to provide real services through the implication of many actors in the value chain.

Some valuable M2M markets opportunities are displayed in the figure below (Figure 6.11), especially in Health market (1 billion of over-weight adults looking for efficient monitoring solutions, or 860 million people looking for tools to manage their chronic disease for example), Energy and Home automation markets (300 million major home appliances, 200 million energy meters, 100 million HVAC equipment for example), and Automotive markets.

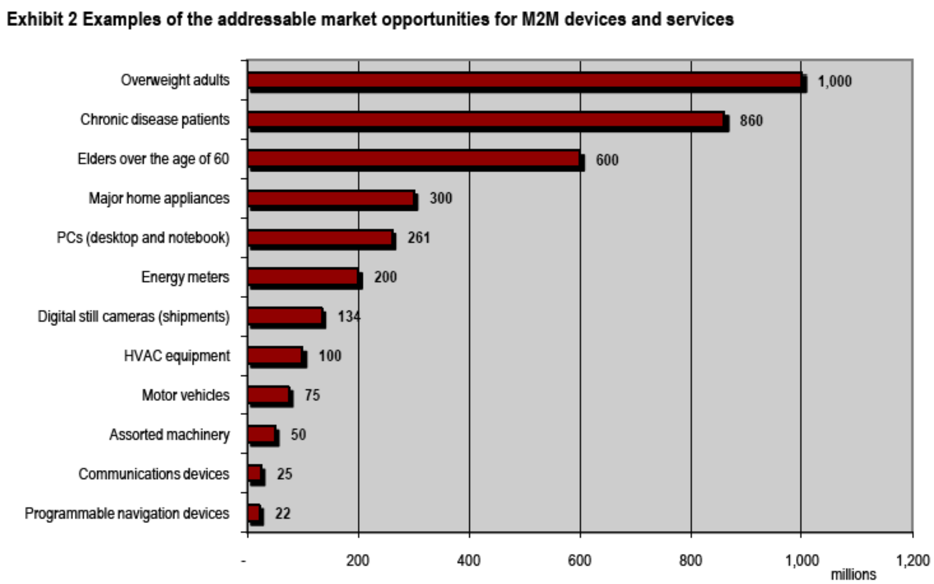


Figure 6.11 Addressable Market opportunities for M2M devices & services (source: ABI research)

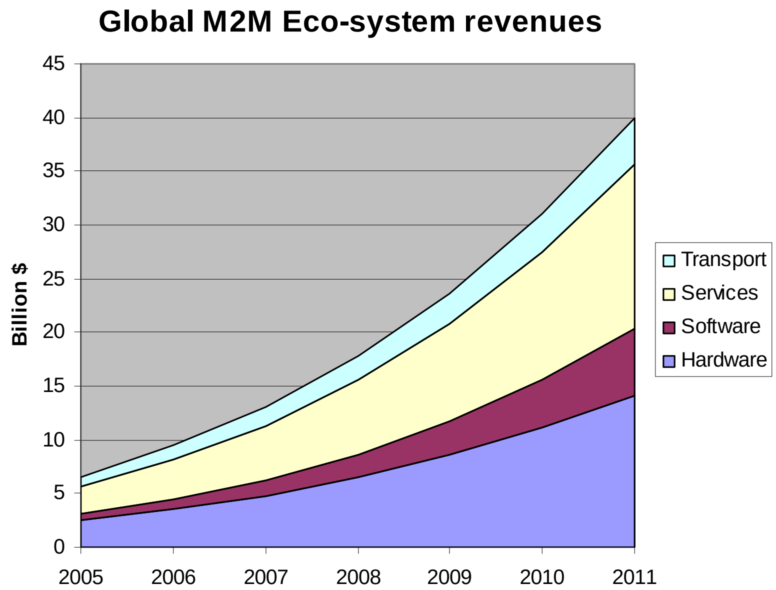


Figure 6.12 Global M2M ecosystem revenues (source: CEA)

The uptake of M2M cellular market continues to vary significantly in different industries and vertical markets, as it can be seen from Figure 6.12 above., and below on Figure 6.13 which just highlight the cellular based M2M markets.

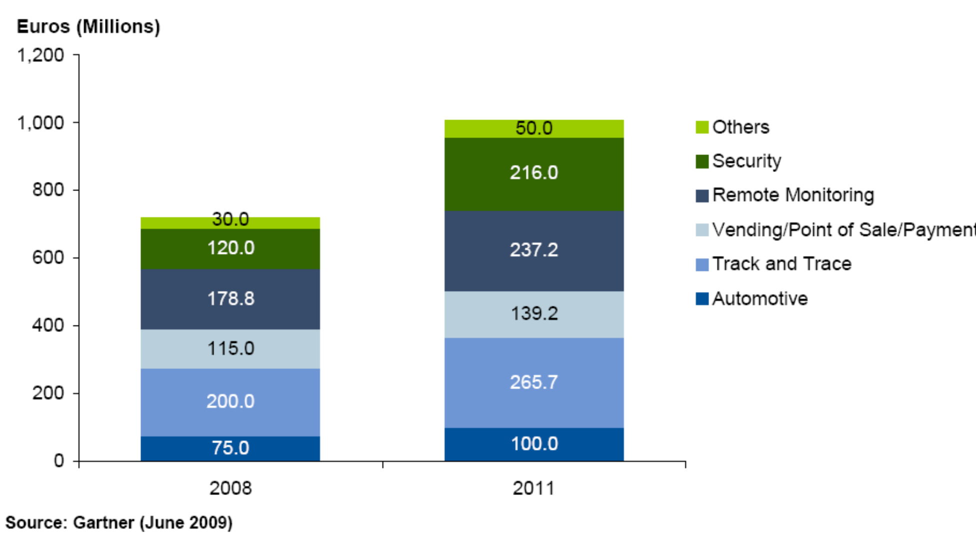


Figure 6.13 M2M Cellular Mobile Vertical Market Growth estimates, 2008 and 2011 (source: Gartner)

Of course, M2M is not only about cellular based markets and this represents only one potential enabler. As a consequence, it is thus also interesting to measure the M2M take-off thanks to shipment of some other technologies, such as ZigBee chipsets, that are fully part of the capillary network technologies. Again, as depicted in the Figure 6.14, below, shipment forecast growth estimates by application segment are by far more than promising, thus suggesting the take-off or maturation of such applications and services.

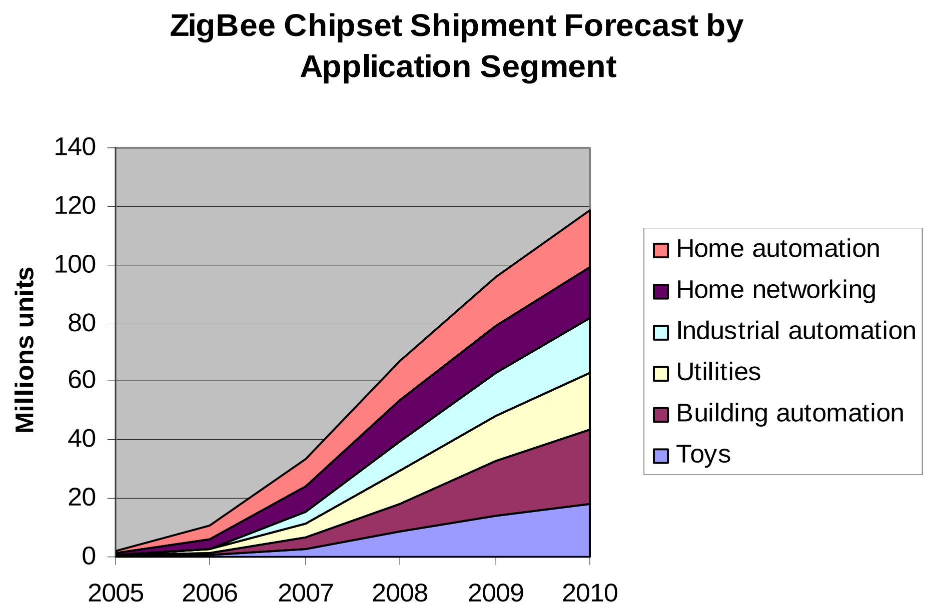


Figure 6.14 ZigBee Chipset Shipment Forecast (source: CEA)

6.3 Industrial Perspective

6.3.1 Value Chain and Evolutions

Understanding the whole M2M ecosystem is fundamental to address the way different enabling technologies can interoperate in order to support the provision of many different applications and services. The value chain of the M2M ecosystem is depicted in Figure 6.15, highlighting its complexity and diversity:

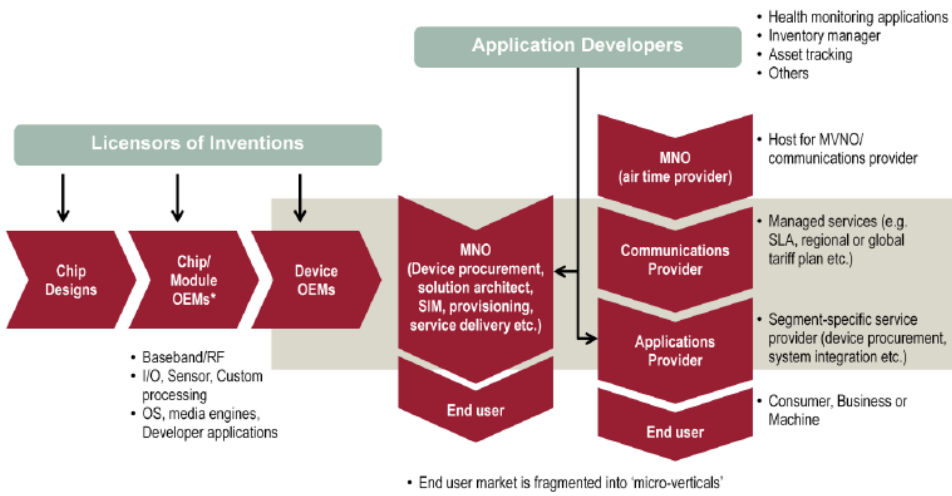


Figure 6.15 Value chain of M2M ecosystem (source: ABI research)

6.3.2 Potential M2M Applications

6.3.2.1 Car Telematics

In recent years, the vehicle paradigm has undergone a complete revolution. Aspects such as safety, comfort and interaction with the environment have been significantly improved thanks to the introduction of new technologies in an environment traditionally isolated from the communication point of view.

According to this recent evolution, transportation (V2V, V2X) are expected to change dramatically the existing transportation systems and their applications, especially in terms of safety and efficient mobility. An example is the spreading of safety messages such as warnings and alerts among different vehicles. Other no-critical services, such as traffic or tourism information or even entertainment applications, could also be delivered to users.

As users tend to spend more and more time inside their cars, one of the challenges of communications is the distribution of telematic services to vehicles. This goal has a complex problem associated to itself and the following aspects should be researched:

- Safety alarms services: new services which distribute and present safety alarms in real time. These services need efficient distribution mechanism which can deal with the strain time requirements of safety applications.

- Infotainment applications on the road: there is an increasing interest in new services such as traffic or tourism information or even entertainment applications. All of them require communications with high quality of service and bandwidth.
- New devices, called On-board Units, which are able to support all this new services and are adapted to work with multiple wireless standards, in order to guarantee universal coverage.

From low end to high end telematics services, the addressable market is huge: the Automotive installed base is expected to reach 700M cars and 150M light vehicles worldwide in early 2010s. In Europe, the installed base was 219M passenger cars and 34M commercial vehicles (28M cars or light commercial vehicles, 6M heavy trucks) in 2006.

In the year 2006, 70M vehicles were produced worldwide (50M cars and 20M light vehicles): 19M in Europe, 16M in USA, 12M in Japan & Korea. The main growth is driven by new markets in developing countries. In fact, electronics in Automotive market is becoming more important, reaching 20 to 30% of the vehicle cost: from US $ 110 billion in 2000 to US $ 240 billion in 2010 broken down to : $150 billion for hardware and $90 billion for software according to Mercer.

6.3.2.2 Fleet Management

Fleet management solutions are currently mainly implemented and used by Logistics companies managing Trucks, lorries or light vehicles.

240,000 companies with 50 employees or more in Europe consider such solutions to improve their efficiency. Berg Insight estimates that these companies have a combined fleet of almost 11M vehicles, plus 1–2M heavy trailers and up to 1M construction equipment units.

The number of fleet management systems in active use is forecasted to grow at a compound annual growth rate of 20.5 percent from 1.1M units at the end of 2008 to 3.3M by 2013 worldwide. The penetration rate in the total population of non-privately owned commercial vehicles is estimated to increase from 3.1%in 2008 to 9.3%in 2013.

However, some other companies are also showing interest in the same kind of solutions to provide new services: for example Rental companies, which can monitor leased & mortgaged vehicles, and Insurance companies, which can offer tailored “pay as you drive” contracts, or Stolen vehicle tracking services and so on.

From political and regulatory view points, Fleet management solutions are considered by Public authorities to implement Road User charging policies. This market is expected to grow significantly thanks to environmental policies in developed countries (Toll Collect in Germany, Kilometre Price in NL, Ecotaxe in France) and to efficient toll collect programs in emerging countries (which allows to consider an efficient way to finance new infrastructures).

The new M2M solutions, such as On Board Units integrating GNSS and cellular connectivity can offers fast, reliable and efficient solutions to calculate and invoice the associated charging.

6.3.2.3 Parking and traffic management in urban areas

Approximately, 80% of Europe's population resides in urban areas. In such scenarios, it is estimated that half of traffic congestion is caused by drivers looking for an (outdoors) parking space. Interestingly, reducing congestion, in turn, makes finding a parking space much easier, in addition to reducing noise and pollution levels. Considering all the above, the potential benefits of an M2M-based communications system capable of (i) collecting information on the availability of parking spaces in a geographical area; and (ii) conveying such information and providing guidance to nearby drivers, offer huge market opportunities. Some critical design aspects of such systems encompass the required reliability levels of the free/occupied decisions made at the sensing nodes installed in the parking spaces, the stringent requirements in terms of system latency (outdated information on the availability of parking spaces renders useless), and the means to convey information to the drivers (panels, messaging services, to name a few). Other issues to be carefully considered include the fact that data being collected and conveyed to drivers is very sensitive to location information (only information on nearby parking spaces should be conveyed to them), or that sensing devices, which are installed on the street level, should be tamper- and theft-proof. One positive aspect is that, in urban areas, cellular networks, which are needed to convey sensor readings to the managing system, are ubiquitous.

6.3.2.4 Positioning Systems: park assistance

The "park assistance" application aims at speeding up the search for a specific parking place in parking lots. The communication happens between beacons located in the parking lot and the vehicles that entering. It works as a location and guidance procedure. Depending on the technology and the specific scenarios the challenges may vary but are important to be considered as research issues:

Fast detection of the vehicles in the parking lot; fast means that no vehicle trespasses a beacon radio coverage without being detected, which needs a balance between parameters such as radio coverage, vehicle speed and device discovering time.

Reliability and accuracy of the location technique applied. Location is a very challenging research field, with a lot of researchers involved, but that has not obtained yet very promising results with techniques based on Received Signal Strength (RSS). Other techniques based on time or angle of the received radio signal are much more accurate but at the same time are not as extended as the former, which is actually available in almost of the current radios.

Energy consumption: especially when the beacons are not connected to the power grid. In addition to power-efficient algorithms, these situations may ask for a different approaches, such as a change between the roles between beacons (usually more energy-demanding devices and clients (usually less energy-demanding because of their role of “listeners”).

The Europe's in-car automatic emergency call system, “eCall”, aims at speeding up the rescue operation as soon as a road incident occurs: eCall automatically dials 112, Europe's single emergency number, when a car has a serious accident and sends its location to the nearest emergency service – even when passengers do not know or cannot say where they are. Rolling out eCall requires close cooperation between public authorities, car companies and mobile phone operators. eCall system has the potential to reduce the accident response time by about 40% in urban areas and about 50% in rural areas, and could save up to 2,500 lives each year in the EU when fully deployed and reduce the severity of injuries by 10 to 15%.

Today, as a matter of fact, more than 40,000 people die and 1.7M are injured annually on Europe’s roads. The annual cost of accidents has been estimated to be €200 billion, representing 2% of EU GDP (Communication from the Commission on the Intelligent Car Initiative - “Raising Awareness of ICT for Smarter, Safer and Cleaner Vehicles”, 15 February 2006). To accelerate the development and deployment of these life-saving technologies, ERTICO, the European Commission and the European Automobile Manufacturers Association (ACEA) has launched some initiatives (from eSafety initiative in 2002). Representatives of the industry's GSM Association underlined their commitment to this life-saving technology by signing the EU's Memorandum of Understanding on the 9th of September 2009, in order to implement eCall across Europe in a short term.

6.3.2.5 Smart Metering

A 3rd generation of metering technology will increase the growth of this market, which was as large as 188M worldwide in 2007 (meters’ shipments), mainly with non-cellular technologies (PLC, DSL, ISM frequencies). In the 1st generation, the meters were initially read manually. In the 2nd generation, the meters were initially read automatically (AMR : Automated Meter

Reading) and in the 3rd generation, AMM (Advanced Meter Management) provides now a two-way real time data communication between the customer and the utilities, offering many benefits:

- improved customer service with accurate bills instead of bills based on estimated consumption
- ability to implement real time pricing with variable tariffs based on the time of the day;
- network optimization through distributed automatic monitoring, with a greater level of functionality including remote control (connect or disconnect and outage notification);
- reduced costs for meter reading staff and increasing data collection efficiency.

6.3.2.6 POS Terminal

A new generation of Point Of Sales Terminals will increase the growth of this market, which was as large as 10.8M worldwide in 2007 (POS terminals' shipments), mainly with PSTN terminals. More than 16% CAGR is expected by 2012, driven by fixed-to-mobile substitution that offers several advantages:

- faster transactions (20seconds with PSTN, 5seconds with GPRS),
- mobility (taxi business),
- price (GPRS chipset and affordable subscription),
- growth in non-cash payments.

6.3.2.7 Security

Three main segments can be considered:

- Residential security: with alert services, the first M2M applications were dedicated to remote surveillance and alarm at the beginning. A new generation of devices (including smart cameras) will increase the growth due to fixed-to-mobile substitution (or provide backup in case of primary connection fails): these smart devices usually decrease significantly the operation costs for the alarm services, which can be priced cheaper. A significant growth is expected (+21% per year according to Berg Insight forecasts in 2008), alarm system with cellular connectivity increasing from 7% of total alarm systems in 2007 to 66% in 2010. Security alarms shipments in 2007 were 7M worldwide, but mainly in North America (3M), and mainly with fixed line (cellular in only 7%). Worldwide installed base in 2007 was 38M units. This market is highly fragmented, with many integrators; telecom carriers are more and more interesting addressing this market, as part as "Home Automation" services.

- Personal security : safety and health requirements for lone workers are more and more taken into account in country-specific regulations; dedicated mobile devices have been developed to serve this market at the beginning; fragmentation is increasing in this market as well, with dedicated boxes integrating several sensors.
- Vehicle security: This market is expected to grow significantly thanks to country specific regulation : in US with E911 & E912 directives ("GM Onstar" standard launched in the Americas by GM and ChevyStar), in Brazil with tracking device required in all new cars from mid 2010; in Europe with eCall from 2011. This segment is usually more considered (and valued) in Car Telematics.

6.3.2.8 Remote monitoring of green energy power plants (aero-generators/photovoltaic plants)

The increasing number of photovoltaic and eolic energy plants deployment quest for novel and efficient tele-monitoring/tele-command/tele-management systems. In order to carry out and efficient energy management it is required to have a global view of the different plants. This allows to react faster to the instantaneous energy requirements. In this framework, the constituent elements should be considered as part of the M2M landscape with their particular requirements in terms of QoS attributes.

6.3.2.9 Remote Management of Assets & Products

A remote asset management solution allows owners or users to monitor critical parameters of an equipment or perform remote commands on this equipment. This usually avoids on-site operations, driving to cheaper operation costs.

A remote product management solution makes it possible for equipments' manufacturers to perform inspections and maintenance as part of a service agreement. Remote product management solutions are more and more considered as an integral part of the total product design.

6.3.2.10 Environmental monitoring and ICT support to a sustainable economic growth

Sensor networks have many applications but environmental monitoring is a domain where they may have a huge impact. Recent climate change-related catastrophes reveal how important a detailed knowledge and understanding of our environment and its evolution can be for the human being. Some examples of parameters to be monitored encompass greenhouse gas (e.g. carbon dioxide, nitrous oxide) emission levels in urban areas, flow level and pollutant concentration in rivers, soil moisture, salinity levels in sea water, etc. Typically, both the spatial and temporal variations of the monitored parameter(s) are of interest and, often, the distortion in the resulting estimates or the reporting latency are used as performance metrics.

Environmental monitoring, in particular, is very demanding due to harsh outdoor conditions that may greatly impact hardware performance. Besides, network deployment can be particularly challenging in remote areas (e.g. forests, deserts) where, in addition, the availability of a communications infrastructure to convey the measurements might be questionable. Other difficulties arise when the area to be monitored is large (for example, inter-node connectivity), or when the number of sensing nodes is very high (e.g. problems associated with their massive deployment and/or the need to resort to data aggregation techniques). In those cases, a careful choice of communication technologies and infrastructures, such as multi-hop transmission and clustering for sensor-to-sensor links in combination with cellular networks for long-distance data transmission, can be particularly useful. Finally, one should also bear in mind the temporal and spatial correlation of the measured data that, in many cases, follows from the underlying laws of physics (diffusion, heat propagation, etc). By appropriately designing e.g. sleep/active cycles and/or differential encoding techniques, one can effectively save energy, this translating into longer lifetime periods.

6.4 Trends in Key Functionalities for M2M

Key functionalities and technical requirements of M2M are:

- Intelligent devices (processing power, sensing and context awareness, communication)
- Efficient internetworking of heterogeneous networked embedded devices;
- Platform for shared information; Access to information in a secure and trusted manner; composable information for new services of Real World Integration (RWI)
- Distributed decision making

- Interfacing from capillary network technologies to telecom networks, and from M2M capabilities to service platforms
- Security and privacy at Networked Embedded Device, infrastructure and service levels
- Identity management: multiple identifiers for people, machines, objects; identity assignment
- Object discovery services, associated with additional information such as location, time, sensor information (IETF ESDS = Extensible Supply chain Discovery Service); object classes (identifiers, sensors, actuators, transmitters/bridges, processors)
- Miniaturization (nano-technology): towards smart dust
- Hierarchical communications networks (from short-range to wide area), pervasive communications; Real-time infrastructure; Resilience (ability to respond to failures)
- Energy efficiency and harvesting

6.4.1 Security, Privacy and Trust

Security is an essential requirement for M2M, specifically when considering scenarios in which M2M systems are deployed, such as; highly sensitive applications in manufacturing, healthcare, security.

6.4.1.1 Security services

This section elaborates on range of possible attacks expected against M2M sub-systems that consists of: physical devices, communication links between devices, software applications running on the M2M devices, all can be specifically targeted. These attacks are classified in what follows according to the security service they infringe. Note that while M2M systems may generically suffer from the same attacks that are launched in today's Internet, the emphasis here is on how they specifically affect an M2M architecture.

Prevention of intrusion and execution of malicious code

The deperimeterised M2M architecture breaks the classical, centralized, firewalling model. With each device being able to dynamically change its position relative to the other nodes, one can obviously not assume that a single node may ensure the safety of data received by all interacting M2M nodes. Furthermore, the higher probability for a node to get compromised, as compared to physically secured nodes/architectures, further highlights the need for distributed firewalling capability.

This approach is required, independently of their possible dedication to a specific task, for M2M devices be made resilient to network attacks (firewall) and –optionally, depending on their software architecture– be made immune to malicious code attacks (antivirus) as well.

Intrusion detection

M2M framework makes the intrusion detection process more complex. In addition to trying to minimize the number of false negatives and false positives, M2M nodes should also attempt to minimize power consumption by intelligently choosing between incidents that should be reported, and at what time this report should occur. However, the analysis and correlation process may require more resources (RAM, computing power) than available on the nodes, hence a trade-off has to be made between report quality and battery consumption. Security adaptation requires even more intelligence (e.g. to locally take defensive action, such as radio technology switch) and possibly collaboration among M2M nodes (e.g. to dynamically update the global security policies in an autonomous fashion).

Validation of nodes' integrity

Due to their physical vulnerability, M2M devices should make regular validity check to deal with possible node's compromising. Two validation scenarios are possible: an M2M node will generally perform regular self-validity checks, to make sure that it has not been tampered with. On the other hand, M2M nodes may initiate group action to collaboratively identify possibly compromised nodes and take appropriate action.

- *Self validation* may happen at different times (boot time, network attachment) and may be based on different mechanisms.
- *Identifying compromised nodes* and taking countermeasures to mitigate their negative impact on other nodes of an M2M infrastructure is a particularly challenging topic, especially in the fields of sensor networks.

Remote management of security services

Considering that many M2M architectures involve deployment of M2M nodes over large areas and/or on hardly accessible places, there is a need for a simple remote management solution for these nodes.

Authentication and network access control (M2M device to infrastructure)

Like any node, an M2M device wanting to use connectivity offered by an access network provider has to undergo an authentication procedure that, if successful, is followed by network access control enforcement. 3GPP is considering the enhancements that could be designed to specifically accommodate the needs of an M2M node connecting to a cellular network.

Integrity of the transmitted data

Data transmitted from an M2M node to another should be protected against modification by forwarding nodes. Classical end-to-end security protocols running at network (e.g. IPsec) or application (e.g. SSL) layer are designed to afford data with the integrity protection service. Specific M2M considerations relevant to this service are: implementation of lightweight security protocols on M2M devices and key management.

Source authentication

It might be required that data transmitted from an M2M node to a peer be cryptographically bound to an unequivocal identifier of the sending peer, thereby ensuring the source authentication service. This security service is generally afforded using the same mechanisms as for data integrity, and is impacted similarly by the M2M scenario.

Confidentiality of the transmitted data

Data exchanged between M2M peers might be sensitive enough so as to require that no other peer than the sending and receiving ones be able to read the transmitted data. This end-to-end data confidentiality service relies on encryption/decryption cryptographic algorithms.

Non-repudiation

This security service allows guaranteeing that a node will not be able to deny having sent some data in the past. This security service is generally not used in most M2M scenarios.

Key management

Two specific problems arise with respect to key management and M2M devices. On one hand, cryptographic material (“key”) on an M2M device cannot be easily updated. The consequences of a compromised shared key on a single device may impact an entire group of M2M devices. On the other hand, the physical vulnerability of the M2M device requires that a stored key be strongly protected against side-channel attacks.

Authentication and authorization

A node offering a service to other nodes should ensure that a contacted peer is authorized to access the service it is providing. Hence, there is a need for an authentication and or authorization protocol between M2M nodes. A well-known example of vulnerable authorization system can be seen in some RFID-based solutions used for granting physical access, where the RFID tag is simply presenting an identification string upon request from a reader. Here the authorization scheme is clearly inefficient, since a valid identification string can easily be recovered from a device and replayed later. Even if the authorization mechanism is cryptographically secure, M2M specificity requires that it be adapted to prevent flooding from valid, yet compromised nodes.

Service advertisement and discovery

IA devices may advertise to neighbouring nodes the service(s) they can provide. Various attacks can be launched against this system, largely depending on the offered service and the security quality of the protocol it relies on.

Privacy

Privacy in a machine-to-machine environment essentially raises three technical challenges:

- *Secure storage of sensitive user data*. M2M devices in an open environment may easily be stolen. As such, special care should be taken to make user data resistant to unauthorized access, e.g. by storing them under an encrypted form and/or on hardened memory areas.
- *Secure transmission of sensitive user data.* Protecting sensitive user data against malicious eavesdropping typically relies on confidentiality mechanisms, as described above.
- *Minimal disclosure of sensitive user data.* That is, private information should only be disclosed to the nodes that explicitly require it. For example, an access enforcement node may not need to know the authenticating information of a user, but only the authorization result.

Communication path security

Almost all layers of the OSI protocol stack can be specifically targeted in order to disrupt communications between two M2M nodes. In parallel to attacks launched against these layers, M2M devices may also be victims of DoS attacks against authentication or mobility protocol(s).

Secure group management

Beyond group-level authentication, confidentiality and remote management, M2M devices may require specific security functionality so as to enable advanced group services. For example, some groups allow the group member to vote to promote or demote another group member. Depending on their rank, group members can then perform different actions, up to the admission of new members to the group. Here special care should be taken to prevent collusion attacks where a set of malicious nodes act together to disrupt group communications.

6.4.2 Autonomous Operation Vs Network Management

Network management in current technologies is located outside the network in servers that interact with network elements via management protocols in order to execute any management task required such as configuration, accounting, monitoring, security management and so on. This centralized network management entity requests specific parameters and variables from those network elements in its domain. Afterwards this information is processed in the management station and based on a specific policy necessary actions are taken.

M2M communications in the future will potentially include networks of many more wireless nodes that the ones we have today, with the additional complexity of mobility or even other aspects such as resource constraints that make the network concept much more dynamic and complex that the type of networks these current management approaches were designed for. Research required on specification and optimisation of distributed and autonomous network management for M2M. Autonomous operation could solve the main problems of traditional management techniques such as scalability and dynamicity, but at the same time brings the problem of controllability, i.e. predictability of the network behaviour that decreases rapidly as the size of the autonomous network increases. From this point of view, autonomous operation is not necessarily an optimal solution, however one wonders if such optimal solution is desirable or even achievable in networks that are so dynamic as the ones expected in future M2M communications.

6.4.3 Ubiquitous Connectivity, Interoperability

Ubiquitous connectivity and interoperability are the two requirements whose fulfilment make M2M devices able to operate independently of their physical location, irrespectively of their manufacturers. They are therefore particularly important for ensuring the development of new M2M services. This section first considers current trends in enhancement of radio connectivity for M2M nodes. It focuses then on the IP protocol considered as a means to provide a unified basis for the M2M framework. Finally, collaborative activities and ongoing standard development are briefly reviewed, as foreseen solutions to ensure future interoperability.

6.4.3.1 Ubiquitous radio access

Connection anytime and anywhere is the goal of most communication systems. Terms like roaming and handover are broadly used when mobility is involved. Cellular network is an example of those networks, in such a way that anyone with the proper terminal can be connected to a cellular network almost anywhere in the world. In our multi radio technology universe this intra-technology ubiquity is very limiting and consequently future M2M scenarios tend to go beyond, requiring a full ubiquity that lets a M2M solution run no matter the radio technology underneath. While M2M devices generally use a single radio technology (e.g. ZigBee) to communicate with each other when forming a group topology, the ability to connect to the infrastructure through multiple radio technologies is clearly an essential advantage when these devices are expected to be mobile. Industry is clearly following this trend, by miniaturizing and integrating multiple radio-capable chips within the M2M platform they produce possibly in addition to other value-added circuits such as GPS. Although mobility is expected to be the main reason to switch radio technologies, some others like spectrum management or other radio cognitive aspects in addition to context- aware issues could also trigger the procedure.

Special effort has been made by 3GPP to identify which adaptations of the cellular communications could be made to facilitate machine-to-machine communications. It appears that the communication framework can be made lighter, taking into account the following specificities of machine-to-machine environment:

- When communicating with the infrastructure, M2M devices belonging to the same *group* generally adopt an N-to-1 communication model[1], with all nodes communicating with a single destination server;
- Most of M2M scenarios consider that the communication between the M2M device and the infrastructure server will be initiated by the former.

Considering the expected handling of large numbers of terminals has led 3GPP to make the following recommendations:

- A mechanism should be found to allow the operator to deal with a plurality of M2M terminals at the same time, instead of addressing each one independently;

[1] Note that 3GPP currently explicitly excludes the *many-to-many* communication model.

- Mobility management should be made deactivable for non-mobile terminals. On the other hand, mobile terminals that do not expect infrastructure-initiated connection should be able to mute their incessant, battery-unfriendly location update messaging.

In addition, the following guidelines have been issued:

- More flexibility in the allocation of a terminal to network operator should be provided; likewise, subscription change without human intervention should be made possible;
- Charging records should be made less detailed for M2M nodes and may be delayed until the next off peak traffic period;
- M2M nodes communicating via SMS would advantageously switch to IP-based communications. SMS has been used as an easy means to transport small bursts of data, but is not particularly adapted to M2M communications.

6.4.3.2 Interoperability

The interoperability of M2M technologies aims at the achievement of a unique seamless scenario where different type of nodes act in a collaborative way for the same goal. Whereas ubiquitous connectivity can be achieved wit only one technology, interoperability implies much more, not only at physical level but at any level imagined. Inside M2M, Wireless Sensor Networks (WSNs) intend the achievement of an integrated sensing system, in which sensors work together to produce more value than individual observations. To that end, sensor standardization initiatives from the IEE and the Open Geospatial Consortium (OGC) are to overcome the heterogeneity of devices, communication protocols, networks, data formats and structures. However, in order to support the interoperability of WSNs over time it is necessary to deal with the dynamic changes in the network, components and functionalities. In general , interoperability can be structured in different levels:

- The technical one, i.e. the interconnection of WSNs at physical level, considering HW and SW aspects.
- The syntactic one that deals with the exchange of information among WSNs using a common data structure, language, logic, records and files.
- The semantic one, that supports the exchange of information using a common vocabulary.
- The dynamic interoperability level, focused on the monitoring of operation of WSNs and response to changes.

From a different approach, there is a need of data interoperability in the sense of multiple heterogeneous data sources combining their data for the inference of knowledge. This data combination requires a very well-defined syntax and semantic. At the same time, in terms of network interoperability is also necessary cooperation between network components to monitor and react to internal and external events. In this context, metadata is essential to generate the knowledge of a sensing system and the common thread that will connect all the states and functionalities of WSN. The research challenge is to define a model for interoperability of WSN based on metadata, which provides a description of observations, processes and capacities, as well as their status and configuration to enable the understanding of the network itself and to ensure the interoperability with other sensor networks.

6.4.3.3 Pervasive IP connectivity

The Internet protocols (IP and above) are particularly relevant to the M2M context. The following elements are especially to be taken into account:

- Connectivity to the Internet. Even in scenarios that do not require M2M nodes to contact a distant server, Internet connectivity can be an essential advantage to provide the node with updateability and reporting capability. Of course, IP will allow for remote M2M node management as long as its natural end-to-end capability is not interrupted (NAT), which may require IPv6 deployment.
- Versatility. IP is capable of routing data for any type of application, independently of its requirements in terms of QoS. IP generally also allows for higher throughput as compared to old M2M technologies (e.g. SMS). Furthermore, IP enables a huge variety of devices to communicate together irrespectively of their manufacturer, hardware capabilities, operating systems and radio access technologies, forming the baseline for global interoperability of M2M services.
- Lower Cost. Not only is IP based on scalable, robust, proofed and well-known protocols for which very few specific M2M mechanisms are to be reinvented, but also the management of an IP infrastructure is typically not a complex operation. Hence deployment, operation and support costs are reduced with IP as compared to proprietary protocols.

The need for IPv6 deployment to bootstrap new M2M services is widely acknowledged in the industry. This is leading to the creation of new services, where traditional ISPs emphasizes the match of their (novel) IPv6 offer with the requirements of M2M. Correspondingly, multiple chip manufacturers propose specific dedicated IP chips (possibly integrated with a wireless modem) to IP-enable M2M devices. Alternatively, lightweight IP stacks would be desirable to be integrated into the device's software space.

6.4.3.4 Standardization and collaborative work

Two IETF working are especially dedicated to the elaboration of specific protocols for the M2M environment:

- ROLL (Routing Over Low power and Lossy networks) designs specific routing protocols adapted to the specific constraints of M2M in term of radio environment, topology, communication pattern and nodes limitations, the evaluation of existing routing protocol having demonstrated their insufficiency to address these requirements.
- 6lowpan (IPv6 over Low power WPAN) designs specific modifications to the IPv6 protocol for adapting to the 802.15.4 radio technology. In a nutshell, it relies on cross-layer optimizations for obtaining intelligent header compression, specific packet fragmentation and novel neighbor discovery scheme.

M2M interoperability may also require standardization at application level above the network layer. BiTXml and M2MXML are two proposal of XML-based protocols that allow performing classical M2M operations such as sensor querying and device configuration.

The IPSO (IP for Smart Objects) Alliance regroups 50 partners that aim at promoting the use of the IP protocol "into resource-constrained devices over a wide range of low-power link technologies". To date, three white papers have been produced which respectively give an overview of the suitability of the IP protocol for smart objects, review lightweight IPv6 stacks implementations and present the results of 6lowpan working group.

The European Telecommunications Standards Institute (ETSI) decided in June 2008 to create an M2M Standardization ad-hoc group**Error! Reference source not found.**. Four work item documents are being produced, dealing respectively with *M2M service requirements*, *M2M functional architecture*, *Smart Metering Use Cases* and *M2M definitions*.

6.4.5 Context Awareness and Monitoring

M2M applications can benefit from having additional attributes related to the context. Examples of urban bus timetables which are automatically updated, at every bus stop, according to traffic conditions is a good example of how context information can provide a better end service to “its consumer” (machine, person, entity,…).

Context attributes have to be identified according to the parameters and variables that may have impact in the provision of the service. The monitoring application taking care of such variables will be responsible for feedbacking, that information, to the cognitive engine responsible of deciding the right corrective action according to the potential event.

6.4.6 Firmware Over the Air

Essentially FOTA is the remote management (i.e. activation, update, de-activation and removal) of software components (i.e. parameters, applications or full software) on any M2M device (i.e. GSM module, main CPU, GPS module …) on site. Despite its name FOTA is achieved through any physical channels (RF, CPL …).

M2M devices carry sophisticated software and an increasing number of parameters. There is a greater need to manage this software:

- ability to deliver and update M2M features after sales and customise devices
- reduction in time to market and cost for new M2M features

FOTA can be split into three domains:

- the update itself,
  Due to weak throughput of many M2M links it is required to shrink the firmware using standard delta generator or more sophisticated ones. In addition, signature of the delta is necessary to prevent from malicious use.

- the protocol used for firmware download,
  Many protocols have been defined, the two most famous are the Open Mobile Alliance (OMA) Device Management (DM) and TR69 (mainly for broadband access), however both protocols are throughput eater and proprietary protocol may be used. In addition to its lightness the proprietary protocol should be flexible enough to manage different type of configurations.

- and servers
  Server should be reliable to assure service continuity. It should be scalable to render possible the upgrade of 1,000 to more than 1,000,000 M2M devices in a short amount of time. It should have a user-friendly MMI.

6.5 Technologies

6.5.1 Wireless and Wireline Networking Technologies

M2M concept is an end-o-end solutions which enable machines to “talk” to each or to be controlled by people using wired or wireless communications networks. The choice of the communications technology depends on several factors such as range, frequency use and the underlying business model (including cost).

- The first and most familiar is broadband-wireless systems with currently area cellular communications technologies such as GPRS/EDGE, 3G (UMTS, HxSPA) and 4G systems (WiMax, LTE). These technologies offer data access with global roaming.
- The second type of technology includes non-cellular wireless technologies such as Wireless Local Area Network (WLAN). WLAN supports high-speed data traffic over short distances of between 30 to 100 meters.
- The third is a mix of proximity technologies including Bluetooth, Zigbee and all short-range transmission technologies and NFC (Near-Field Communication), which enables touch-based interaction for mobile devices.
- Finally M2M end-to-end solutions are using wireline technologies. Obviously the end-to-end solution include the connection to core network using Ethernet type of connection. The PLC is also an increasingly popular technology as termination technology.

6.5.2 M2M API

The present M2M API approach can be described as a mesh of overlapping initiatives, with more emphasis on one area to the detriment of the other. Up to now, no research or standardisation action has been addressed to the fulfilment of the following technological areas in a coordinated way:

- Definition of a basic extendable M2M Application layer API that could be opened to different M2M actors, similarly as in OSA/PARLAY, but with higher degrees of flexibility as well as with more powerful security and access control mechanisms.
- Models and semantic representations for machine generated data and meta-data exchanges for different services and applications as an enhancement to the basic M2M application layer API. Harmonization for semantics and representation should be defined over shared M2M service ontologies or information models.
- Definition of an Internet layer API, enhanced from the basic sockets API, for access to a harmonised IP bearer service covering the inter-domain functionality required for end-to-

end maintenance of QoS, Security, Mobility, Location, Multicast, Name resolution, Routing, Authentication Authorisation and Accounting (AAA), and including Management.

For the application layer several non-standardized solutions exist. They provide some functionality for the service creation that range from simple data transmission facilities to more complex functions like Publish/Subscribe/notify mechanisms, device discovery, etc. Several communication protocols are fairly well established, but there is still very little standardization at the application level. In fact, for an evolving market, there is a broad consensus that most of the development work done in M2M is still largely customized for each adopter (i.e. vertical segmentation).

6.5.3 Middleware / Interoperability

As some advanced research projects, as SENSEI EU Project (www.sensei-project.eu/), envision, future M2M Middleware capabilities should evolve to enable a paradigm shift from current application-specific infrastructures to more complex platforms built on top of highly interconnected heterogeneous, dynamic and geographically dispersed nodes. To this end, the SENSEI EU Project has conceived an overall architecture that separates a real world resource layer and an underlying communication service layer, as depicted below.

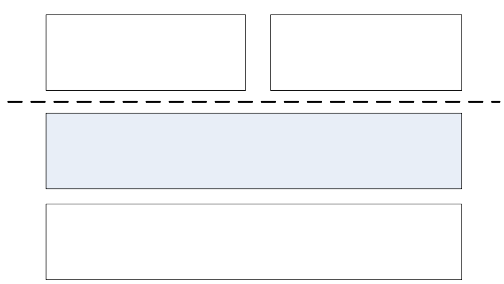


Figure 6.6 High level Real World architecture overview

In this architecture:

- Applications and services gain unified access to real world M2M information and interaction capabilities via interfaces provided by the real world resource layer.

- o Functionality can be defined without making too many assumptions on the underlying connectivity functions. The conceptual architecture of the real world resource layer can thus be mapped to different connectivity substrates, such as evolutions of the current Internet for near-term deployment, telco networks, NGN or more revolutionary clean slate designs.

The idea of introducing the Real World Resource abstract layer extends the concept of M2M Network Middleware since it provides a logical abstraction for the services provided either by machines, sensors, sensor networks, processing services, etc.

The overall new challenge will be to provide a context system that spans all layers from the low level sensor nodes, the WSN or M2M islands to the high layers of the context information service. The goal is to allow adaptation and optimisation across all these layers of a highly distributed and heterogeneous system. On the one hand context information has to be provided on the required abstraction level and with the desired quality, on the other hand the required scalability has to be achieved. The currently existing context systems only partially address these requirements.

6.5.4 Service Oriented Architecture

Judged by the Industrial attention and efforts on standardisation, SOA has a promising future. Protocols such as SOAP are widely applied and e.g. OSOA promote architecture-level standardisation. Interoperability and management solutions are important goals, and the way it seems, possible to be achieved. SOA has also more ambitious goals, particularly regarding semantic information, that have more constraints but are active research topics nevertheless. In other words, SOA is applicable in its current state-of-the-art, but has much to be improved.

6.6 Roadmaps and Standards

6.6.1 Activities and developments at IETF

6.6.1.1 ROLL

The Internet Engineering Task Force (IETF) is the open recognized International Standards Organization (ISO) in charge of standardizing the IP protocol. IETF working groups are organized into several areas, such as routing, transport, and security. Clearly, the adoption of IP in M2M contexts would facilitate a seamless integration of such smart objects into the Internet. However, a number of features of such smart objects (e.g. limited range and computational complexity, power supply-related aspects mobility, potentially large number of nodes, etc) should be explicitly taken into account. Two IETF working groups are currently standardizing IP-based protocols for embedded objects communications: 6lowpan (IPv6 over IEEE 802.15.41) and ROLL (Routing Over Low power and Lossy networks). The IETF-ROLL working group was formed in January 2008. According to its charter, IETF-ROLL focuses on IPv6-based routing solutions for a subset of application areas (out of the vast amount of existing ones): industrial, connected home, building and urban sensor networks for which routing requirements have been specified. The main work items in the agenda of this WG include the specification of routing metrics for path calculation, the provision of an architectural framework for routing and path selection at Layer 3 (addressing issues like distributed vs. centralized path computation model, whether additional hierarchy is necessary), the elaboration of a routing security framework for routing in LLNs, protocol design work.

6.6.1.2 ETF-6LOWPAN

6LowPAN is the International Open Standard that enables building the Wireless "Internet of Things" aiming for bringing IP to the smallest of devices - sensors and controllers. 6lowPAN is an acronym of IPv6 over Low power Wireless Personal Area Networks, or (as the "personal" qualification is no longer relevant), IPv6 over LoW Power wireless Area Networks. The 6lowPAN group has defined encapsulation and header compression mechanisms that allow IPv6 packets to be sent to and received from over IEEE 802.15.4 based networks. IPv4 and IPv6 are the work horses for data delivery for local-area networks, metropolitan area networks, and wide-area networks such as the Internet. Likewise, IEEE 802.15.4 devices provide sensing communication-ability in the wireless domain. The inherent natures of the two networks though, is different.

Up to the time of writing this document 6lowPAN has completed two Request for Comments (RFCs): "IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals" (RFC4919) that documents and discusses the problem space and "Transmission of IPv6 Packets over IEEE 802.15.4 Networks" (RFC4944) which defines the format for the adaptation between IPv6 and 802.15.4.

6.6.2 Activities and development at ETSI

After ETSI identified a growing demand for standardisation of M2M communications during 2008, a new Technical Committee “M2M” (TC M2M) was formed in early 2009. In the following, a short outline of the motivation to establish ETIS’s TC M2M and the scope of the group are provided. Furthermore the organization of technical work in ETSI’s TC M2M up to the time of writing this document is summarized.

6.6.2.1 Motivation and Scope

It is anticipated that many M2M deployments will make use of short-range radio links that might be standardised already or use a proprietary technology. However, for access connectivity, mobile cellular-based M2M communications will most likely play an important role when wide area mobility is required and/or when other access technologies are simply not available. Cellular-based M2M communications could also be attractive due to possibly easier installation and provisioning, especially for short-term deployments.

Since requirements on connectivity and services regarding communications characteristics might be quite different for M2M communications than those for which existing telecoms networks were designed, there is a need to optimize existing network functionality in order to support M2M communications in a cost-effective manner. To avoid (further) market fragmentation and enable cost-effectiveness as well as economies of scale, standardisation of M2M communications is required.

So far, a rather large number of different component-level standards and some proprietary technologies exist – including various radio interfaces – which are all capable of providing M2M functionality to some extent. Each of these available standards and/or technologies are optimized for particular application scenarios and hence, lead to some level of fragmentation and to a lack of a unified end-to-end solution for M2M communications. With the establishment of TC M2M, ETSI is trying to close this gap.

ETSI’s TC M2M is aiming to identify the needed areas for standardisation of M2M communications from an end-to-end point of view. The scope of ETSI’s TC M2M can be roughly divided into three main areas:

- Definition of M2M applications and use cases
- Derivation of requirements of M2M communications services and applications

- Specifications of a functional architecture to support M2M communications including required interfaces

A main goal is to specify standards in a way that required functionality and needed interfaces become independent of underlying access technologies. This would allow individual access technology standards to be optimized for M2M support at the discretion of the standards setting organization of the respective access technology. For this reason ETSI's TC M2M will co-operate closely with ETSI's activities on Next Generation Networks, and also with the Third Generation Partnership Project (3GPP) on mobile communication technologies as well as a number of other relevant standards setting bodies and industry fora.

ETSI's TC M2M has explicitly stated that there is no intention to replicate work that has already been done in other relevant standards setting bodies. Moreover, it is the goal of the committee to re-use existing work wherever possible and provide means to integrate it into the standards framework that ETSI's TC M2M is supposed to create. One advantage that ETSI sees in covering the standardisation of M2M communication is the Institute's expertise in interoperability and testing. This expertise could eventually provide conformance test specifications that are essential to guarantee end-to-end functionality and interoperability.

6.6.2.2 Organization of Work in ETSI's TC M2M

Up to the time of writing this document, ETSI's TC M2M has created 3 Work Items along which the technical work in the committee is organized:

- Smart Metering Use Cases
- M2M service requirements
- M2M functional architecture

The Work Item "Smart Metering Use Cases" intends to collect relevant use cases that can be identified for the smart metering application. Smart metering is becoming increasingly important in light of a standardisation mandate issued by the European Commission in order to support smart metering in Europe within a fairly challenging time scale (Mandate M/441). ETSI's TC M2M is co-operating closely with the European Smart Metering Industry Group to cover all relevant use cases of a smart metering application and to define the needed communications functionality to support smart metering. The information that describes these relevant use cases and the corresponding communications characteristics is collected and maintained within ETSI's TC M2M in a technical report TR 102 691 "Smart Metering Use Cases".

From M2M applications like smart metering (and most likely others), ETSI's M2M is deriving service requirements which need to be supported by the M2M communications services which will be specified by the committee. Under the Work Item "M2M service requirements", the committee is deriving end to end system requirements in terms of capabilities for supporting M2M communications services. The derived requirements are captured in a technical specification TS 102 689 "M2M service requirements". The mapping between the use cases of M2M applications and the derived service requirements / capabilities will be documented in an informative annex of this specification.

The ultimate goal of the work in ETSI's TC M2M is to arrive at a specification for a high-level functional architecture, a detailed definition of the functional elements, the related capabilities, and the required interfaces, that could be used to support M2M communications services and applications on top of various access technologies. The output of that work is gathered in a technical specification TS 102 690 "M2M functional architecture".

6.6.3 Activities and development at 3GPP

Several studies on M2M communications indicated the potential for machine-type communications (MTC) over 3GPP systems. Clearly, due to the past scope of designing networks that have been used exclusively for human-to-human communications, 3GPP systems are less optimal designed for efficiently providing machine-to-machine, machine-to-human, or human-to-machine applications. Especially if aiming for mass-market machine-type services, 3GPP networks needs to be evolved and re-designed to provide machine-type communication services such as telemonitoring of products after they are shipped or remote maintenance of heating and air condition, alarm systems and other applications in home environments. Furthermore, it is also important to enable network operators to offer machine-type communication services at a low cost level, to match the expectations of mass-market machine-type services and applications.

3GPP started its machine-to-machine communication activities in 2005 with the establishment of a study item in working group SA1 with the scope of facilitating machine-to-machine communication in 3GPP systems. In the following, we list past and ongoing 3GPP activities in the area of machine-type communications up to the time of writing this document. So far, main activities has been on services and systems aspects and have been addressed within the working groups SA1, SA2, and SA3 while the working groups on radio access have started only recently.

6.6.3.1 Working group SA1

At the end of Q1 2007 the SA1 study item into M2M communications was completed. The working group SA1 approved at SA #35 the deliverable TR22.868 “Study on Facilitating Machine to Machine Communication in 3GPP systems”. TR 22.868 mainly describes potential study areas such as the type of communications, the handling of large numbers of terminals, and considerations on charging, security, and addressing. The main conclusion is a list of possible requirements listed while the most controversial issue was the soft SIM/downloadable credentials.

In May 2008 SA1 agreed on a work item for normative requirements. TS 22.368 “Service Requirements for Machine-Type Communications” specifies the service requirements for network improvements for MTCs. In particular it

- identifies and specifies general requirements for machine-type communications,
- identifies service aspects where network improvements (compared to the current human-to-human oriented services) are needed to cater for the specific nature of machine-type communications, and
- specifies machine-type communication requirements for these service aspects where network improvements are needed for machine-type communication.

6.6.3.2 Working group SA3

In parallel to the activities in SA1, working group SA3 started a study item on soft SIM issues in 2006 time frame. The deliverable TR 33.812 “Remote Management of USIM Application on M2M” presents a study of the feasibility of securely and remotely managing (x)SIM applications for M2M equipment within a 3GPP system. Security aspects of some M2M use cases are analysed. Based on this analysis SA3 defined a number of security requirements and evaluation criteria. Also a variety of solutions for securely and remotely managing (x)SIM applications for M2M equipment has been defined and evaluated against these criteria. In particular, the solutions that have been analysed are

- TRE-based solution with remote subscription provisioning and change
- UICC-based solution with no remote subscription provisioning and change
- UICC-based solution with remote subscription change; Key transfer between operators
- UICC-based solution with remote subscription change; Pre-configured Key list on UICC

The detailed threat analysis showed as major conclusion that no insolvable security problem exist for remotely managing (x)SIM applications for M2M equipment within a 3GPP system.

Currently, SA3 has an open study item on the remote management of credentials in context with Virtual SIM (VSIM).

6.6.3.3 Working group SA2

Triggered by the SA1 study item and its deliverable TR 22.868, recently, SA2 opened a work item with the intention to take the results on network improvements from the study item forward into a specification phase (stage 1). Based on these stage 1 requirements specification, SA2 will address in a stage 2 phase system architecture impacts to support machine-type communication scenarios and applications. But, as it is not possible to handle the huge variety of M2M communications aspects in a single work item, SA2 has decided that its work item on architectural activities has the following focus:

- machine-type communication via mobile while machine-type communication solutions via wireless sensor networks and/or fixed communication networks are not included,
- the work item will specify a machine-type data communication service, it will not specify particular M2M applications
- only improvements on the radio and network side are considered, machine-type communication aspects of (x)SIMs and/or new models for the management of (x)SIM are out of scope of this work item.

This work item has started recently with fairly large number of contributions, and, hence, at this early stage it is not clear at all what kind of architectural impact the provision of MTC services will have.

6.6.3.4 Working groups RAN1-4:

On the radio access side, the working groups RAN1-4 initiated a study item for investigating potential optimizations on RAN level for machine-type communications.

6.6.3.5 Technical specification group GERAN

GERAN has started recently its machine-type communications activities by opening a study item on improvements for machine-type communications on the radio access. GERAN working group WG2 is primarily responsible for this study item and being supported by GERAN WG1. These

WGs expect to present a first technical report in May 2010 and to approve this report in Sept 2010 at GERAN#47.

In particular, some examples of objectives of this work item are:

- study GERAN enhancements for GERAN to improve the support for MTC considering their specific requirements and optimisation categories identified by SA1,
- to study GERAN enhancements which enable or improve efficient use of RAN resources and/or which lower complexity when a large number of MTC devices are served, and
- to study ways to reduce signalling latency and minimise user plane data overhead.

6.7 Research priorities Synthesis

Many research issyues were highlighted in this chapter under different technology areas. In summary one could list the following as the main top level research issues.

- Management, scalability and heterogeneity
- Networked knowledge and context: filters, new traffic patterns, data models… New network traffic models! (and billing models)
- Privacy, security and trust

6.8 Recommendations

Due to the very wide scope and nature of technologies involved in the M2M communications domain, interoperability is going to play a critical role in their market take up and success, Thus, there is a strong need for standardization and coordination/liaison between many multiple groups & forum.

As a consequence, strong recommendation would be to strengthen the responsibilities and visibility of ETSI as a keystone for future investigations, via future wider mandates jointly with some particular SDO (e.g. CEN-CENELEC for M/441).

7. Cognitive Radio Systems

7.1 Rationale

Traditionally, two different policies to access the radio spectrum have coexisted: licensed regulation, whereby the rights to use specific spectral bands are granted in exclusivity to an individual operator; or unlicensed regulation, according to which certain spectral bands are declared open for free use by any operator or individual following specific rules. While these paradigms have allowed the wireless communications sector to blossom in the past, in recent years they have evidenced shortcomings and given signs of exhaustion, mainly associated with the high cost of licenses, the perceived scarcity of spectrum and, in the unlicensed case, the spectral efficiency constrained at the Medium Access Control layer by the lack of coordination and interference management.

Current spectral sharing policies in wireless communication networks are not sufficiently flexible to guarantee the best assignment of the available spectral resources over time. Despite the general view that the spectrum is a scarce resource, large swaths of licensed bandwidth remain either unused or very lightly used. Consequently, it is quite usual to encounter fully overloaded mobile communication systems coexisting with unused contiguous spectral bands.

This is exemplified in Figure 7.1, which shows the typical spectrum occupancy measured in Washington DC on a typical Wednesday in September at around 10:00 a.m. (measures were carried out by Shared Spectrum Company, see www.sharedspectrum.com). In the lower plot, we see the evolution of the spectrum (horizontal axis) over time (vertical axis). Observe that a high portion of the spectrum is not occupied, and those bands that are occupied are being used by medium and short duration signals. The result is a vastly free spectrum even when all these bands are theoretically being reserved and in use. This general spectral wastage, which is a direct consequence of the traditional way frequency bands are strictly assigned to a particular system

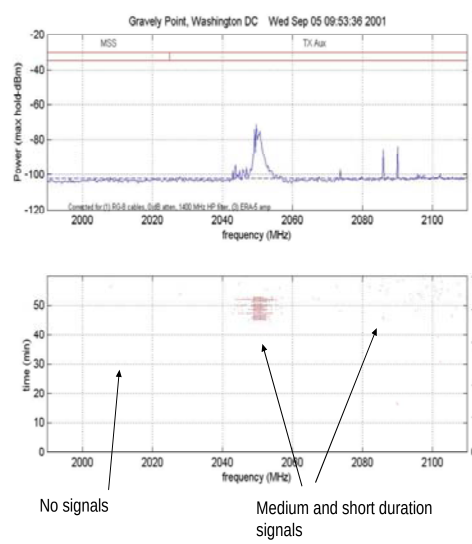


Figure 7.1: Frequency occupancy measured by Shared Spectrum Company in Washington DC.

or service, constitutes a serious limitation to the spectral efficiency of wireless communication systems.

This clearly advocates for a more flexible and dynamic allocation of the spectrum resources which can only be achieved with the so-called cognitive radios (CR). Such devices are capable of (i) accurately sensing the spectrum occupancy; (ii) learning about temporarily unused frequency bands; and (iii) reconfigure their behaviour and, more precisely, their transmission parameters (band, transmit power, etc), in such a way that the spectral opportunities can be effectively seized.

More generally, the concept of a cognitive network (CN) arises as;

"a network that has the ability to learn and react in order to adapt in response to conditions or events based on the reasoning and prior acquired knowledge".

On the basis of the above-mentioned contexts, profiles and policies, and by resorting to e.g. optimization, machine learning and/or artificial intelligence techniques, a cognitive network makes decisions based on reconfiguration actions. Such actions can be triggered at all layers of the OSI protocol stack. At the physical and Medium Access Control (MAC) level, decisions can be made concerning e.g. the selection of Radio Access Technologies (RATs), frequency band, transmission power, or modulation scheme. At the network level, actions are aimed at establishing routing and congestion control mechanisms, element interconnection (via legacy or emerging network topologies like mesh), etc. At the application and service level, actions can be devoted to the assignment of different QoS levels to the corresponding applications.

7.2 Research priorities

This section provides an accurate description of priority research activities and open challenges related to the different functionalities of cognitive radios and networks. More specifically, Section 7.2.1 summarizes the main open problems related to the theoretical characterization of cognitive radios as well as the optimization of physical layer functionalities in these networks. Section 7.2.2 goes one step up in the protocol stack and provides a description of the main research challenges that arise from the system point of view, including aspects related to MAC protocol optimization, traffic modelling, RRM strategies, routing paradigms or security issues that are specific to the cognitive radio network. Next, Section 7.2.3 focuses on problems related to the practical hardware implementation of cognitive radios, giving especial emphasis to sensing capabilities, reconfigurability and cognitive control and management. Finally, Section

7.2.4 gives a description of current activities related to the standardization of cognitive radio systems.

7.2.1 Information theoretical characterization and physical layer realization

In order to establish the theoretical benefits of deploying cognitive radio networks, it is very important to characterize their performance limits from an information theory perspective. Cognitive radio networks can be modelled as a particular case of the information theoretical interference channel, where the goal is to transmit as much information as possible over the secondary (i.e. cognitive) transmitter-receiver pair without noticeably disturbing the communication over the primary (e.g. licensed) pair. To that aim, the secondary link should exploit to the largest possible extent the overheard undesired information or any other a priori knowledge about interference's structure. In this respect, it is important to propose, study and characterize the performance of different transmit-receive architectures that try to exploit this knowledge on the interference structure in the cognitive radio framework. Of particular interest is also the characterization of these techniques when a large number of primary and secondary terminals are present in the network.

One of the most important requirements of cognitive radio systems is the fact that secondary users making opportunistic use of the spectrum need to have a very accurate description of the instantaneous spectrum occupancy. The implication is twofold: on the one hand, very accurate spectrum estimation techniques are needed in order to avoid situations where a secondary (opportunistic) user wrongly transmits through a spectrum portion that is used by the primary user. On the other hand, the spectrum estimation needs to be highly adaptive in order to cope with a highly varying radio environment. Hence, there is a pressing need to develop novel sensing algorithms capable of detecting primary users as rapidly as possible, and that are able to operate in the low-power regime. An interesting approach to leverage spectrum sensor sensitivity is to use collaborative sensing, which can be beneficial to avoid interference in scenarios with hidden nodes. In this context, broadcast techniques based on cognitive pilot channels are of great interest in order to spread and share spectral information among neighbouring nodes within the network, enabling the use of detect-and-avoid cognitive techniques. In order to foresee future situations, statistical inference techniques could contribute to efficiently distinguishing the spectral pattern of the primary user based on the historical statistical behaviour of its data. It is worth pointing out that cognitive radio systems will need to operate on huge frequency bandwidths. In this context, there is an urgent need for developing efficient albeit fast spectral occupancy estimation algorithms by means of avant-garde sampling techniques such as compressive sampling.

In cognitive radio networks, knowledge of the instantaneous spectral characteristics of the environment can effectively be used by the secondary users in order to avoid (or possibly mitigate) potential interference to neighbouring licensed users. This can be implemented by adapting the signal waveform to match the instantaneous spectral characteristics of the environment, and/or using multiple antenna systems to radiate power only along directions that generate less interference to the primary system. The adaptability of the spectral characteristics of the signal to the environment can be easily guaranteed by the use multi-carrier modulations, especially filter-bank based multicarrier modulations, which can provide high levels of frequency selectivity. Another important aspect that deserves further attention is the methodology for adapting the channel waveform to the statistics of the information source that is used. Cognitive data can significantly restrict the utilized modulated waveform, and ultimately sets a trade-off between source and channel matching of the channel signals.

In summary, in order to establish the benefits of the deployment of cognitive radio systems, it is of utmost importance to understand and characterize their performance limitations from an information theory perspective, and to design and optimize physical layer and spectrum sensing techniques in order to guarantee that cognitive radio networks can be effectively deployed in realistic scenarios. To achieve this, it is imperative to conduct research on the following topics:

- Accurate information theoretical characterization of cognitive radio. This characterization needs to ultimately establish the theoretical performance limits that are achievable in a cognitive radio system, and therefore fix the potential advantages that can be obtained in practical situations. Results will establish theoretical performance benchmarks in order to assess the performance of practical methodologies.

- Innovative techniques for rapid and accurate spectral estimation. Use of advanced compressing sampling algorithms and collaborative sensing architectures, giving especial emphasis to their applicability in practical cognitive scenarios.

- Adaptive waveform design; in order to match the signal characteristics to the instantaneous spectral availability. This needs to include the joint design of channel coding and modulation techniques in order to maximize the spectral efficiency of cognitive radio networks.

7.2.2 Research priorities in cognitive networking

At the system level, cognitive radio architectures can be roughly classified into centralized and decentralized. In both cases, interference management is the most critical challenge for feasibility of cognitive radio. The challenge is to spatially reuse a frequency band without causing harmful interference to a primary receiver, which, as it is the case in TV bands, may be a passive user, so that its position is unknown to the secondary transmitter. This problem is still unsolved and it is the main reason for scepticism from a network operator perspective. Considering the difficulties in solving this issue, conservative solutions based on geolocation and on the maintenance of a database from where secondary users can download information related with spectrum occupancy are currently gaining momentum from the point of view of the main spectrum regulators, such as FCC (Federal Communications Commission) and OFCOM. The standard IEEE 802.22, and so many other contributions in the literature, proposes a solution to this problem based on introducing a keep-out region, which is defined as a protection region around the primary transmitter aimed at ensuring that the primary receivers are not affected by the secondary transmissions. However, a system composed by multiple secondary users simultaneously transmitting in the same frequency band could cause excessive interference to a primary receiver, even if each secondary user is meeting the above mentioned keep-out region constraint. In the literature, little work can be found with respect to the aggregated interference that multiple secondary users can cause to primary receivers, which results in the second key open problem in the context of interference management. Smart solutions should focus on learning approaches where the secondary users are able to interact with the surrounding environment and learning resource allocation policies capable of maintaining the aggregated interference generated at primary receivers under a desired threshold. An interesting research line should be devoted to evaluate the applicability to the cognitive radio scenario, of traditional and novel machine learning approaches. Some aspects that should be taken into account in this evaluation are computational complexity, memory requirements and learning rate of these approaches.

One more open problem, is how to exchange information among cognitive radios in decentralized architectures. In the literature of cognitive radio, the hypothesis of existence of a common control channel where secondary users share control information is usually rejected, since it requires a static assignment of licensed spectrum before deployment, which is against the same philosophy of cognitive radio. Additionally, this solution increases the cost and complexity of secondary receivers, limits scalability in terms of device and traffic density and is not robust to e.g. jamming attacks.

Many new challenges, with respect to traditional ad-hoc networking, arise when it comes to routing. First of all, routes need to be selected not only according to the concept of physical proximity, but also based on the channel into which each secondary device is tuned. In addition, the availability of spectrum for secondary user access might vary with the location of secondary users, as well as with time, so that, the route selection process should account for up-to-date spectrum availability information at all the secondary nodes involved in the communication path. Finally, the implementation of routing strategies requires the possibility of exchanging control information among nodes, which should be realized, without the implementation of a common control channel, as it was discusses before. To solve this problem, an interesting solution which has recently been proposed in the literature and which needs further investigations, is to study the application of network coding in cognitive scenarios.

A research area which still needs significant effort is that of security. Standardization groups have already identified this as an open problem. However, the security sublayers derived by these efforts have been proven still vulnerable to many attacks. In particular, cognitive radio networks are vulnerable to the attacks encountered in decentralized networks, since the nodes can only sense the spectrum within their reception range, so that observations vary depending on their location. As a result of that, cognitive radio networks are usually based on the paradigm of cooperative sensing and primary detection, which makes that a malicious node could intentionally forge information in order to disrupt the overall network performance. A possible countermeasure to this problem is to build reputation systems, which however requires lengthy interactions among nodes. In general, in decentralized cognitive radio networks, it is infeasible to monitor the neighbours' behaviour for a sufficiently long time, since nodes are characterized by high spectral mobility, which generates security implications very similar to vehicular ad-hoc networks, characterized by spatial mobility.

Apart from the aforementioned vulnerabilities, some threats which are specific to cognitive network deserve special attention:

- objective function attacks (OFA),
- cross-layer attacks from physical/link to transport layer,
- primary user emulation (PUE) attacks.

More precisely, OFAs are targeted to disrupt the learning algorithm of cognitive radio devices. The cross-layer attacks from physical/link to transport layer attempt to disrupt the transport protocol by means of specific jamming. The PUE attack considers that some secondary users capable of transmitting signals with the same spectral characteristics of a legitimate primary signal may prevent other secondary users from occupying a certain channel.

Finally, with respect to cognitive networks, wireless beyond 3G systems are characterized by multiple and heterogeneous radio access technologies (RAT) coexisting and cooperating in the same geographical area. This fact can be exploited by the network operator in order to cost-effectively achieve the required Quality of Service (QoS) and, ultimately, raise customer satisfaction. QoS refers to performance (e.g., bit-rate, delay, etc.), availability (e.g., low blocking probability), reliability (e.g., low dropping or handover blocking probability), as well as security/safety). In this multiple-RAT context, there is a pressing need to reduce complexity in terms of network and terminal infrastructure, and user requirements. An option for handling this complex scenario is to exploit cognitive capabilities of retaining knowledge from previous interactions with the environment and of determining future behaviours according to this knowledge, as well as to other goals and policies, so as to adapt to external stimuli and optimize their performance.

To sum up, it is crucial to invest efforts to solve the following system level issues:

- Management of aggregated interference in multiuser cognitive radio networks: After many years of research in the area of cognitive radio, interference to primary receivers is still the main concern of spectrum regulators and network operators, in particular for the case of *passive* primary receivers. In particular, interference management in systems with multiple uncoordinated secondary users is a crucial issue that has to be investigated since, otherwise, such aggregated interference jeopardizes the perception of quality of service of the primary system.
- Application of Machine Learning approaches: A cognitive radio has traditionally been defined as a secondary user of the spectrum that uses methodologies of learning and reasoning to dynamically adapt its transmission parameters. These self-configuration capabilities are crucial for the adaptation to the surrounding environment. However, still a lot of work needs to be done with respect to studying the applicability of machine learning approaches to cognitive radio scenarios. The computational complexity of such approaches, the rate with which they adapt to the high variability of the wireless scenario and their memory requirements should be studied in order to prove their feasibility.
- Securing cognitive radio networks: Security in cognitive radio networks is still an open problem, which requires effort in both research and standardization. Contributions available in standards like IEEE 802.22 includes a security sublayer to provide subscribers with privacy, authentication and confidentiality. However, contribution in the literature demonstrate that these efforts are still far from addressing the key security threats and are characterized by many vulnerabilties.
- Common control channel: To define how secondary users coordinate and exchange signalling information is a priority, to solve several design challenges that arise in cognitive radio networks.

7.2.3 Research priorities in cognitive radio platforms

A cognitive radio is mainly composed of four subsystems, namely, (i) a sensing unit which provides raw information on the environment (e.g. spectrum occupancy); (ii) a cognitive engine which structures the sensed information and may have knowledge of other factors (e.g. regulatory rules, spectrum masks); (iii) a decision unit which decides if and how the radio should reconfigure itself to adapt to changes that may occur, considering the flexibility capabilities of the radio; and (iv) a flexible radio unit than can modify its parameters according to the decisions taken by the decision unit module. Essential support in the radio platform is needed to support cognitive behaviour. Specifically, the following features of the radio platform are crucial in order to be able to fully benefit from the cognitive radio concepts: spectrum sensing capability, reconfigurability of the radio platform, and cognitive control and management.

Current radio architectures, which are focused on the reception of a predefined channel, are not particularly suitable for spectrum sensing and frequency scanning operations (in order to search for optimal transmit opportunities) in a timely, cost and energy effective way. Due to the requirements on sensitivity, which are often more stringent in the sensing module than in the classical communication receiver chain, it is often not relevant to consider a sensor that covers the full sensing band, but rather to scan this band with a narrower band sensor. However, novel signal processing algorithms, namely, those based in energy detectors, or cyclostationarity properties, are capable of trading-off sensing reliability as a function of the level of knowledge the secondary system will have on the primary system or computational complexity. In parallel, novel radio architectures are investigated that allow sensing multiple channels in parallel while allowing to flexibly tune the centre frequency.

As for reconfigurability aspects, both the digital baseband, and the analogue RF front-end, should feature the necessary capabilities to adapt to the generated waveform. The requirements on the reconfiguration are stringent: rapidly switching among multiple subchannels of (potentially) high bandwidth and operating in high frequency bands; high performance offered at low power; and good interference-rejection capabilities. One solution towards the realization of reconfigurable radios platforms is through Software Defined Radio (SDR) technology that basically assumes that all the radio modules are implemented by software. This can be seen as "moving" the analog/digital and digital/analog converters closer to the antenna, operating at (up to) RF sampling rate. Of course, flexible RF front-end design remains a very important research topic, basically because of the need to trade-off the ideal approach described above against the evolution of electronic component capabilities. Considering the digital part, research in Software Defined Radio implies three main aspects:

- Design of open hardware platform based on software configurable elements such as FPGA's, microprocessors (e.g. MP-SOC) and DSP's;
- Implementation of waveform library that can run in real time and be mapped onto the platform for each communication technology; and
- The reconfiguration mechanisms of the radio which is often based on a hardware virtualization middleware. Alternatively, other reconfigurable radio platforms are designed on the basis of parameterizable hardware components

Cognitive control and management strategies cover aspects related with the run-time operation of cognitive wireless devices. This encompasses the design of advanced management functionalities enabling wireless devices to determine their configuration and behaviour based on profiles, policies, experience and knowledge. In other words, cognitive devices should be upgraded with the following capabilities: (i) management of user preferences and behaviour, equipment capabilities and network policies, such as user's traffic and mobility patterns, preferred QoS levels for specific applications; (ii) acquisition of context information, this encompassing to periodically check whether additional RATs have become available, monitor relevant statistics and trigger, if needed, a reconfiguration action; and (iii) negotiation with the available networks and RATs, and selection of the most appropriate reconfiguration action.

In summary, cognitive radio systems constitute a very promising technology for the sustainable support future connectivity needs. However, the actual deployment of cognitive radio systems may in practice be hindered by implementation constraints, both on hardware and software, and the availability of radio platforms featuring the required functionality and performance, at low cost and power. In order to avoid that the progress towards cognitive radios in hampered or even jeopardized, it is crucial to invest in the following areas:

- Co-design of systems and platforms for cognitive radios: This is essential to guarantee that the advances in wireless systems opened up by cognitive approaches will be realized in actual systems. More specifically, next generation reconfigurable radio platforms featuring spectrum sensing capabilities can be conceived based on system requirements, yet implementation constraints will on their turn put some constraints on system functionalities.
- Disruptive approaches, showing a high potential towards drastically increased flexibility and adaptability, yet involving high risk R&D. As a prime example, 'intuitive software radios' concepts can enable longer term solutions and following generations of cognitive radios, yet their implementation is still pre-mature.
- Strategies for control and management of cognitive radio systems and platforms: Indeed important benefits of cognitive radios occur from how they do or do not behave. Adequate control and management will be essential.

7.2.4 Priorities in standards-related activities

Cognitive radio introduces a new approach to spectrum access. For spectrum regulators, cognitive radio provides an opportunity to improve the efficiency in spectrum use and to promote the introduction of new services that could be provided by new technologies. At the same time, however, it is important for the regulators to preserve the rights of the current spectrum users. Therefore, the introduction of cognitive radio techniques in the real world requires acceptance by the regulatory domain.

To create the basis for this acceptance of Cognitive Radio by regulators in the future, a close cooperation between the research community and the regulatory bodies is necessary. Research results on cognitive radio should drive the identification of new spectrum policies to be adopted by the regulators. In particular, cognitive radio will require new performance indicators to ensure sufficient protection of legacy spectrum users, and an evaluation of the technical constraints for the coexistence of cognitive radio and pre-existing systems on different spectrum bands will be needed.

The upcoming World Radiocommunication Conference 2012 (WRC-12) of the International Telecommunication Union (ITU-R), will consider regulatory measures enabling the introduction of SDR and cognitive radio systems. The group ITU-R WP 1B “Spectrum management methodologies and economic strategies” has the main responsibility regarding this agenda item, whereas ITU-R WP 5A “Land mobile service excluding IMT; amateur and amateur-satellite service” is responsible for the technical work. To that aim, ITU-R WP 5A is developing a report entitled “Cognitive radio systems in the land mobile service”.

Within the European Telecommunication Standards Institute (ETSI), the mandate of the Technical Committee on Reconfigurable Radio Systems (TC RRS) is to draft feasibility reports describing what standards for SDR and CR could be developed and how. More precisely, TC RRS aims to study the feasibility of standardization activities related to Reconfigurable Radio Systems; to collect and define requirements from relevant stakeholders; and to deliver its findings in the form of Technical Reports and/or ETSI Guides. This technical committee is organized into four working groups, namely, WG1 System Aspects, WG2 Radio Equipment Architecture, WG3 Functional Architecture and Cognitive Pilot Channel, and WG4 Public Safety.

The IEEE Standards Coordinating Committee 41 (IEEE SCC41, formerly IEEE1900 Standards Committee) works on Dynamic Spectrum Access Networks (DySPAN). The objective of this effort is to develop supporting standards dealing with the technologies and techniques for next generation radio and advanced spectrum management. Some representative examples of work carried out by the SCC41 committee encompass the definition of standards for spectrum sensing interfaces and data structures for dynamic spectrum access (IEEE 1900.6 working group); or standards on architectural building blocks, interfaces and protocols enabling network-device distributed decision-making for optimized radio resource usage in heterogeneous wireless access networks (IEEE 1900.4). In particular, the field of application of the IEEE P1900.4 standard is radio systems forming a composite radio access network, i.e. with multi-Radio Access Networks (RAN) using different Radio Access Technologies (RAT). The end-user terminals are multi-RAT terminals with cognitive radio capabilities, such as the ability of operating flexibly on different frequency bands.

Several non-profit international industrial associations also work in the cognitive radio arena. First, there is the SDR Forum™ the members of which span commercial, defence and civil government organizations at all levels of the wireless value chain and include service providers, operators, manufacturers, developers, regulatory agencies, and academia. Complementarily, the Cognitive Networking Alliance (CogNeA) alliance unites influential players in the consumer electronics, personal computing, home entertainment, semiconductor and digital imaging spaces in an effort to help drive the definition and adoption of industry-wide standards for low-power personal and portable wireless devices operating in TV white spaces (UHF band). CogNeA contributed its specification to ECMA’s TC48-TG1 that will further develop a high-speed wireless networking standard to be finalized by the end of 2009. The Standard comprises Physical (PHY) and Medium Access Control (MAC) layers that include interference-avoidance mechanisms. ECMA International is a non-profit industry association of technology developers, vendors and users. ECMA is a frequent practitioner of “fast-tracking” of specifications through international standards organizations (e.g. ISO, IEC, ISO/IEC JTC 1 and ETSI). The above-mentioned wireless networking standard will serve a broad range of applications, including in-home high-definition multimedia networking and distribution (indoors), and internet access for communities (outdoors).

Some priorities for standards-related activities in the field of cognitive radio encompass:

- Harmonization of terminology and definition of reference models: There is an urgent need for work on harmonization of terminology and definition of appropriate reference models for Cognitive Radio (CR) and Software Defined Radio (SDR). In the community there are still confusions regarding the terminology and scope of CR and SDR. These terms are to some extent arbitrarily and liberally used and mean many different things to different groups. As an example, CR means for one group “Dynamic Spectrum Access”, for another group “Smart, Context Aware Radio” and for a third party “Opportunistic Spectrum Use”. Obviously, harmonization is required. This task comprises regulatory, technological, social and economical dimensions. For instance, the regulatory aspect could go beyond just a simple spectrum regulation and include aspects such as equipment conformance, interface regulation, and standardization (e.g. cognitive pilot channels).

- Analysis of tradeoffs and potential risks and benefits of CR and SDR technologies: Many arguments being made regarding the benefits of CR and SDR are solely based on political or marketing perspectives. In addition, the regulation and business needs are not yet fully understood and the integration of technology in the entire technology landscape is rather unclear. The scale of costs which may result from new technology deployment and/or due to the increase of interference risks is vaguely understood. Quantifiable facts are necessary here. Instead of making vague statements about the amount of “unused spectrum” available, it is required to quantify the amount of really exploitable opportunities, the potential novel approaches to utilize these opportunities and resulting consequences. There are needs for solid measurements and provision of modelling frameworks to enable all stakeholders to participate in the discussion. In summary, further work is needed to analyze tradeoffs and potential risks and benefits that are related to CR and SDR technologies.

- Continuous monitoring and contributions to relevant standardization bodies: Further studies are required in the CR field to understand the implications of white space spectrum. Given the FCC decision on white space spectrum, CEPT has started to work on this topic in Spectrum Engineering group 43 (SE43) for the UHF band. The conclusions drawn could be crucial in a longer term for all CR work.

7.3 Recommendations

Over the past years, research in cognitive radios and networks has spurred lots of interest in the industrial and academic communities alike. This has resulted into a number of activities in both in standardization bodies and industrial fora worldwide. Despite of that, many open issues at the scientific, technological and regulatory levels, still remain this preventing from a widespread adoption of cognitive radio and network technologies. The large potential impact of cognitive systems on the ICT sector (e.g. more efficient re-use of the scarce spectral resources, CAPEX/OPEX reductions in wireless networks) and society (e.g. increased connectivity, more environmentally-friendly reconfigurable devices) calls for an increased and more coordinated research work in the years to come. To that aim, we propose the following recommendations and way forward:

R1). Further efforts should be devoted to understanding and characterizing the performance limitations of cognitive radios from an information theoretical perspective, and to the design of physical layer and spectrum sensing techniques in order to guarantee that these networks can be effectively deployed in practical scenarios.

R2). A closer interaction with the artificial intelligence research community should be promoted in order to take advantage of the background already available with respect to traditional and novel learning and reasoning approaches. It is very important to evaluate the feasibility of these schemes for cognitive radio networks, in terms of computational complexity and learning rate.

R3). Closer interaction between the signal processing, network protocol, radiofrequency and microelectronic design communities is urgently needed in order to overcome a number of technological problems mostly related with reconfigurable radio platforms and sensing devices.

R4). Business opportunities and challenges together with specific charging mechanisms for secondary users must be clearly identified taking into account market and regulatory trends.

R5). Continuous monitoring of, and provision of inputs to, standardization bodies (e.g. ETSI, IEEE), industry fora (e.g. SDR forum or CogNea coalition), along with interaction with regulatory bodies is critical for the purpose of ensuring global impact and economies of scale of CR/SDR technologies.

R6). Broad and sustained support from publicly-run research funding programs continues to be necessary in order to underpin the aforementioned research and standardization efforts.

8. Broadband Mobile Systems

8.1 Rationale

Wireless technologies have experienced major cycles of development in the past twenty years or so. The introduction of digital transmission schemes e.g. in GSM, the numerous attempts to drastically improve the capacity for voice traffic by introducing CDMA to cellular systems, the migration of voice oriented cellular systems to mobile internet for consumer markets in the case of 3G cellular are just a few examples of such development. Most recently, broadband wireless data systems have been introduced for mobile cellular users, both in WiMAX and 3G-LTE based systems. However, during their evolution, these systems soon faced the problem that the radio transmission rates over a link have almost reached the theoretical limit. A promising technology is the IMT Advanced (IMT-A), which aims to provide mobile users with data rates that exceed 100 Mbps. Despite the rapid progress in developing new technologies, the underlying network topology has not changed considerably in the past two decades: The basic cellular network architecture with centralized control is more or less present even in today's 3G-LTE and future LTE-A concepts although quite recently the focus has been towards more decentralized radio access network control.

The ITU-R process to define IMT-A is on-going and there are high expectations to introduce totally novel ideas for radio spectrum sharing, network self-organization and local optimization techniques, improved energy efficient architectures, intelligent radio resource management, user scheduling schemes and so on. In addition, several on going research developments envision to drastically change wireless networking. These include extending various multi-antenna concepts to, the so-called, coordinated multi-antenna transmission and reception, improving transmission range and reducing interference in macrocellular environments by exploiting relay nodes, maximizing local capacity in hierarchical cellular networks through femtocells and enhancing spectrum usage through spectrum sharing and secondary spectrum usage.

In parallel to mobile cellular network development several research initiatives have been launched to study future Internet. The Internet originally was not designed to be a backbone technology for global communications and trade as it is today and its technical solutions were not intended to facilitate connectivity of billions of devices into the ubiquitous information infrastructure of the future networked society. It is obvious that the expected transformation includes great opportunities, but also poses huge challenges. The key technical driver for Internet development in the future stems from the need to account for wireless mobility. As the networks will become more dynamic and aware of their surroundings, all content exchanged in the Internet is expected to become dynamic as well. Under such a setting, server based information acquisition will become very inefficient and user co-operation and information exchange will become more attractive.

Partially related to dynamics in the network utilisation, centralized network control in general needs to be gradually replaced by intelligent context aware network control. This is often called cognitive networking which is a concept where, radio, network and available computation as well as power resources are utilised in the most efficient way in a dynamic network environment. The concept of opportunism should also cover the utilisation of spatial domain, user location and context information, co-existence of several access technologies, knowledge of channel statistical behaviour and traffic pattern that includes long-term monitoring and prediction, network topology awareness in mobile device, and so forth.

The transmitted data volume increases approximately by a factor of 10 every 5 years, which corresponds to an increase of the associated energy consumption by approximately 15 – 20 % per year. Currently, 3 % of the world-wide energy is consumed by the ICT infrastructure. However, if the energy consumption doubles every 5 years, it is natural that it will lead to serious problems. Decreasing the energy consumption of future wireless radio systems is currently being investigated in the framework of green radio networking. Another challenge is to globally reduce the electromagnetic radiation levels to achieve better coexistence of wireless systems and to further decrease human exposure to radiation.

The anticipated major growth in wireless business focuses mainly at emerging markets in China, India, Africa, and South-America. This does not only open new markets for promising technologies, but also brings forth newer technological challenges and opportunities. The need in these market economies is for relatively inexpensive, easily accessible, diversified, and expandable communication services, ranging from basic voice and data services to more content-rich multimedia and broadcasting optimized for the masses. The network set-up should be as simple as “plug and play” procedure that allows a flexible network topology, spectrum usage, co-existence of technologies. Also, the data rate requirements are very diverse depending on the type of services needed. Both CAPEX and OPEX should be low, meaning e.g. auto/self everything, very high energy efficiency in a very flexible wireless network. This may open up a new paradigm in the development of wireless systems relatively soon.

As wireless networks are becoming more complex and diverse, understanding the fundamental behaviour and reasoning of different types of networks is becoming increasingly important. The well-established theories for fixed and often static networks need to be extended to dynamic heterogeneous wireless networks with different types of traffic. Instead of the optimal centralized solutions, practical decentralized networking management schemes must be sought. The cross-layer optimization methods are not yet well understood and need careful studies before they can be successfully applied to the evolution of future networks. All these need careful investigations from the scientific community before they can be used as powerful tools for future wireless network design.

To summarize, the key dimensions and drivers for the development of future wireless networks can be summarized to include at least the following key aspects:

- Evolution of Mobile Cellular Access and Networking Techniques
- Future Internet Architectures
- Position and Context Aware Network Management
- Cognitive Wireless Networking in a Heterogeneous Network Environment
- Opportunistic and Flexible Spectrum Usage
- Energy Efficient and Green Networking
- Special Needs for Emerging Markets
- Development of Fundamental Theories for Wireless Networking

Based on these remarks, the future research agenda on wireless networking are in the following areas:

- Broadband Mobile Access
- Mobile Wireless Driven Future Internet
- Fundamental Enabling Networking Technologies
- Wireless Technologies and Applications for Emerging Growth Markets

8.2 Research priorities

8.2.1 Research priorities in broadband mobile access

The need for higher data throughputs, driven by the high bandwidth demands of a continuously increasing number of multimedia applications, will continue to increase in future wireless networks. Those are enabler for future wireless entertainment, intelligent transport systems, telemedicine, emergency and safety/security applications and more. Furthermore, applications, such as 3D Internet, virtual and augmented reality, and tele-presence are expected to emerge in the future and push the demand of data rates to completely new orders of magnitude. At the same time, it is expected that a trillion of devices will be connected to the Internet of the imminent future, creating great technological challenges in terms of the networking architecture.

To achieve the high data rates needed for enabling the future services, new technologies are needed over the complete radio networking protocol stack. New radio technologies will be operating at significantly higher carrier frequencies. This poses remarkable challenges to the radio frequency (RF) and baseband (BB) hardware, software, and other implementation technologies. More importantly, to make the vision of the futuristic high rate services a reality it will be mandatory to enable concurrent usage of multiple radio frequencies, technologies and heterogeneous networks.

8.2.2 Evolution of mobile cellular systems

The ITU-R process of defining the IMT-A is in progress and there are high expectations for some totally novel ideas for radio spectrum sharing, self-organization and local optimization networking concepts, energy efficient networking architectures, intelligent radio resource management and user scheduling schemes. There are also other developments that are evolving which have the potential to change the wireless networking concepts drastically. Different multi-antenna concepts have been extended to the so-called coordinated multi-antenna transmission and reception, relay nodes have been utilized to improve range and reduce interference in macro-cellular environments, femtocells have been exploited for local capacity maximization in hierarchical cellular networks and spectrum sharing and secondary spectrum use have been suggested to enhance spectrum usage, just to mention few examples.

8.2.2.1 New radio technologies

Today modern WLAN systems using OFDM based basebands, combined with multiple-input multiple-output (MIMO) techniques, use typically 20–40 MHz of bandwidth and can communicate at a speed that can reach 600 Mb/s, as indicated in IEEE802.11n. New discussions in the IEEE802.15.3c already try to go beyond the 1 Gb/s and achieve 2–6 Gb/s by using the 60 GHz band. Currently, the bandwidth for this speed is 2 GHz, which results in a spectral efficiency of less than 1. Novel physical layer radio interfaces and RF-BB solutions must be designed to improve the spectral efficiency of the transmission schemes and exploit the unutilized frequency resources. To realize data rates of tens or hundreds of Gbit/s on wireless short range links, even a substantial increase of the modulation level, requires a bandwidth in the order of tens of GHz. This can only be found by exploiting higher radio frequencies, e.g., in the bands beyond 60 GHz all the way up 100–500 GHz.

MIMO systems operating in higher frequency bands can leverage small wavelengths, because directive antennae can be implemented onto small size devices. However, this poses also enormous challenges at the signal processing level due to the high signal processing rates. Even more so, the antenna technology and RF parts of the transceivers will require significant R&D to realize this vision.

8.2.3 New network technologies

The evolving novel radio technologies open opportunities for completely new radio resource control, frequency allocation, and multiple access mechanisms. The selection of the best route and space-time-frequency resources poses a complicated multidimensional optimization problem.

The future wireless networks will have novel network topologies to complement the legacy cellular topology (see Figure 8.). Fixed relay stations will be applied in future networks to improve capacity and coverage via improved link budget and increased diversity. Peer-to-peer communications and mesh networking are likely solutions for future high-speed networks. The concurrent full-duplex usage of multiple radio technologies and frequencies will become feasible in the future. This opens a new venue for routing, radio resource control, and usage of the available radio connections in a coordinated manner. For the realization of the promised performance gains, new solutions for network optimization are required.

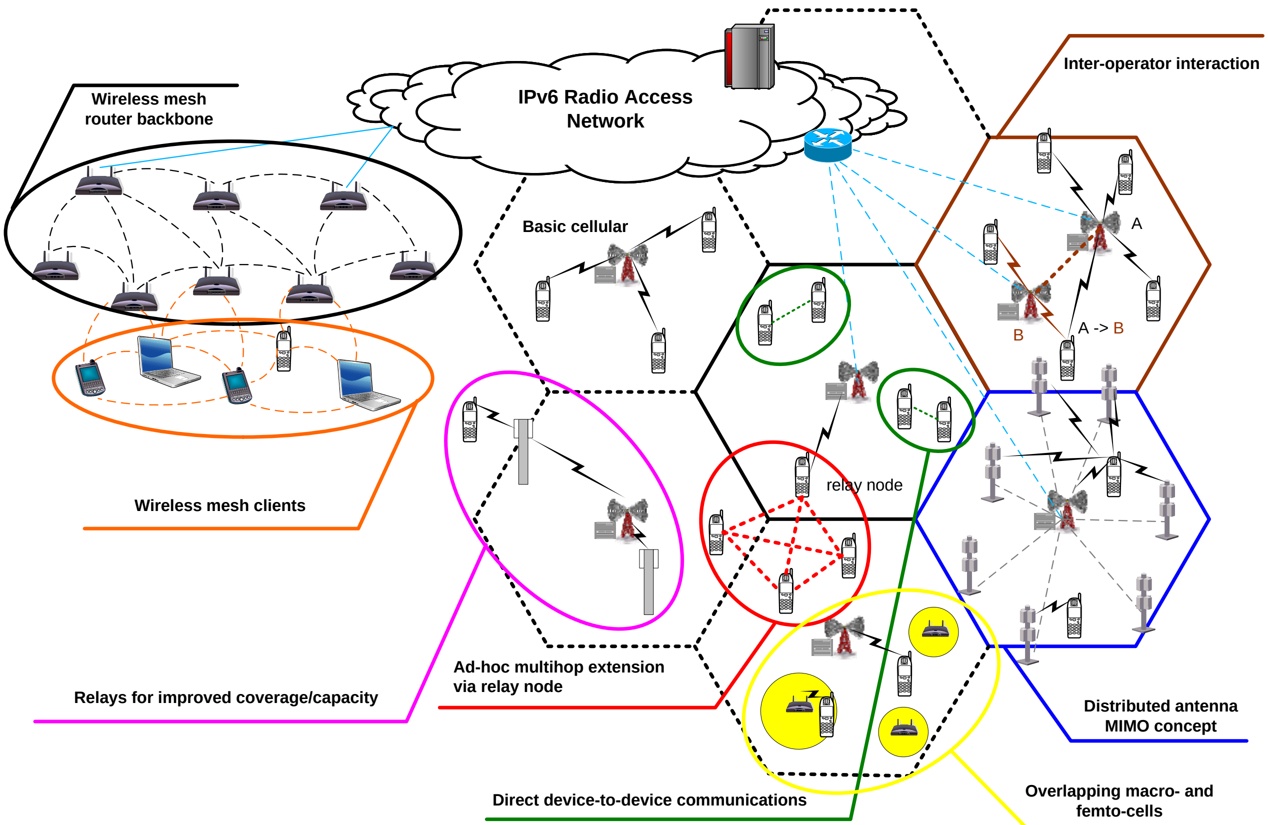


Figure 8.1 New wireless network topologies.

8.3 Research priorities in fundamental enabling networking technologies

8.3.1 Motivation

Undoubtedly, wireless technology has broadly entered the contemporary era and promises to provide the wireless users with a vast amount of data services. The rapid proliferation in the number of wireless users mandates the efficient utilization of the available spectrum and the achievement of high data rates to support the continuously increasing user demands. Furthermore, traffic in future wireless systems is anticipated to be composed not only of non-real time applications, such as web browsing, messaging or email, but also of real-time traffic such as video, multi-media, and teleconferencing. The latter type of traffic mandates the ability of the network to provide Quality of Service (QoS) guarantees to the wireless users, for instance in terms of (i) satisfying a minimum rate requirement and (ii) maintaining packet delays that with high probability do not exceed a given maximum value. In addition, the heterogeneity between the different traffic types introduces new problems regarding how to support simultaneously non-real time and real time users so that the former receive a maximum possible throughput rate without affecting the QoS requirements of the real-time users.

Finding answers to the above challenging questions is further hampered by the fact that wireless systems require a fundamentally different treatment than the preceding wireline ones. One of the main difficulties in wireless is the observation that there is no “hard” notion for a link. Instead, the notion of a link is “soft” and depends on various parameters such as the transmission power and rate of a transmitting user, the channel quality, and the amount of interference at a receiving user that originates from other concurrent transmissions. Furthermore, adverse effects such as fading, scattering and unpredictable user mobility cause the channel quality to fluctuate with time, which consequently affects the corresponding achievable rates. On the other hand, the wireless medium can be viewed positively from its shared nature; (i) can act synergistically towards achieving better performance as it allows the possibility for opportunistic communication and (ii) offers novel ways of communication that can be exploited such as making use of its broadcast nature to facilitate multicast communication and allow user cooperation.

The Open Systems Interconnection (OSI) architecture is built upon the assumption of the existence of a robust physical layer providing “reliable” links with “stable” capacity. Furthermore, the OSI architecture does not foresee the possibility of exploiting the time-variations and the new modalities that the physical layer has to offer. Instead it views the physical layer purely as a “pipe” of bits. By restricting the ability of the physical layer to influence the layers above, the OSI architecture maintained a well-defined separation between the layers, which modularized and simplified the study of the different functionalities by requiring communication only between directly neighboring layers. Thus, the applications and the higher layer protocols such as protocols related to routing, congestion, and flow control could be designed almost independent of each other. Although this separation was reasonable in wireline networks, it is clear that in wireless a lot can be gained by exploiting the coupling between the physical layer and the layers above it.

8.3.2 Cross-layer design revisited

For wireless systems to fulfil their promise in terms of providing a broad class of services to heterogeneous users at high data rates cross-layer interactions at all layers have to be considered. In particular:

- Medium Access Control: Due to the fact that concurrent transmissions interfere among each other appropriate scheduling algorithms need to be introduced to mitigate the effects of unwanted interference. Although scheduling is a decision of the Medium Access Control (MAC) layer, the ability to schedule two or more users concurrently depends on their transmission powers and rates as well as on the underlying channel conditions. Thus, there is an inherent coupling between the MAC and the physical layer. As an example, in the downlink of a base station a scheduler that takes advantage of the channel variations by giving priority to the users with instantaneously better channels, like in the CDMA2000 HDR can do better in terms of performance, e.g., maximizing the total throughput or proportional fairness, as opposed to a blind Time Division Multiple Access (TDMA) scheme. To further exploit the coupling between the MAC and the Physical layers, apart from the transmission powers and rates, parameters regarding space-time codes and signal combining can be exchanged between these two layers with the aim to improve the achievable rates.
- Network Layer: Taking the cross-layer issues one step further, the routing algorithms also need to take into account information regarding the physical layer as well as the scheduling decisions at any given time in order to send the packets through the routes that utilize links with the highest capacities. For example, decisions regarding to which relay node the traffic should be forwarded have to take into account the underlying physical layer.
- Transport Layer: A cross-layer design is also necessary to support users of real time applications since it is not clear how the higher layers should adapt to the continuously changing wireless environment and traffic conditions. Also, it is non-obvious how to maintain performance guarantees in networks with a large number of connections. For real time applications, apart from the requirement that packets must reach their destinations in short time, in order delivery is also of paramount importance. The prevalent protocol in the internet for reliable end-to-end transmission of data and congestion control is the TCP/IP. This protocol assumes that a packet was dropped by a router due to congestion in case it has a timeout without seeing the identity of this packet. As a reaction to that, it decreases the source rate and thus decreases the network throughput. Although TCP/IP, in its original design, is unable to account for losses due to the unreliability of the wireless medium, various adaptations of TCP/IP have been suggested in the literature. One such adaptation is to introduce the Explicit Congestion

Notification (ECN) where an ECN bit is introduced in the packet header. The bit is initially set to zero by the source. In the event of congestion, the router sets the ECN bit to one to indicate congestion. Once the packet reaches the destination, the latter will inform the source that congestion occurred by checking the ECN bit and the source will be able to adapt its transmission rate. Clearly, providing end-to-end reliability is more difficult in the presence of multi-hop transmissions and cognitive radios since the transport protocols run at the end nodes and do not have knowledge of the underlying channel and traffic conditions or congestion of the intermediate nodes.

8.3.3 Systematic cross-layer design for future internet

Future internet requires employing new network topologies, such as multi-hop wireless networks, mobile ad-hoc networks, integrations of wireline and wireless networks. It further calls for advanced routing, scheduling, radio resource management, and radio link control solutions, capable of using the spectrum efficiently and adapting to diverse traffic behaviour. A fundamental problem in designing such complex systems is to derive a network control mechanism comprising of flow control, routing, scheduling, and physical resource management, which can ensure network stability under a large set of service demands and can, at the same time, provide a certain degree of fairness among concurrent sessions (corresponding to different users and/or services). Designing network protocols that achieve these goals requires a holistic network optimization, which cannot be achieved without crossing the boundary between the standard OSI layers. Network protocols for layered architectures have historically been obtained based only on an engineering intuition, and many of the recent cross-layer designs are conducted in the same ad-hoc manner. Despite of the recent progress, there is little understanding of how to divide the network protocol into layers in a systematic (i.e., optimal in some sense) rather than in an ad-hoc way. A completely new approach, based on a rigorous mathematical theory, is required for optimizing the future network architectures.

An important step towards a systematic cross-layer network protocol design was performed in the late nineties, when Kelly et. al. introduced the concept of network utility maximization (NUM) for providing fairness in wireline networks. The Kelly's NUM framework has been extended to model, analyze, and design various protocols and resource allocation algorithms. These extensions led to a novel design concept, known as layering as optimization decomposition (LOD), which can be summarized as follows: The network protocol is modelled as an optimization program which maximizes a network utility function, defined according to the needs of the main application. Standard optimization decomposition techniques (e.g., primal and dual decomposition) are employed to obtain different decompositions of the original NUM problem, and each one is mapped to a possible layering scheme. Specifically, each sub-problem resulting from a given decomposition scheme corresponds to a layer in the protocol stack. In this way, the different layers become well-defined optimization sub-problems instead of being products of ad-hoc decompositions. In addition, the interfaces between layers can be rigorously designed. The outputs of the layers are the primal and/or the Lagrange dual variables of the sub-problems they solve, and they represent the variables of a master problem.

Different layers iterate on different subsets of the decision variables using local information to achieve individual optimality. Coordinated by the master program, these local algorithms attempt to achieve a global objective.

The above LOD approach provides a mathematically rigorous framework for systematic cross-layer network design. It is capable of specifically addressing the application needs (by an appropriate choice of the utility function), providing a globally optimal performance benchmark, and leading to a systematic design of a decomposed solution to attain the benchmark. By exploring the space of alternative decompositions and comparing the resulting algorithms, the network control designer can obtain answers to questions as “how to and how not to” layer. By modifying accordingly the utility functions and the constraint set, the framework can be further generalized to incorporate other degrees of freedom, such as multiple routes, beam-forming patterns, transmit powers, contention probabilities, channel codes, and modulation schemes.

Despite its generality, the standard NUM framework typically assumes that the user population remains static, with each user carrying an infinite backlog of packets that can be treated as a fluid, injected into a network with static connectivity and time invariant channels. While this model proved very successful in the case of fixed networks, it is not accurate enough for the future wireless (or hybrid) networks. In such networks, the links’ capacities are time-varying due to the fading in the radio channel and the users arrive with a finite workload and depart when the jobs are finished. In addition, the network connectivity is also time-varying due to the users’ mobility, battery limitations, etc. Therefore, creating a general framework, which leads to a systematic design of general, time-varying multi-hop wireless networks, is a challenging, and yet open problem. Specifically, stochastic networks with wireless and/or wireline components, randomly arriving traffic, and time-varying channels with possible disconnections and user mobility should be considered.

The concrete goal is to integrate various network protocol layers into a unified optimization framework, by considering them as distributed over the network components (or sub-problems) of a general utility maximization problem. Coordinated by a master program, these local algorithms attempt to achieve a global objective. By modelling the wireless network as a queuing system with transmission rates that depend on resource allocation decisions and time varying channel states, cross-layer control techniques for the flow control, routing, node scheduling, and radio resource allocation can be derived in order to achieve joint optimal performance. Particular emphasis should be on deriving algorithms and protocols that allow distributed implementation. Different performance criteria, including e of Brazil, China, India, South Africa, open not only new markets for technologies, but also brings forth throughput, delay, and robustness against topology changes, can be investigated.

8.4 Research priorities in wireless technologies and applications for emerging growth markets

The emergence of economies in the Asia-Pacific, Indian sub-continent, Africa, and South America, notably thos newer technological challenges and opportunities. The economic needs of these markets seek for relatively inexpensive, easily accessible, diversified, and expandable communication services, ranging from basic voice and data services to more rich in content multimedia and broadcasting operation, optimized for the masses at the bottom of the economic pyramid. Various broadband (wireless and wireline, including optical) access techniques for instance have attractive attributes like scalable service offering and flexibility to provide tradeoffs between service quality and availability with costs and service coverage. The challenge however lies in adapting the various technologies available in networking, computing, user interfaces, and content, and possibly creating new ones, and further developing innovative business models to cater to the specific needs of the remaining 4 billion people still untouched by the Internet. The challenges and the opportunities both are astounding.

Some of the key drivers calling for advanced R&D, targeted towards the needs of the emerging economies, are as follows:

- The majority of growth in the networking business is already happening in the emerging economies.
- Competition in these markets is going to be fierce since all manufacturers and operators are increasingly focusing on the same markets.
- True adoption of mobile internet experience will come from these markets since mobile handhelds have already higher penetration than personal computers (PCs), and most people in developing regions never had a PC-based Internet experience. The aggregate ownership of mobile phones (and subscriptions) in the emerging economies is in the order of billions, whereas the ownership of computers (desktops and laptops) is only in the millions. For example, in India, there are over 400M mobile users as compared to about 50M computer users while in China the mobile users exceed 600M as compared to the computer users, which reach 125M.
- Since the wireline infrastructure is very poor and most developing nations have already decided to cap their wireline expenditures in favor of going for broadband wireless, LTE and other non-cellular wireless access technologies (e.g., WiFi, WiMAX) will have a much faster speed of deployment and easier generational skip than in the developed economies.
- There is a huge pent-up demand in rural areas for improved quality of life that networking technologies can meet mainly because of the lack of transport, financial, healthcare, and entertainment infrastructure.

- The broadband wireless Internet will enable a plethora of new useful applications and services for a vast majority of subscribers in the lower middle-class and those at the bottom of the economic pyramid. These considerations call for greater investments in R&D specialized towards creating value propositions through creative business models and technologies tailored to emerging markets.

It is important to first summarize the key demographic, economic, and business reasons why we should pay particular attention to the needs of these markets to “fuel” the economies of the developed markets, especially in the present time of severe recession, and use this research as a driving impetus for the rest of the technical research agenda. We make a case for focused R&D targeted at communication technologies for these new growth markets. To start with, some of the incorrect notions associated with these markets need to be expounded and clarified:

- Solutions that exist for developed regions can, with trivial modifications, be applied for developing regions.
- The scope and necessity for technological innovation in emerging economies is limited.
- Only cheap products are suitable for emerging economies.
- An economic case cannot be made for offering networking technologies in developing regions.
- Users in the rural areas provide low average revenue per user (ARPU) and are not ready for new services and applications.

This will then be followed by determining the specific requirements for the wireless client devices, broadband internet access and services, and where the priorities should be from the perspectives of the network, service, and equipment providers. The identification of the research topics must also meet the challenges of minimizing costs (capex and opex) and sustaining the environment. More specifically, from the networking perspective, the key challenges are in efficient allocation and usage of the spectrum, serving extremely dense urban areas and outlying sparse rural areas, radio access and backhaul technologies that use the vastly deployed but unlit fibre, QoS support for multimedia and broadcast/multicast content, and ease of deployment, management and operations. Also the availability of network access can be discontinuous and highly time and position dependent, which needs to be taken into account at applications layers.

From a business perspective, it is suggested that the focus ought to be on meeting local needs, creating value, and not necessarily on maximizing profit margins in order to boost a faster uptake of the broadband services that will in turn result in higher investments in the infrastructure and equipment. The research will also prove that the solutions (both the business models and technical) for the emerging markets can equally be applied in the developed markets to reduce service costs to the subscriber and to maximize the return on investment for the service provider.

In conclusion, the research outlined above falls in four key areas: Value Creation with Novel Services and Applications, Innovative System and Network Architectures and Solutions, Innovative Spectrum Usage Solutions, and Innovative Business Models (including public-private partnership).

8.5 Recommendations

There are still many unexplored areas for optimisation of radio interface and advanced network architectures requiring major investment and research effort towards achieving efficient ubiquitous personal broadband communications. The key areas requiring research investments are in the development of

R1). Broadband Mobile Access Technologies

R2). Mobile Wireless Driven Future Internet Technologies

R3). Fundamental Enabling Networking Technologies

R4). Wireless Technologies and Applications for Emerging Growth Markets

9. Optical Fibre Technologies and Radio over Fibre

Wireless communication is entering a new phase where the focus is shifting from voice to multimedia services. Present consumers are no longer interested in the underlying technology; they simply need reliable and cost effective communication systems that can support anytime, anywhere, any device (ATAWAD). Globally, mobile data traffic will double every year, and reaching over 2 Exabyte's per month by 2013. Furthermore, mobile data traffic will grow from 1 petabyte per month to 1 Exabyte per month in half the time it took fixed data traffic to do so. In the 7 years from 2005 to 2012, it will have increased a thousand-fold. In addition, the Internet traffic grew from 1 petabyte per month to 1 Exabyte per month in 14 years.

As shown in Figure 9.1, there will be three waves of Internet video. The first phase is experiencing a growth of Internet video as viewed on the PC, the second phase will see a rise in Internet delivery of video to the TV, and the third phase will involve a surge in video communications. Each phase will impact a different aspect of the network. The first two phases will be felt primarily in the metro and access networks, while the third will impact the core. In addition to Internet video, there is very high growth in the IP transport of cable and IPTV video on-demand services. Only the virtually unlimited bandwidth of optical fibre access network can provide such capability both for wired and wireless connectivity. Radio-over-Fibre has been addressing how to distribute broadband wireless signals in access networks, including dynamic allocation of resources.

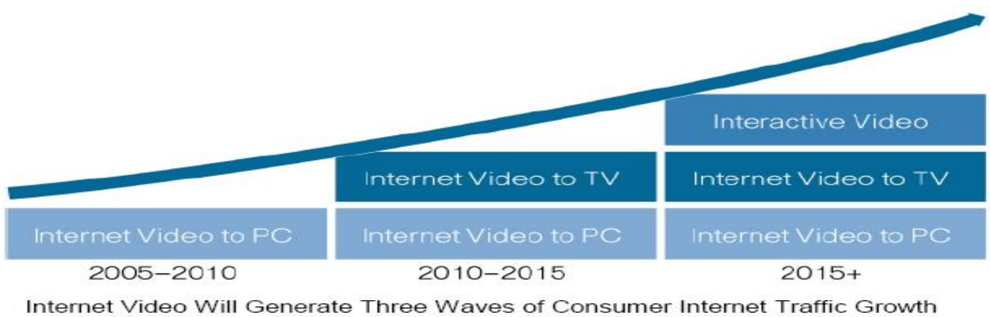


Figure 9.1 Internet traffic growth.

Driven by ever-increasing users' demands for broadband services, worldwide fibre-to-the-home (FTTH) rollout has recently surpassed thirty million users and is continuing to grow at a rapid rate. To realize various FTTx solutions, passive optical networks (PONs) have been considered as the most promising technology. Next-generation PONs are expected to deliver new and legacy services, both analogue and digital, in a single converged conduit. One such example is the radio-over-fibre (RoF) technology which makes use of an unspecified spectrum to backhaul wireless signals from multiple remote antenna ports via one trunk fibre.

The rapid and global spread of the internet is accelerating the growth of optical communication networks and the demand for more bandwidth has driven the use of photonic technology in telecommunication and computer networks. The diversity of future services will require high-capacity optical networks featuring dynamic and high-speed routing and switching of data packets. The new generation very high-bit rate optical packet switched networks require a potentially faster approach to decode the header bits optically so that a given routing decision can be made on-the-fly.

Internet traffic has been increasing at an annual growth rate of around 40%, and it will reach 1 Terabit/s in the core optical network according to Figure 9.2, as the bandwidth demand increases in the future network.

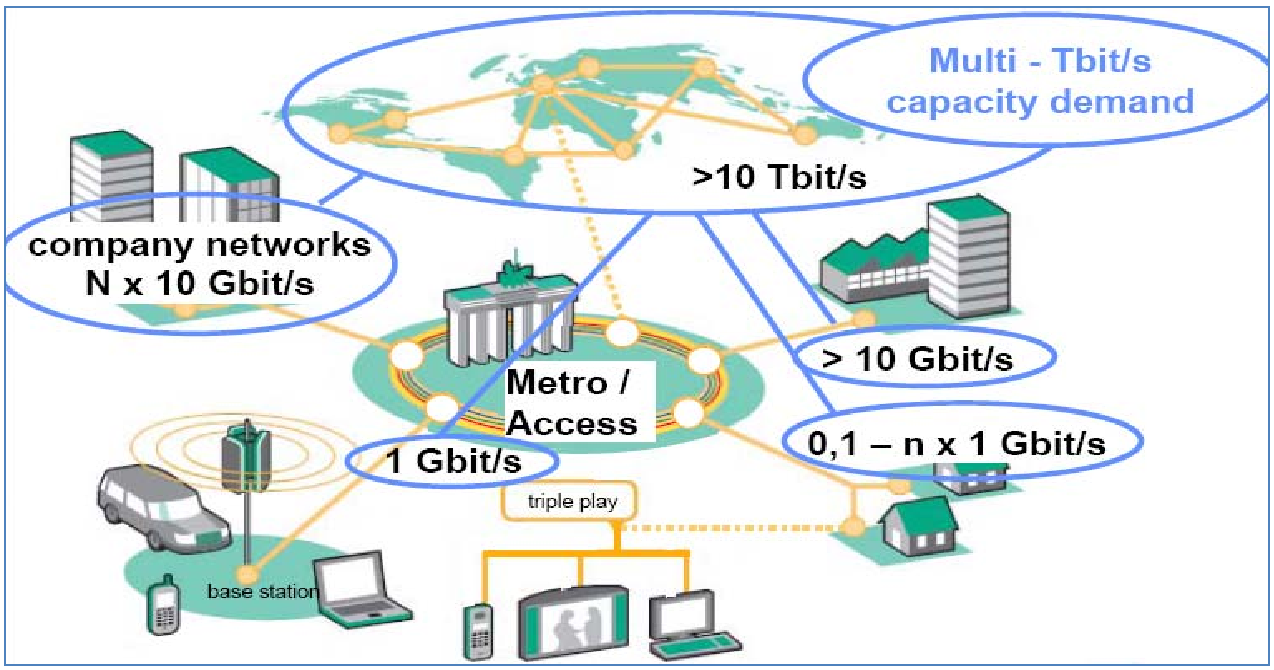


Figure 9.2 Bandwidth demand in future network

With the constant evolution and innovations in the processing capabilities of consumer devices capable of handling rich multi-media content, the current available bandwidth and the capacity of last mile wireless networks proves to be a major bottleneck. Provision of higher bandwidths to the end users thus becomes mandatory in order to streamline with the evolving multi-media applications and higher demand. Having a wired network although can provide higher bandwidths; it limits the overall convenience, mobility and has a significant impact on the cost. On the other hand, an end to end wireless solution does not serve the purpose because of capacity constraints at the access domain. An integrated approach as shown in Figure 9.3, however, becomes an attractive alternative and with suitable planning, an acceptable compromise can be achieved between providing high bandwidth to the end users as well as being cost effective and convenient. To augment the bandwidth of the network, Radio over Fibre (RoF) Access points can be used at suitable locations throughout the network along with mesh routers to provide a low cost and high bandwidth solution. Optical Routers and switches can be used in the back end to aggregate the traffic and route it to the appropriate destination. Therefore, a high bandwidth and low cost solution can thus become feasible as well as scalable to cope with the future demands of increased bandwidth and high traffic volumes.

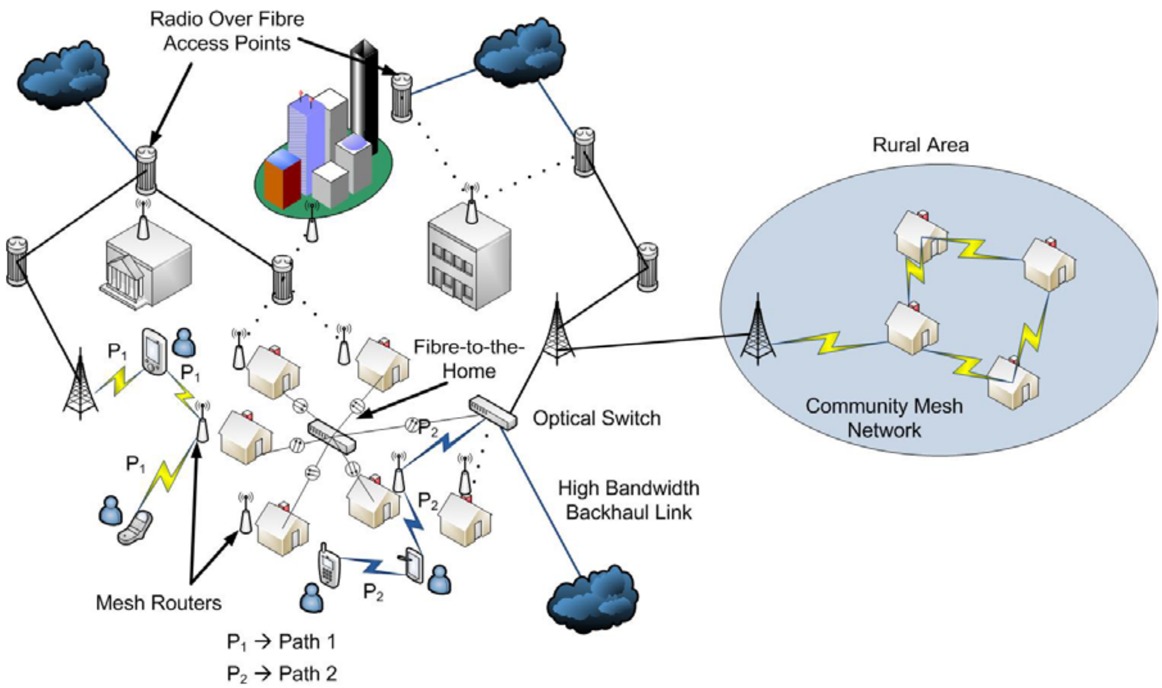


Figure 9.3 An Example of Integrated Wired-Wireless Network

With current technologies, however, networks will frequently suffer from bottlenecks in the face of rapidly increasing traffic, meaning traffic congestion caused by the insufficient processing speed of the electronic circuits inside the routers. In addition, the overall scale of electrical router node facilities, including switching bays and OE/EO line card bays, will become increasingly larger and will require ever higher power consumption. To solve these problems, node technologies based on ultra-fast optical packet switching have been intensively developed to replace conventional electrical router nodes, with the goal of eliminating unnecessary O/E and E/O conversions in the data plane, even in packet header recognition.

9.1 Rationale

Radio over Fibre is a rather ideal technology for the integration of wireless and wired networks. The main reason being is that it combines the best attributes of two common communication methodologies. A wireless network connection frees the end-user from the constraints of a physical link to a network which is a drawback of conventional fibre optic networks. Meanwhile optical networks have an almost limitless amount of bandwidth with which to satiate even the most bandwidth hungry customers where bandwidth for wireless networks can be a significant bottleneck. Thus RoF networks offer customers the best of worlds by allowing them to maintain their mobility while also providing them with the bandwidth necessary for both current and future communication/entertainment applications (i.e. HDTV, Video on Demand, 3DTV, video teleconferencing, etc.). Furthermore RoF networks also provide for greater geographical flexibility as compared to using either one or the other methodologies. Such network topologies could be useful in places such as large buildings, subways and tunnels where large amounts of people are mobile thereby making physical connections impossible and standalone wireless systems being faced with the difficulty of bandwidth limitations and handover issues.

While the concept of RoF networks has been around for several decades now, there is still a substantial amount of work that needs to be undertaken in order to improve their characteristics and capabilities. Several research priorities have been identified that should be addressed in order to improve not only the capabilities of RoF networks but also their cost effectiveness and robustness. The requirement to communicate a very high data rate such as rich multimedia with low power and low cost are the reason behind the integration between wireless and wired domains using RoF as this integration is the only way to allow high data rate with low power and low cost. The integration has the potential to make the networks more transparent, dynamic, faster and greener.

9.2 Research Priorities

9.2.1 Business Models and Network Architecture Design

The use of fibre technologies to distribute radio signals from a central office location into the access network has the potential to have a significant impact on power consumption. As part of the investigations into RoF technologies the reduction in power consumption compared with a more conventional approach using optical and radio backhaul networks with either SDH/SONET or Ethernet switching should be a key topic for research.

One of the most important advances in containing the overall power consumption of the Internet could be the efficient and innovative use of optical technologies in providing a converged access/metro network which is designed to carry all types of high speed traffic. This could include business and residential, and provide ultra-high speed broadband access to both domestic and business customers.

9.2.2 Support for on-Line Applications and Storage to Enable Fully Mobile Access to Business and Personal data

Business users have for some years needed access to their data while away from their operating base. They need access in two ways: while static in a remote office: while travelling to or from a remote office. The static connectivity may be provided by a wire connection but increasingly users assume that some form of wireless access will be available. The mobile access has to be provided by wireless but this may be a continuous high speed connection or a store and forward service such as is offered on trains and buses. In each of these business users scenarios the upstream data rate is as important as the downstream. In some cases there may be a requirement for a higher upstream than downstream, for instance when a field worker needs to upload photographic data.

This is a very different scenario than for the domestic user whose main requirement remains the desire to download music or to watch sports events while on the move. For sports events in particular the downstream data will far outweigh the upstream. However, it is likely that many users will be looking for the same data so a network with broadcast capability could improve the spectral efficiency of the air path considerably.

9.2.3 Network Costs Paid by Content and Service Providers but Free to End Users

States look to electronic systems to reduce their costs. They are under pressure to provide universal connectivity to match the other services such as water, gas, electricity and roads. In general users believe that these services are free to use. They overlook the costs they pay via their taxes. The networks are provided by commercial operators who must deliver a return to their shareholders. The challenge is to reduce the cost of the infrastructure to a point where services may be delivered to all member of the community. However, there could be an argument that people who choose to live in areas of low density population may be required to pay higher fees than those who live in dense urban areas.

It would be helpful if the various technologies harmonized standards to encourage reuses of components and thereby reduce the network costs. It would also be helpful for regulation to encourage infrastructure sharing. A prime example is the provision of 3G mobile services. Available spectrum would indicate that a single national wireless network makes most sense. But legislation required that each operator should provide their own access and trunk networks. Some progress towards sharing has been made with multiple operators on single masts. Greater efficiencies could be made if spectrum and access hardware was also harmonized.

9.2.4 Optical Network Switching for Hybrid Traffic

Efficient control plane architectures and routing algorithms are a key issue for building hybrid networks that integrate optical equipments and multi-technology wireless meshes. This scenario is particularly critical in the metro/access segment that can be characterized by different topologies of the optical domain, such as the tree, the ring, and the partial or full mesh. The topology layout often depends on the switching/transmission paradigm (e.g. PON or active optical switching) and the type of the switching nodes (e.g. a control station, a base station or an intermediate node in the fibre backbone). These optical switching elements should provide various functionalities to cope with the hybrid wired/wireless networking, such as advanced traffic mapping, services delivery, and dynamic traffic allocation, in order to support the demanding user driven applications in mobility scenarios covering a large set of wireless technologies, such as WiMAX, LTE, Wi-Fi, characterized by different QoS metrics and radio resource allocation mechanisms.

The IEFT GMPLS is one of the most promising control plane architectures to be evolved in support of the reservations and routing procedures in hybrid networks. GMPLS is natively designed to provide automatic provisioning of end-to-end connections with traffic engineering, traffic survivability (i.e. protections, restorations), automatic resource discovery and management. The core GMPLS specifications are fully agnostic of specific deployment models and transport environments: they are built upon the MPLS procedures and broaden the applicability of those mechanisms beyond the single data plane envisioned by the original MPLS specifications. However, due to the multiplicity of underlying Transport Plane technologies, some specific procedures and protocol extensions have just been defined in GMPLS to control transport networks as diverse as SDH/SONET, DWDM-based OTNs, OTNs with G.709 encapsulation, and Ethernet. This process of enhancement of the GMPLS protocols foundations is still active in IETF, because it needs to cope with new emerging transport technologies, such as the Carrier-grade Ethernet (i.e. PBB-TE) and the dynamically reconfigurable optical devices (ROADMs).

The natively generalized control approach enabled by GMPLS on the underlying Transport Plane allows a simplified handling of multiple switching technologies under a single Control Plane instance, like in the case of hybrid networks. This scenario is often referred to as Multi Region/Layer Networks (MRN/MLN), and it allows overcoming the traditional approach of overlaying specialized control instances, which is more and more inefficient. IETF CCAMP and MPLS WGs produced several solutions to handle the multiple switching technology issue in (G) MPLS. Among these, it is worth mentioning the LSP nesting [RFC 4206, RFC 5212] and the LSP stitching [RFC 5150]. With LSP nesting, multiple low-granularity LSPs can traverse a higher granularity H-LSP, which represents a Forwarding Adjacency in the Transport Plane. The H-LSP could be set up in a switching region and subsequently exported/used by other LSPs as a single hop. On the contrary, in LSP stitching a single end-to-end LSP is built by stitching a set of "LSP segments" (S-LSP) with the same switching granularity. The S-LSP could provide a solution for the control of multiple domains of bandwidth granularities under the same switching capability.

An enhanced GMPLS Control Plane should be designed to support the high capacity and multi-granular switching in hybrid wired/wireless networks adopting DWDM or VHDWDM sub-systems as transport technology for the optical segment. These research tracks could produce innovations in terms of dynamic management of optical resources based on several criteria, such as service availability, user requirements, and traffic type. The main differentiating factor with respect to the GMPLS state of the art will be the nature and dynamics of the triggers for the Control Plane, which will mainly derive from the multi-technology wireless network. Therefore, new bandwidth specifications and possibly new tunnelling services may arise from these activities on Control Plane.

9.2.5 Design of the RoF Subsystems and Components

As the number of radio services becomes greater, and as their signal bandwidth and carrier frequency increases, there is a need to define the performance of the radio over fibre link which carries the signal. There is a range of techniques to do this, ranging from the simple design based on link gain (but ignoring noise and distortion) to sophisticated time domain system models based on physical model of individual devices. The former approach has the advantage of simplicity but does not give any insight into the ultimate limit of the RoF system. The latter approach is much more accurate but requires large amounts of computing resource and long computation time, making this approach an ungainly one when carrying out link optimization. A useful compromise, which has many attractions in terms of flexibility and speed of computation, is the link budget approach. Here components are parameterized in terms of their RF gain, noise and distortion, thus enabling simple, but still accurate, spreadsheet based models. The models can be used to identify the critical components in a link and thus the performance that they require to improve link performance. It is crucial to realize that the design of RoF links should address in many cases the hybrid fibre-wireless channel. Proper link budget design over the hybrid wireless (indoor) - wired (fibre) channel will enable overcoming the inherent tremendous wireless propagation loss by using wired segments

The choice of sub-systems for any given RoF link and the service(s) that it needs to carry depends on many variables. For instance optimization in terms of performance is likely to require very high performance (and therefore expensive) components and so there will be many trade offs (of which cost-performance is only one). Ongoing trends are (i) cost reduction – as telecom lasers become cheaper as a class (it is now possible to buy a 10 Gbs laser in bulk for <$1 compared to $1k five years ago), direct modulation analogue lasers are also reducing in price, (ii) higher bandwidths and carrier frequencies, (iii) higher power generation from source lasers and power handling from photodiodes, thus improving link gain and (iv) increased co-use of electronics and optics to improve overall link performance.

9.2.6 Implementation of Radio over Fibre Units

Most current RoF links that are available commercially have relatively limited frequency ranges. Firstly most commercial systems are narrowband and only carry a single (or at most a low numbers) of radio services. Consequently if a system is to carry a multiplicity of services, it will need multiple parallel RoF links. There should be a broadband solution which is attractive for providing a single infrastructure able to support multiple services. Secondly most services that are carried have relatively low carrier frequencies, with the majority of commercial services having a carrier at a frequency < 3GHz. Clearly as required data capacity rises, inevitably so must carrier frequencies.

There is consequently a great deal of room for development of components and systems that (a) operate at higher carrier frequencies (with all the issues that causes in terms of fibre dispersion, component cost etc), but perhaps more importantly in developing broadband networks able to support the multiplicity of services that are now required, mostly for commercial / enterprise environments, but increasingly even in the home. Whilst broadband optical transmitters and receivers are available, multi-octave RF components are not, at least at the commodity price points that are necessary.

9.2.7 Digital Distribution

Currently most traffic which eventually ends up as a radio signal is carried digitally over an operator owned or public telecoms network and it is only at the base station or access point that the data is modulated onto a radio carrier. RoF systems usually take the analogue signal, either directly from the base station or via a repeater, and then transport it as transparently as possible to a remote antenna. The advantage is that distributed antenna systems can increase coverage and capacity without requiring a base station for each antenna, particularly important for in-building applications. The downside is that the RoF link inevitably adds noise and distortion to the analogue signal, thus limiting the dynamic range (and hence radio range) of the overall link.

As the performance of analogue to digital convertors (ADCs) and digital to analogue convertors (DACs) improves and their costs drop over time, it is now becoming possible to digitize the analogue signal for transmission over a digital link, followed by reconstruction of the original analogue signal at the receiver unit. Once the signal is in digital form, it can be transported and distributed without any loss of quality or information, unlike the analogue RoF signal, which is a key advantage.

This approach requires a high number of digitization bits (14 being the minimum for a usable, dynamic range with 16 or even 18 being preferable) though DACs/ADCs are now on the market which can achieve this resolution with bandwidths compatible with radio services. One issue is that the digitization of a relatively narrow radio bandwidth (e.g. 50MHz to enable WCDMA services to be digitized), would require 50 x 2 (for Nyquist sampling) x 16 (for number of digitization bits) = 1.6 Gbs digital transmission. However, this sort of data rate is now not expensive with Ethernet and the Fibre channel standard driving down the costs of optical data communications networks well below the costs of a narrowband RoF link.

Whilst this field is in its infancy, various feasibility papers have appeared in the literature and a growing number of groups are beginning to study this field. Important areas to study are (i) digital RoF system specification, (ii) trade-off between ADC/DAC resolution and system performance, (iii) transport protocols, including the transport of the necessary timing information, (iv) reconstruction of the analogue signal at the remote unit.

9.3 Meshing Fibre with Wireless:

Although an integrated wired-wireless approach can resolve most of the issues related to provision of high bandwidth to the access domain, there are some issues which need to be investigated and suitable algorithms and solutions need to be devised to eliminate or mitigate these issues.

9.3.1 Routing in a Heterogeneous Environment

In an environment with different available wireless Air Interfaces (AIs) and as well as wired interfaces, efficient routing becomes an important as well as a non-trivial issue. The operating range and attributes of available wireless AIs and the requirements of a particular flow for which the path need to be established are important factors which should be taken into account to discover an end-to-end path which is stable, robust and can satisfy the QoS of the flow between end devices. Similarly, depending on the type of the end devices, the feasibility of using a high bandwidth wired route in the middle to the destination wireless network also needs to be investigated.

9.3.2 Mobility Management

With the induction of RoF access points as well as high bandwidth optical switches in a wired-wireless network, the handling of flows from mobile devices and the respective mobility management becomes an important issue. The appropriate vertical and horizontal handover strategies and the effect of handover delays need to be taken into account while forming a path between end devices for a flow which has delay constraints. Furthermore, if the path consists of RoF access points, the processing delays also need to be taken into account while switching from wireless to wired domain and vice versa.

9.3.3 Resource Allocation Strategies

In a dynamic heterogeneous environment with a high demand imposed by user devices in congested urban areas, the efficient allocation of spectrum resources becomes mandatory. Appropriate resource allocation policies need to be defined which can allocate a fraction of spectrum based on the expected density of users that are going to use a particular AI at a particular time and hence utilize the part of the spectrum which deals with that AI. A history of previous allocations can be used and efficient spectrum usage estimation techniques need to be developed to aid the resource allocation algorithms.

9.3.4 Service Aware Network Connection

The main problem for the wireless and fibre networks would be to ensure minimum data rates for each service for the end to end connection. In order to optimize the data rates on the wireless links and on the wired links, a service aware Quality of Service could be used. Multi Services Level Agreements (SLA) has to be negotiated in order to guarantee QoS for the different applications (voice, video, data) while simultaneously optimizing the network resources.

9.3.5 Bridging Wireless Mesh and Fibre Protocols

Today most of the interconnections between wireless and wired equipments are performed at IP level. This allows simple architectures but implies processing delays between the lower layers in the protocol stack and the higher layers. This delay is not compatible with the Gigabit data rates. Furthermore, this solution cannot guarantee a global QoS from end to end as it does not take advantage from the medium access control mechanisms implemented on the wireless and wired networks. So, new approaches have to be taken into account especially at the lower level protocol stack in order to guarantee end to end QoS and smooth transitions between wireless and wired networks. One possibility would be to define at the MAC level the interoperability and cross layering between both wireless and wired networks.

As an example, using two radios for each radio relay on a wireless mesh network would allow with a TDMA protocol to provide end to end guaranteed data rates using appropriate time slots on each radio (with a TDMA protocol).

As described previously, the interoperability and cross layering between wireless and wired networks is of importance in order to provide efficient bridging between wireless mesh networks and fibre networks.

There is a big interest to combine wireless mesh networks and optical fibre. One application example would be the following one allowing Fibre to the Air transmissions for the last mile and optical fibre networks for the core network. Figure 9.4 shows an application example using wireless mesh networks and optical fibres. The wireless networks can be based on millimetres waveforms or on UWB waveforms or both combined. In this example, the services which are delivered are composed of broadcast of a large number of digital TV channels (HD included), collection of video streams for video-surveillance in addition to a large capacity for usual VoIP and data transmission.

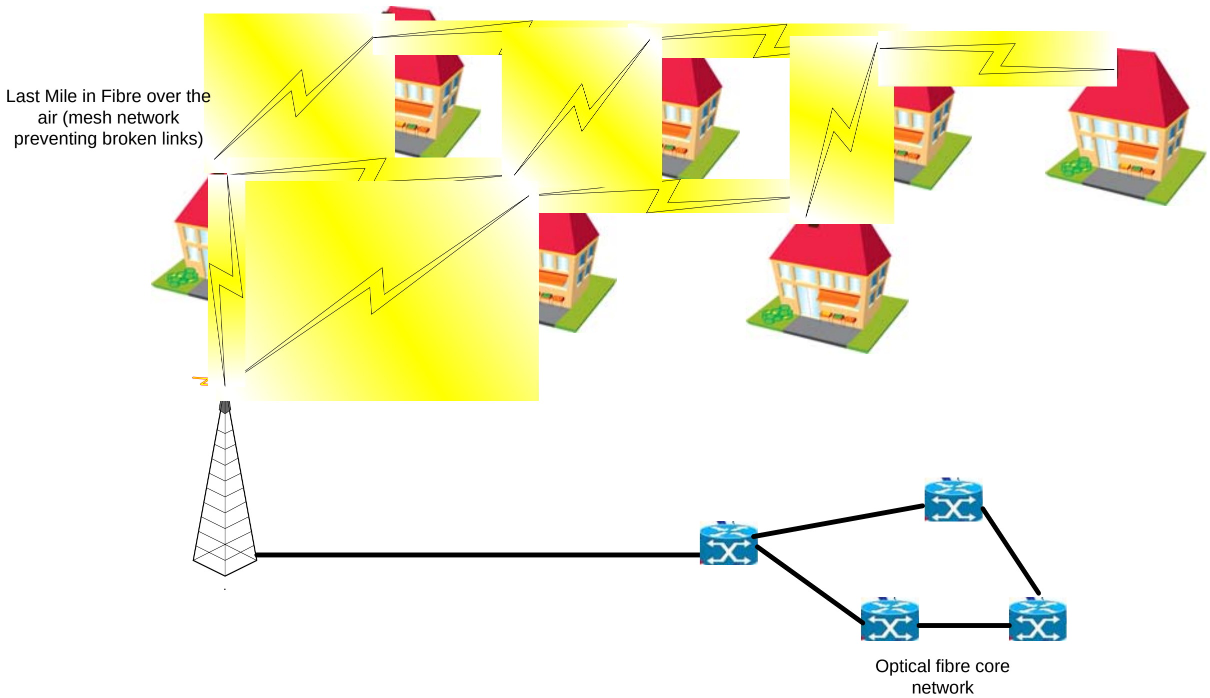


Figure 9.4 Meshing Fibre with wireless

9.3.6 Optical-Wireless Component Integration

Over the last thirty years the microelectronics industry has undergone a revolutionary transformation due to integrations. By combining discrete electronic components onto a single monolithic platform, microelectronic components have realized a dramatic increase in device performance while also providing a substantial reduction in cost. Currently the field of optoelectronics is undergoing the same sort of revolution as Optical Electronic Integrated Circuits (OEIC's) are a hot topic at the moment. The idea is to capitalize on the same cost and performance benefits that the microelectronics industry has reaped over the past few decades by combining electronic and optical components onto a single substrate.

It is believed that this integration could be taken one step further. By combining wireless, optical and electrical components monolithically, cost and performance improvements could also be had for RoF devices. Furthermore these devices could be developed so to address the deleterious problems such as latency due to data conversions between the various media types (i.e. wireless to electrical to optical). If some of the intermediate conversion steps could be eliminated through the use of direct media conversion components, issues such as latency, power consumption and cost could all be minimized thereby making RoF networks more efficient and cost effective.

9.4 Network Architecture

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 an RoF network architecture is reliability. This aspect is especially true as personal health monitoring technologies become mainstream. If the fibre backbone were to be severed in an 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.

9.4.1 Coexistence of Digital and Analogue in Hybrid Fibre Wireless Systems

Passive optical Networks (PON) technologies such as EPON, GPON and APON realize sophisticated and economical optical access network for providing broadband access and also provide different multiple services such as CATV, telephony, as well as high speed Internet access. There will be growing demand for broadband wireless access and mobile communications. In particular, the hybrid broadband optical system and optical feeder architecture for wire line and wireless access nodes are promising. These hybrid optical platforms can simultaneously transmit digital baseband (for example 1Gbs or 10 Gbs Ethernet) and Radio Frequency (RF) signals. Therefore the issue of the coexistence of digital and analog transmission becomes very important. The technical challenges of implementing next generation PON technologies include new architectures to support migration path from already deployed 1 Gbs systems towards 10 Gbs along with analogue video overlay on the downstream. In these context requirements for coexistence between 1 Gbs-10 Gbs and analogue signals is mandatory to assure a smooth migration path. For example the wavelength allocation plan for 10 Gbs EPON must take into account the existence of 1Gbs equipment on the same PON plant. The downstream channels for two data rates will be WDM (Wavelength Division Multiplexing) multiplexed. The upstream channel coexistence most likely be resolved via Time Division Multiplexing (TDM).

Three wavelength channels are usually addressed to support digital upstream/downstream and an analogue video overlay on the downstream. Requirements place on the network such as optical loss budget, transmission distance, split ratio etc. Impose challenging problems to address as: potential conflict in wavelength allocation, non-linear crosstalk between high power PON and analogue video signals and challenging power budget requirements along with challenging implementation of a burst receiver design to support both legacy 1Gbs and 10Gbs.

9.5 Green Radio over Fibre

By "Green Radio" we mean technologies that can be considered safe in the sense that allow for the lowest possible consumption and radio operating power levels. Typical use cases for these technologies are "safe connected home" and "future hospital". In the first scenario a full range of short-range in-house emerging wireless standards are expected to coexist as 802.11n, WHDI along with new high data rate streaming audio& video, wireless sensor and remote control networks. Recently, femto-cell has emerged to drastically improve coverage and capacity of mobile communications indoor by communicating with the cellular network over broadband wired connection. With "always on" home networks people are possibly exposed to undesirable electro-magnetic (EM) radiation.

A similar consideration holds for hospital environments where weak vital signal functions have to be monitored and interchanged continuously over the radio channel in the presence of sick and therefore vulnerable people. At present some 8 – 10 functions per patient are monitored. These numbers are expected to grow rapidly in the coming years. Advanced in-body wireless systems (as Pillcam video capsule, see www.givenimaging.com) became available and provides patient-friendly with superior diagnostic efficiency alternative to other imaging technology.

In essence the use of "green radio" with very low EM radiation is of utmost importance.

That means reducing the EM radiation for indoor environment by two order of magnitudes to levels much below 1mW.

Reduction of the emitted radio power in-doors to minimum levels comparable to the levels of the parasitic emissions by using hybrid fibre – wireless technologies is a promising approach to realize green radio and implies series of challenges discussed below.

- Topologies and network concepts to support the delivery of Gbs radio signals over hybrid fibre/wireless channels
- Support the functionalities of multi-radio
- Multi standard ad-hoc networking and interworking of devices of different standards
- Versatile interconnection to the outer public access network

9.6 Optical Packet Switching

Optical switching removes the need of converting optical signals to the electronic domain in the intermediate nodes. This fact entails key advantages: The bottlenecks caused by the limited speed of electronics are avoided, costs and power consumption associated with the optoelectronic conversions are minimized, and latency is reduced due to the unreachable speed of photonics.

Three optical switching paradigms have been proposed: optical circuit switching (OCS), optical burst switching (OBS), and optical packet switching (OPS). From all of them OPS presents the highest degree of flexibility and bandwidth use, implying QoS capabilities and costs savings respectively. This technique relies on switching each packet independently in the optical domain, which is the optical counterpart of current electronic packet networks. The challenges hindering the implementation of optical packet networks are, however, significant.

Three strategic areas of research are identified to advance in OPS feasibility:

9.6.1 Optical Memories:

Photonic buffering mechanisms for storing optical packets, as electronic memories store optical packets in current routers. Currently, the only commercial solution has been employing coils of fibre for this purpose but this is not a desirable technique in terms of integration, access speed, or tenability.

9.6.2 Large, Ultra-Fast Optical Switching Fabrics:

Switching elements must have response times below 1ns for avoiding latency inefficiencies. The most extended and mature technology for optical switching is MEMS (Micro-Electro Mechanical Mirror Systems) that features switching times on the order of several microseconds. Other switching mechanisms, such as employing electro-optic materials or SOAs (Semiconductor Optical Amplifiers), present the adequate ns speeds. However, significant research must be performed in order to solve the issues hindering their scalability, such as losses, crosstalk, etc.

9.6.3 Control Mechanisms:

The implementation of a light, flexible and efficient control plane is required. A GMPLS (Generalized Multiprotocol Label Switching) control plane seems to be promising for the implementation of OPS. An important field of research is open regarding labeling coding/decoding and swapping techniques, routing algorithms for optical packet networks, and optical QoS matters.

9.7 FTTH and its Application at Home

To increase the network capacity for the in-home environment, RoF technology has the potential to support broadband access for personal area networks (PANs) and short range communications in Femto and picocell networks. Such a broadband infrastructure needs to be very cheap, both in itself but also crucially to install, and so large core diameter plastic optical fibre (POF) has been indentified to offer the advantages of "do-it-by-yourself" installation, easy maintenance and smaller bending radius (5 mm) over conventional silica single-mode or multimode fibres. Meanwhile, the recent commercialization of low power consumption and broadband transceivers at visible wavelengths also add to the potential for the use of POF RoF networks in the home.

The main issue is that the POF has a very low intrinsic bandwidth and so multi-carrier technologies are necessary to increase the data rate it can carry to useful values. For the POF PANs described above, wireless-USB has become a very attractive solution for short range high capacity in-building and in-home links, providing as high as 480 Mbs data rate for personal communication devices. The ECMA-368 alliance for physical and media-access-control layer, wireless-USB standard utilizes multi-band orthogonal frequency division multiplexing (MB-OFDM) to combat with multi-path fading effect in air interfaces, while providing high capacity at the same time. The required bandwidth for each sub-band of MB-OFDM UWB signal is 528 MHz using 122 sub-carriers. The 6 MB-OFDM sub-bands are centred at frequencies from 3.96 to 10.3 GHz.

As data rates delivered to the home rise beyond the Gbs rate, as is already happening in the far-east, it will be necessary to develop multi-tone sub-carrier multiplexing technologies to increase the UWB rates currently available. Cost reduction of the transceiver units will also be necessary in order to commoditize this.

9.8.1 Radio-over-POF for in-Home Networks

Fibre to the home will not be the end game. In order to enable true broadband service delivery up to the end users, fibre networks need to be extended into the user's home itself. Moreover, in order to improve the manageability and upgrading we foresee that the present diversity in in-building network infrastructures (twisted pair, coaxial, CAT5E) needs to be replaced by a single network capable of delivering all types of services. Due to its huge bandwidth, EMI immunity and signal format transparency, optical fibre is the preferred medium. Future research towards in-building networks should focus on finding optical fibre network technologies, which should be easy to install and to maintain. In particular, plastic optical fibre (POF) with large core and large numerical aperture is a very promising type of fibre for easy 'do-it-yourself' installation by unskilled (residential) users. Several flavours of POF can be found including single fibre step- and graded index and multi-fibre variants. The recent multi-core single POF is an interesting candidate, as it features reduced dispersion and increased tolerance to bending losses. These fibre types do have considerable modal dispersion and hence a quite limited bandwidth-distance product. Recent researches on POF is directed in one hand to achieve transmission capacities of multi-gigabit per second using advanced modulation formats and in the other hand to deliver transparently wireless signals over 1-mm core diameter 50-m long fibre. For wireless delivery of services over POF, the bandwidth limitation could be overcome by processing the radio signals at baseband in the optical domain and (down/up)converting them in the antenna sites. Other techniques such pre- and post equalizations could be employed to further increase the bandwidth. Since low-cost transceivers should be used to generate and receive the visible light signals, research on components should be directed to achieve large linear operations and high optical signal to noise ratio. Another aspect worth to consider is to consolidate all microwave radio signal generation and modulation at a central site. The challenge is to carry and route the microwave signals over the highly dispersive and lossy POF. Remote generation of microwave carriers for >60 GHz range could be a major step forward in reducing network costs in terms of installation and maintenance because maintenance and upgrading can be done from one central place. Beam shaping and steering by means of smart antennas and MIMO techniques in single- and multi-core POFs could lead to higher capacity and more robust radio-over-POF networks.

9.9 Recommendations

Based upon the research priorities discussed above, the following recommendations are put forth in order to address the identified priorities:

R1). Investigate methods to integrate wireless, optical and electronic components. This effort should result in lower cost, lower power consumption optical/wireless transceivers with significantly improved characteristics as compared to transceivers comprising discrete components.

R2). Investigate methods to allow for direct conversion of data signals from one media (i.e. wireless) to another (i.e. optical) without requiring intermediate conversion steps (i.e. electrical). This effort should minimize latency times and power as well as power consumption by the network.

R3). Investigate the tradeoffs between the financial and technical aspects of RoF networks. Some of these tradeoffs would be capital and operational expenses as functions of bandwidth, reach, mobility and repeatability. This effort would provide service providers a better understanding of the costs involved in rolling out and maintaining an RoF network as compared to using either all-optical or all-wireless networks.

R4). Reduce the operational and capital costs of ultra fast broadband using both wired and wireless technology.

10. Mediation Bus for Ubiquitous Services

10.1 Rationale

The mediation bus could be defined as a distributed environment that achieves an optimized operation of Future Internet (FI) by performing mediation operations among the service and network/transport layer entities that are plugged into it enabling both service and scenario-oriented end-user treatment by instructing the involved entities to execute the appropriate commands in an efficient and network agnostic way.

The mediation bus operations concern:

- Translation of policies (rules, constraints and requirements of the optimized operation of FI) and context view (e.g., spectrum, energy status, user profiling, etc.) to executable transport workflows (functionalities) optimizing the usage of both computing and network resources.
- Wrapping functionalities for creation (open APIs) and delivery (adaptation, orchestration and execution enablers) for existing and future Internet services.
- Examples of wrapping functionalities constitute generic services enablers/facilitators for searching, negotiating, reasoning, subscribing, publishing.
- Transition path from current application and transport (TCP/IP) layers deployments to the Future Internet one.
- Vertical control and management functionalities for bus optimum operation (e.g., for green aware performance) and self-organization.

The first key research priority is the identification of the location of the mediation bus in the context of the evolving Future Internet approach. Targeting at the convergence of network and services, the apparent place of mediation bus is between application and transport layer as as in Figure 10-1. A first approach could be to keep unaffected the application layer of the current TCP/IP protocol stack, while to pass some of the existing transport layer functionalities at the mediation bus in a more advanced context.

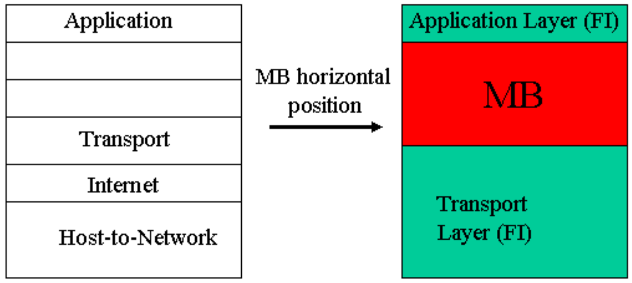


Figure 10-1. Mediation bus between the application and transport layers

The policies actually will constitute the service APIs for the communication of the mediation bus with the application layer, while the workflows will formulate network APIs for the communication of the mediation bus with the transport layer. The combination of this with the necessity for future communication systems to be self-organized entities, clearly explains why the mediation bus is not simply a layer but a vertical environment that handles also control and management operations. The backward compatibility with current TCP/IP protocol stack could be achieved by putting again the mediation bus between the existing application and transport layer. Figure 10-2 illustrates these two layers.

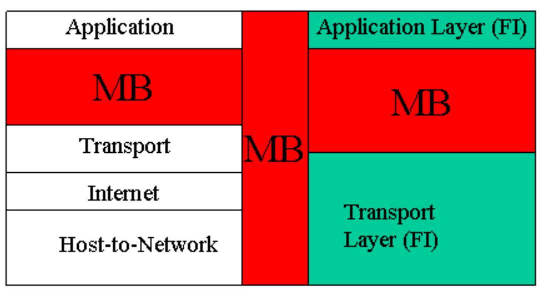


Figure 10-2. Mediation bus as both vertical and horizontal layer between the application and transport layers.

Furthermore, as the adaptation of the mediation bus to both application and transport layers is not going to be something static but it is going to be heavily affected by the service, the end user’s context and the underlying network capabilities, the mediation bus could be thinned in some cases.

The launching of the mediation bus is expected to extend the "Walled Garden" network-service architectures including IMS making a full range of valuable network services accessible in an open and network agnostic way to all current and future applications/services.

10.2 Research Priorities

The presence of mediation bus draws a number of research priorities for the new generation communication systems. The subsequent subsections outline those research priorities, which actually derived from the features of the mediation bus.

10.2.1 Adaptation and context awareness

The extremely dynamic nature typical of ubiquitous computing environments, the very heterogeneous and differentiated capabilities of user access terminals, the need of tailoring service provisioning and networking to user location, attributes, and characteristics, are only few examples of the challenging issues still waiting for solutions in the design of ubiquitous services.

Ubiquitous Computing scenarios can hardly be supported by traditional service management approaches, because new requirements introduce challenges that ask for new guidelines and solution strategies. In fact, only new middleware level solutions can autonomously and dynamically perform ubiquitous service management operations tailored to the current context. In a principle perspective, there is a variety of literature in the ubiquitous computing field that define context, but we intend context as the collection of information that can be used to characterise the situation of an entity, where an entity can be a person, a place, or a physical or computational object. According to a support point of view, it is particularly important to make context information available to all interested layers, up to the higher application level, for eventual tailoring and adaptation.

Along this line, the Mediation BUS should provide a rich set of tools to represent and gather context information, to process and aggregate it according to the application requirements and to propagate its visibility to all interested entities. The Mediation BUS should rely on context information for the autonomous configuration and its dynamic reconfiguration of services. As a consequence, the Mediation BUS should also support the description and the enforcing of service management policies, e.g., reconfiguration policies, access control policies, together with any other requested one. In addition, context information visibility should be propagated up to the application level to adapt applications accordingly.

Challenges to be addressed are:

- Structuring and modelling of context information/knowledge and modelling of knowledge (this encompasses community driven ontology management as knowledge modelling should result from a consensus).
- Global context/knowledge frameworks integrating sensor and actuator networks incl. body area networks, smart and virtual objects (dealing with the Internet of Things)
- Context reasoning.
- Human behaviours and subsequent patterns: this encompasses modelling of end-users through observation, learning and generation of behaviour patterns or more global elaboration around human activities, how they relate the one another and how to make use of them for the sake of content/service delivery.
- Frameworks for context-aware multi-modal content adaptation/delivery and related supporting multi-media standards.
- Transcoding techniques (cross modality content delivery).
- Adaptation via service composition: Semantically enhanced and context dependent service composition, e.g. depending on content format preferences and on the quality requirements/resources availability (based on business models for traffic and user priority classes). Also exploitation of workflow-related technologies for automating composition decisions and management.
- Challenges coming from dynamicity: for instance how to deal with client mobility and change of locally available middleware adapters? Or how to deal with nomadic mobility of users dynamically changing their access devices?

And the more importantly:

- Investigation of MB key context concept as a set of dynamic APIs referring to a pool of underlying network services that could be exploited in an open and network agnostic way by MB towards the creation and the delivery of future Internet services.

10.2.2 Both inbound (regeneration) and outbound policies

The Mediation Bus will incorporate Knowledge-enhanced and Policy-based Management features; specifically, according to the perspectives under consideration about outbound and inbound policies, the Mediation Bus in the outbound case can be considered as cooperating with external entities for:

- Policy integration coming from various stakeholders.
- Knowledge building based on decision making and policy integration experience.
- Ontology management for exploiting description logics advances and reasoning capabilities for facilitating policy integration.

Alike, in the inbound alternative, the Mediation Bus will embed advances policy management and knowledge management features. Such features will include:

- Policy Generation according to the involved entities goals, and preferences by conceptualizing the underlying network infrastructure.
- Policy Enhancement regarding additional information coming from outside entities and rapid changing environment.
- Policy Evaluation according to operational feedback regarding the provided QoS and efficient resource management.
- Knowledge building according to decision-making, high and multi-directional personalized policy derivation. Knowledge Management key aspects are also incorporated in every policy related logical function.
- Harmonized Ontology management for efficient conceptualization of the underlying and interacting infrastructure.

Quite a few challenges are resulting from the above listing, regarding the policy integration, the personalized policy derivation and communication, the policy evaluation and the conceptualization of the technical ecosystem in the various service provisioning scenarios. All the mentioned advances features must be provided in an efficient/optimized way. This implies the need for a complete investigation of the various mechanisms and approaches that have been or need to be developed and/or extended to address the abovementioned challenges.

10.2.3 Workflows

In order to cope with efficiency in service provision in future internet infrastructures, the heterogeneity of execution triggers and actions in such infrastructures should be alleviated by the Mediation Bus. In this direction, the related operations that can be undertaken by the Mediation Bus will focus on the identification of computational, power, spectrum and other resources available for service provision and execution purposes, along with the correlation of alternative resource usage cases for the accommodation of optimal service provision over such heterogeneous networks and devices. The selection operation of the most efficient combination of resources that can match the optimality criteria for both the service provision requirements and the resource usage alternatives will be an important feature of the Mediation Bus functionality.

From the technological perspective, the corresponding resources that are available through the various infrastructures, networks and devices should be identifiable under a common framework, which will enable the association of such resources with specific service provision requirements and alternative scenarios. It is thus quite important to enable the filtering and correlation between resources characteristics and service provision potentials in order to match these (currently disjoint) service execution perspectives under a self-organised series of actions meeting targeted efficiency criteria. In this context the service provision related execution actions become part of an abstracted workflow that can be mediated to heterogeneous systems and can be translated in system specific actions. The Mediation Bus can undertake this mediation operation while the system specific actions are hidden from the individual application and service developers, and deployers.

It is obvious that this yields major research challenges that correspond to the identification and abstraction of resources characteristics, the translation of efficiency criteria to optimal selection of deployment and service provision actions in heterogeneous systems and networks, as well as the evaluation and triggering of alternative actions in future internet systems in order to meet the efficiency criteria.

The Mediation Bus will be a major enabler for the identification of alternative available resources (e.g., spectrum, power, computational resources) for the service provision and for the efficient usage of such resources. To this end, some important research priorities can be identified:

- Identification of available alternative and heterogeneous resources under a common framework , targeting optimal service provision.
- Efficient spectrum and resources usage for service provision.

It is thus apparent that it becomes quite challenging to investigate the abstraction technologies for the resources identification, as well as the triggering and translation mechanisms that can be applied by a common mediation framework towards the alternative resources and execution potentials in order to achieve efficient and optimal service provision.

10.2.4 Deployment model

An important aspect of the Mediation Bus concerns its deployment, more specifically the entity that undertakes the deployment, control and maintenance. Due to its nature, the Mediation Bus should be neutral; that is, it cannot be managed by a single entity. In fact, the Mediation Bus will constitute a policy decision and enforcement point for both inbound and outbound policies, as well as a broker for personal data that are collected and processed in the context of services' provision. Therefore, a fair number of organizations constituting consortia with high level of neutrality should be considered.

This raises a number of challenges regarding the deployment and the business model of the Mediation Bus. From an operational point of view, of particular interest are the issues of distributing the policies and the personal data for ensuring fair operation and privacy protection. On the other hand, availability and performance issues must be taken into account.

From a business perspective, the possible sustainable horizontal and vertical business models should be investigated, along with the motivation, perspectives and opportunities for participation in the collaborative business of the Mediation Bus operation. In this context, the potential participation of public Authorities, such as Data Protection Authorities, should be considered.

The emergence of the Mediation Bus creates several challenging issues regarding its deployment, management and operation that should be investigated:

- What kind of business models the Mediation Bus creates for the operating entities?
- How the desired level of the system's neutrality can be achieved and how the neutrality affects the business aspects?

- What is the optimal policies and data distribution model for operational integrity and fairness, as well as privacy protection and trustworthiness?
- What can be the potential role of public Authorities in the service chain**?**

10.2.5 Privacy/trust/security

The potential impact of Future Internet Services on users' privacy rights is regarded as being among their most evident negative effects. In fact, the Future Internet Services rely to a great extent to personal information collection and processing: personalization, context-awareness, convergence, federation of services constitute only a part of the emerging services' characteristics that motivate as well as facilitate the collection of personal data.

Privacy is becoming a salient issue not only for individuals or other entities that provide personal data, but also for organizations that constitute personal data consumers. From the service providers' point of view, the recognition of the importance of privacy protection is motivated by the business losses due to privacy violations and mishaps that support users' mistrust, as well as by the need for regulatory compliance, since the privacy domain is increasingly becoming a legislated area. Additionally, the emergence of Service Oriented Architectures (SOA) and federated services creates chains of trust and responsibility which complicate the enforcement of fair business practices with respect to personal data handling.

In that respect, the Service Mediation Bus will constitute a personal data avenue, facilitating the collection and circulation of personal data and –therefore– a critical component in the service provision chain from a privacy protection perspective. As a result, not only the Mediation Bus should be a privacy-aware component, but it should be additionally considered to constitute an enabler for the privacy-awareness of the considered services, that is, a "trust broker".

Mediating natively between users and service providers as well as between service providers in the context of federated services, the Service Mediation Bus can be considered for undertaking the enforcement of privacy-aware access control regarding the diffusion of personal data. In that respect, the appropriate policies should be integrated with the overall policy-based management framework of the bus, taking additionally into account the potential privacy preferences specified by the users. The enforcement of access control should be supported by comprehensive models describing the different types of services, personal data, preferences, regulations, actors' roles and any other information that could constitute "privacy context".

Additionally, the service Mediation Bus can cater for the execution of privacy-related operations, the origin of which can be twofold. On the one hand, there are certain behavioural norms specified by the European data protection legislation, such as the request for the explicit consent of a user before disclosing or processing personal information. On the other hand, the Mediation Bus can undertake the execution of certain processing tasks, such as the obfuscation of information, where applicable. Along the same line, the bus could further offer reusable service components for the execution of privacy-critical operations that could be exploited by the service creators and providers. Especially regarding the provision of ready-to-use components for boosting the privacy-awareness of next generation services, an interesting as well as critical issue would be the adaptation of services in terms of their composition models and real-time components discovery.

Being a distributed system and involving a number of different players, the Mediation Bus should establish the means for security and trust. The Bus should cater for making the circulation of information secure, regardless of the underlying –possibly heterogeneous– network and transport means, while it must be secure itself, in terms of integrity and reliability. On the other hand, in the context of its mediation functionalities, the Bus should provide for trustworthy services and applications in the dynamic environment that the Future Internet Services create. In fact, in order for the emerging models to succeed, both the users and the service creators/providers should have a feeling of trust regarding the peer entities, the services and components of which are using.

The Mediation Bus will constitute a critical system in the service provision chain in terms of privacy, security and trust. Not only the Bus should be aware of them, but in can also be their enabler. In that respect, the recommended research priorities include:

- Semantic conceptualization of privacy/trust/security practices, as well as underlying notions (e.g., personal data and their sensitivity), in order to enable the conceptual integration with the other semantic models of the Bus. In other words, incorporation of the "privacy context" to the description of the contextual situations.
- Investigation of the means for the enforcement of privacy-aware access control, as far as the personal data circulated by the Bus are concerned.
- Exploitation of modern software engineering paradigms (such as Aspect-Oriented Programming and Model-Driven Architectures) for the introduction of transparency and abstraction at the services' design phases, regarding privacy, trust and security.
- Specification of the means for authenticating and validating the trustworthiness of services in the new dynamic environments. This concerns not only the end users, but also the service creators/providers that make use of third-party service components.

- Specification of the security means for setting the Bus itself secure (in terms of integrity and availability), as well as for enabling secure data circulation. Therefore, the definition of abstractions regarding the mechanisms offered by the underlying protocols is necessary, for boosting the desired network-agnostic nature of the Bus.
- Integration of the reasoning procedures related to privacy, security, trust to the overall reasoning and policy-based management framework of the Bus. Consequently, a common language for policies specification should take into consideration the corresponding needs.

10.3.6 Common language for policies/federation

As the mediation bus is the mediation among different layers and network components, it needs a language to describe the components involved in the composition of the future internet services, as well as, a language for describing policies that will govern the system.

The flexibility required by the architecture should take into account context, business policies, a knowledge representation of the characteristics and relationships of the evolved entities, etc. For this purpose a common language for describing these policies and resources/components of the federation should be understandable by all system components.

There are many different policy specification languages and service description mechanisms in the literature, but there are still missing a common language that could be understandable among the heterogeneous components involved in the delivering of FI services.

Main research priorities in this point regards the study of available approaches on policy languages in the literature and appropriate NGN service description mechanisms (e.g. ontologies, semantics), in order to find the most suitable one to be used as a common language in the federation (also proposing extensions to the language if necessary).

10.3.7 Service life cycle

One of the major constraints in today's telecommunication services is the huge engineering effort that has to be spent both on development and marketing, in order to get a service running and deployed in the market. The MB offers carefree development, deployment, hosting and maintaining of services using smartly combined abstraction and virtualization methods.

By that the MB vision reduces the risk and complexity for service providers to bring new service into market as it takes care of the autonomic deployment on best fitting resources and necessary resource re-arrangement and allocation to adapt best to the current service need. (This is the Service Provider view, whereas the Resource Provider provides resources which are shared and used on demand based on fluxionary resource allocation driven by external conditions/sensors.)

All that without the need of installing, operating and maintaining the physical resources (cpu, ram, disk space, connectivity ...) or worrying about availability, redundancy or backups. The MB prevents on every layer that independent services may influence each other. The user-centricity of services is gaining momentum in the current opening up of telecom service ecosystems. Within this approach, services are created and managed by the end-users themselves, even if they are not technically skilled. Within a user-centric service lifecycle model, users would like to decide, depending on their own preferences, when, where and how their services must be active (for example, an SMS service sending messages of the results of the local football team should only be available every weekend from Friday afternoon to Sunday evening, or a personal friend finder will be activated based on the location context). Since activation in telecom platforms means the real allocation of resources, and therefore expenses to the platform providers, the deployment activities must be planned based on the initial schedule that the creator has decided for the service. On the other hand, at the end of the lifecycle the operator needs to be sure that all allocated resources are released and can be re-used for other services. Therefore withdrawal activities must be carried out after the service has been deactivated, whether the service is going to be activated again (following the user schedule) or if it is going to be definitely removed.

Service developers are disburdened from the detailed knowledge of the underlying network or the computing resources. They just design and characterize (indicating special requirements as link QoS behavior or maximum latency,...) their service components based on an abstract view. During service creation developers, we see here even end users, compose their own services by orchestrating a set of differently rich service components. At the end of this process a service description is generated and stored in a kind of global repository. A new service is created by composing service components (atomic or compound) whereby the service creator can concentrate on the functionalities of the new service (and not on all the implementation, realization and adaptive deployment details). With the MB the service deployment process is an autonomous platform process to make a service available in the global communications environment. As usually it includes physical installation, provisioning, registration, publication and activation. These tasks must be carried out in a given order. Whenever something fails, the steps already carried out must be undone. Deployment finishes when the service is up and running and ready to be subscribed to by end users. The service components may also include wildcard components where different realization of the same functionality exists (e.g. a transcoding service could be done in hardware or software, and the MB decides which will be used).

After service deployment a service is managed automatically without required action of the service developer/provider, i.e. the MB enables fully autonomous network wide operation. With growing number of customers or service load/requests a service is dynamically rescaled in a transparent way and remapped to better qualified resources. Resources may be re-arranged to always be best adapted to the current service situation and to ensure optimal usage of resources (e.g., resources are automatically re-arranged if required due to changed geographic customer concentration). In service maintenance the service execution status is permanently analyzed. This information will help to improve the service based on monitoring and usage statistics, to optimize the resource usage spent on that service and to identify errors and other runtime problems. A refinement procedure observes the occupied resources of a component during execution and performs a refinement of the component characterization. The objective is to improve the characterization from a first perspective view to a more and more application reflecting version.

If the service is going to be substituted or evolved, or will not be used for a while, it must be replaced in operation or stopped. Then, when it is no longer needed it must be cleared up from the platform. Service withdrawal consists of deactivation, withdraw the publication, deregistration, unprovisioning and physical uninstallation. As the services and their components are stored persistent in a kind of global repository, new concepts to manage service withdrawal have to be found. Version control and ageing concepts to avoid service component garbage have to be provided.

If required for service execution the MB can incorporate any type of new resources like sensors, cameras, or whole computing clusters. The integration of external sensors into a service can have influence on the location where the service is executed. Furthermore, external sensors may influence the resource allocation or service execution location.

10.3.8 Green/Energy aware

One of the biggest challenges facing the world is to reduce energy consumption and carbon emission while fostering economic development by research into disruptive technologies that decrease the telecom energy footprint in the face of rapid expansion. As far as the proposed Mediation Bus is considered the research priorities that need investigation in order to guarantee energy awareness include:

- Design energy-efficient network architectures.

- Design of power adaptive to the current requirements architectures.
- Energy efficient schemes for statistical multiplexing of computing and data storage.
- Transform from always-on to always-available.
- Create infrastructure for virtualization of services, applications and computing.
- Integrated approach universally handling the resources on all layers: transmission, access network technology, switching, routing, server, operating systems, etc.
- Designed for global and everywhere use, for every user and every application.
- Efficient in discovery and allocation of universal resources, end-to-end.
- Priority management and policing to assign guaranteed resources to rivalling parties.
- Assuring integrity and privacy of the data and processing.
- Inherent robustness and self management.
- Global resource sharing asks for new business models, we will only fly when resource providers have the right incentives and users get their fair share, 100% fulfilling their current demand.
- How the bus utilizes the physical/energy resources in order to obtain a green behavior for the entire infrastructure?
- Human affection through radiation pollution.
- Design of simple and fast "wake up" and usage adaptive modes of network.

10.3.9 Vertical management and control

Defining the vertical management and control notably asks for a holistic architecture with optimal support of all types of services - and that as an open and scalable, but still lightweight approach. Target is an access-independent Internet-based resource management that provides the opportunity to unify control and management of both wireless and wireline access next-generation networks. This new concept, which can be applied in flat and open architectures, and even in cellular environments, implies key challenges such as scalability of the architecture, performance of mobile routing algorithms, and the stability of link metrics.

New virtualization concepts for the transport layer of fixed and wireless networks are seen today as fundamental for creating the new Internet. However, new concepts beyond the virtualization approaches known today are required: not only the network resource as such, but also the transport capabilities, mainly bandwidth and quality parameters have to be controlled. In particular for wireless networks the dynamic behavior of these parameters has to be handled. Learning from data records, considering location and other simulative patterns, the MB is even able to act even in a proactive manner.

The following questions have to be answered:

- Which resources and parameters have to taken into consideration.
- What is the architectural concept providing the best support of the required information flows with maximum abstraction between transport and MB realm.
- How is it possible to derive strategies for the configuration of services and functions from the transport characteristics, and that based on the actual demand.
- Besides the simple transport resources, there are further potential network resources to be considered: e.g., packet forwarding enhanced with multi-/any-casting functions or content-related application support functions like caching or new semantic resp. cognitive concepts at the transport layer.
- Dynamic interaction between (self-organized) local control within the transport realm and global control by the MB has to be considered.
- Privacy and priority management to assign guaranteed resources to third parties and assuring the privacy of the data and processing.

An often disregarded topic is the use and interplay between offering of different network qualities and access/usage control. Generic rule: no QoS without policing/metering! However, the flop of signalled ATM shows that a simple application interface is a key. Presumably more successful should be implicit fairness models and simple tariffs, respective charging models preventing from misusage and ensuring network wide compensation of costs. Related measures should be considered as an integrated approach from the beginning.

11. Future Internet, A parallel Internet

11.1 Rationale

The current worldwide research activities on the Future Internet (FI) design are mainly justified by the anticipation of exponential increase in usage, deployment of the new broadband applications, and prevalence of mobile wireless communications ubiquity and Internet of Things (IoT). Recent market analysis report total number of mobile users exceeding the threshold of 5 billion users worldwide and the number is on the increase. On the other hand, IoT reports are forecasting more than 15 billion devices by the year 2015.

Currently, there are two distinct approaches towards the FI, namely, evolutionary and clean-slate approaches.

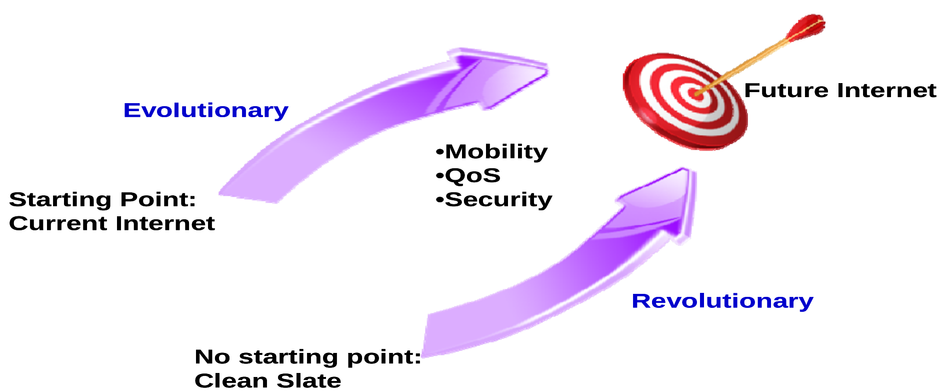


Figure 11.1 Current worldwide research approaches to Future Internet

The evolutionary approach also known as Post-IP, starts from the current Internet protocols and architectures, and attempts to smoothly incorporate mobility, security, and Quality of Service (QoS) in the current internet. The clean-slate approaches, on the other hand, aim to achieve the same objectives (mobility, security and QoS) without being constrained by the current Internet architecture and/or even without the IP networking paradigm. As a matter of fact, there is no starting point in the clean-slate approach, and it follows an additional objective of designing new, flexible and evolvable network architectures. There are certain advantages and disadvantages associated with each of these two approaches.

The evolutionary approach will always have the inherent limitation of the basic concepts that the current Internet was initially based upon: the end-to-end paradigm, state-less networking, and IP networking as an Information network. However, this is not a new approach, as it started about 20 years ago when internet started to be used commercially with addition of patches such as; IPSec, mobile IP, RSVP and so on. This approach will continue with;

- Patch work (mobility, security and QoS) to existing IP and Architecture
- Will turn Internet, an Information network, into a Communication Network towards ICT network
- Solutions will be scalable, but not necessary efficient, as required by communication networks

With the clean-slate approach, it is difficult to perceive if one single architecture or completely new architectures will be adopted worldwide for political. technical and commercial reasons.

- Commercially
    - New architectures and protocols require major investment and infrastructure changes (e.g IPv6)
- Politically
    - One architecture will not be adopted globally
- Technically
    - One size does not fit all (inefficient)

This chapter proposes a new, innovative, and commercially viable approach toward Future Internet, building on the European strengths in mobile communications whilst achieving the expected features of QoS, Mobility and Security in Future Internet.

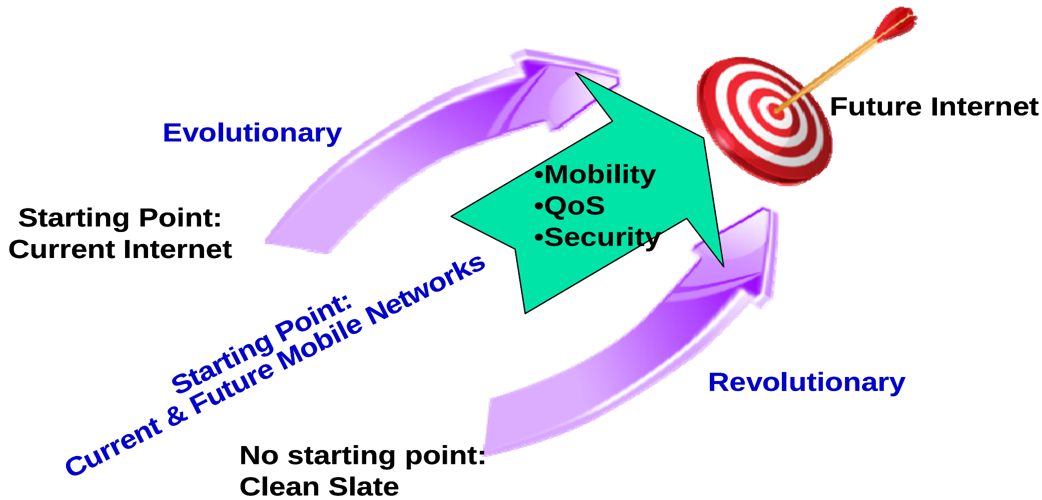


Figure 11.2 Parallel Future Internet based on Current and Future Networks

The concept is called One-Network idea and encapsulates all the above requirements and features, and more importantly is based on evolution and optimisation of integrated 2G, 3G and LTE-SAE networks. In the One-network architecture all the current artificial “wall gardens” between network operators is removed, and will treats all the mobile networks like a utility network in a cloud of resources to be shared by service providers based on their dynamic and evolvable needs.

It effectively proposes a "parallel internet" to the current Internet based on "Networks of current and Future" and leaves it open to market forces to determine whichever way the FI should evolved.

The One-network cloud will turn the current mobile networks into utility networks such as (gas, water, electricity) where cost is directly related to the market size and network usage. This way, the One-network idea is expected to result in significant savings in OPEX, CAPEX including energy efficient networking, and enable seamless and affordable roaming support.

From technical viewpoints, the One-network cloud will make it feasible to incorporate advanced networking techniques and protocols; such as virtualised network/computing resources, efficient routing and load-balancing schemes, self-organisation. As it is an evolutionary approach, all the new techniques will use the current schemes and techniques such as QoS, mobility management, security mechanisms, and naming/addressing, whilst ensuring provision of necessary tools for mobile service providers to be able to differentiate themselves and compete in the market.

11.2 Research Priorities

Taking the current mobile networks as the seeds the proposed architecture would transform the collection of the existing heterogeneous networks into a global inter-network infrastructure, namely the One-network concept, that support a mix of mobile and fixed connections, with packet and circuit switching mechanisms. The envisioned high level architecture of this parallel internet is illustrated in the figure below.

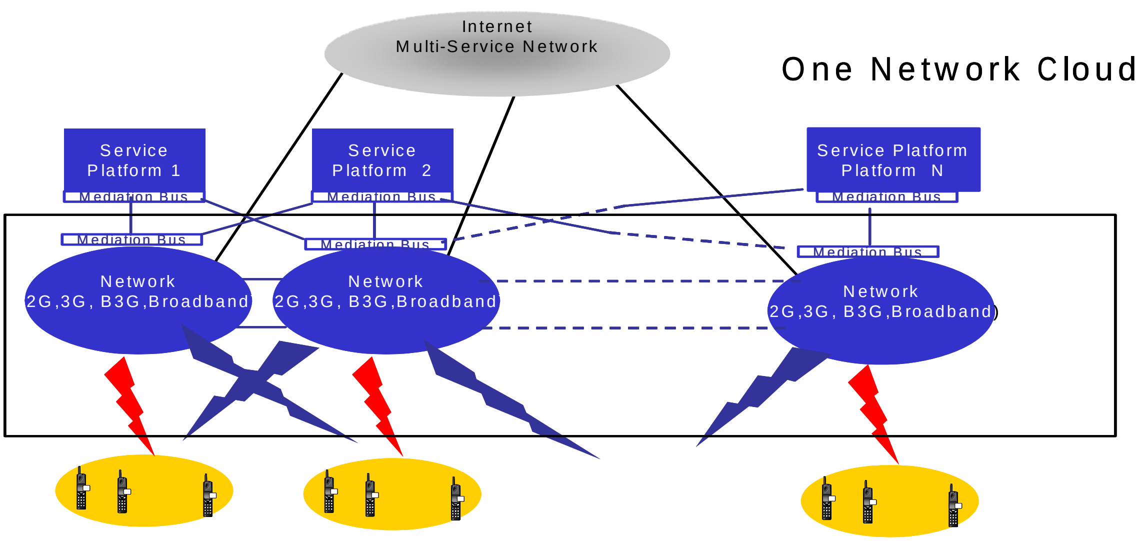


Figure 11.3 Parallel Future Internet based on Current and Future Networks

The proposed architecture would make multiple separate mobile networks to appear as One-network with global scale by removing the artificial "wall gardens" between them. It consists of both mobile and fixed connections and network users will be able to seamlessly move across different networks regardless of their native service operators. The One-network could evolve into a full fledged inter-network that can co-exist initially in parallel with current Internet, and has potential to become a completely new Internet.

The architecture separates infrastructure ownership from network operation and service provisioning. This is similar to the business models adopted by the utility infrastructures, where only a few companies really own infrastructures, while many other players are active in service operation, marketing, and etc., without major capital investment. This will allow innovation and competition that will finally benefit the public. Separation of business tasks among different players will increase the overall quality by allowing different businesses to specialise in a narrower domains.

The one-network should also support a uniform service platform via a mediation bus for different operators to rapidly deploy new services. The mediation bus should provide an abstraction layer that greatly simplifies integration and flexible reuse of business/service components. This will enable configurable enterprise-level quality of service in service-to-service communications. The mediation bus enables incorporation of high-availability features through isolation of applications from server and/or communication faults. Hence, applications can seamlessly operate in the case of node or network failures.

Some of the noteworthy challenges are briefly discussed in the following.

- Mobility management

Mobility management has always been a vital functional component in the design of mobile networks. In present networks, mobility management is handled by a single network to which users are subscribed to. In the one-network architecture the mobility management and in particular handover and user authentication influence the degree and depth of network integration.

- Infrastructure sharing among mobile operators

It is envisaged that in the future computing models, hardware and software will be utility services rather than proprietary assets belonging to the operators. Current business models of hardware/software/subscriber ownership is based on 25 year old business models where extent of coverage was major differentiator between different network operators. These concepts are known as Hardware as a Service (HaaS) and Software as a Service (SaaS) models that are gradually growing as commercial services which are made available via Web 2.0 technology over the Internet. This will allow the future institutions to reduce their capitals investment. In addition, in mobile computing environments, cloud computing can make the services of powerful computing and storage resources of the computing cloud available to the less powerful and energy constrained mobile/wireless devices/nodes. To this end, cloud computing seems a very attractive model for the One-Network architecture.

Cloud computing will be enabled by virtualisation of computing resources that are available in the infrastructure cloud. In addition, the future network operators are expected to operate by acquiring virtual resources, based on their needs, rather than traditional models where the operators own dedicated physical resources. This will increase the flexibility of mobile network operators, and will reduce their capital investment. Furthermore, in this model, the infrastructure and hardware providers will only need to concentrate on their own areas of expertise. To enable infrastructure sharing over the mobile networks, many technical challenges in virtualisation of mobile networks and interoperability issues need to be addressed.

- Service management

The common practice to offer services to end users is to establish a detailed Service Level specification (SLS) which describes the properties of the service provided (e.g. QoS parameters, security levels, tariff etc). In addition to this traditional provider-to-user SLS, provider-to-provider SLS can be also conceived in the One-Network environment. The scope of such SLS may include the provisioning of the quality of transit services provided among operators (optionally with tariff regulation) as well as the use of shared resources.

- Scalability

The scalability issue is often linked with the objective of providing end-to-end QoS to users. Strict per-flow QoS guarantee is usually provided by circuit switching facilities in the existing communication networks. Alternatively, ATM or MPLS like techniques can help to provide per-flow QoS guarantee. While per-flow QoS guarantee may not be scalable, a more realistic approach could be DiffServ-like mechanisms where flows demanding similar QoS requirements can be aggregated into a single class for treatment. Of course, this option is at the expense of loosing the degree of QoS guarantees. Whether it is desirable to follow the strategy of having coarse class-based packet (or even over-provisioning) treatment at the mobile core network while providing finer granularity in treatment (for instance on per-flow basis) at the edge should be investigated. In addition, in the all-IP based environment like LTE, some new paradigms like Evolved Packet Core (EPC) have been proposed in which the traditional circuit switched mechanisms (for voice) have been replaced by virtual containers known as bearers, each associated with unique QoS characteristics.

As each autonomous mobile network operator has its own definition and implementation of bearers, how to bind or map individual bearers in a scalable way across multiple interconnected mobile networks will become a significant technical challenge. In particular, appropriate bearer (QoS class) mapping at network boundaries in the data plane should be carefully designed in order to provide consistent service level to the end mobile users; this should be typically addressed during the establishment of provider-level SLSs.

- Stability

Traditionally, each mobile network operator only needs to deal with its own customers and its dedicated network infrastructures. This situation will change in the One-network environment.

Different methods of network resources sharing should be envisioned. For example, one would be to allocate a minimum network resource to each service provider involved and share the rest dynamically based on demand over time. Another extreme scheme is to complete sharing with no pre-allocation; thus, sharing is based on short-timescale demand variations. The first scheme can obviously guarantee certain degree of operational stability, but at the expense of lower resource efficiency. Whereas, the second scheme can make the system less stable with time, even though it can achieve higher resource efficiency. Various resource sharing schemes should be investigated to allow certain degree of autonomous operation whilst achieving high network resource efficiency.

- Authentication Authorisation and Accounting (AAA)

Security protocols including both user access control for preventing intrusion and Denial of Services (DoS) attacks, as well as, secured data transmission in the One-network environments pose some important questions such as: whether there should be only one AAA system per country in the country-wide cloud? or should the currently associated AAA to each network provider be preserved? This will influence the network cloud architecture, scalability as well as customer-provider relationship.

According to the current situation, individual autonomous mobile network operators may have dedicated AAA systems for their own customers. For instance, a centrally maintained AAA database can be responsible for managing local user data such as security and tariff information, etc. According to the One-Network paradigm, network infrastructure resources are virtually shared by multiple network operators, and in fact customers might not “belong” to any specific provider. In such a scenario, the corresponding AAA system may need to be maintained in a distributed manner by individual operators. As a result, how to perform AAA operations on top of a virtually shared platform will become a challenging task. In addition, mechanisms should also be designed for preventing access to the AAA system from malicious parties that could implement DoS attacks.

- Service-Interwork interface

One of the major hindrances of blooming diverse services in mobile networks has been the adoption of proprietary service platforms, complexity of service-network interfaces, and closed systems. Thus, deployment of a simple and flexible interface between a service domain and the underlying network technologies is essential for mitigation of such problems. This separation between service domain and network domain could provides effective mechanisms for easier introduction of new services, independent of the underlying networking architecture and technologies. One-Network architecture is only successful if complemented with a light-weight and universal interface between service layer and network, with the aim of overcoming the aforementioned barriers through the concept of Mediation Bus.

- Naming and addressing

Due to the expected variety of services and different addressing formats for the entities in a typical distributed computing environment, there is a need for the support of heterogeneous naming and address spaces for flexibility and unanimity. It is important to investigate the current naming and addressing and evaluate their suitability in the One-Network architecture. The solution should consider currently used naming and addressing schemes, user network numbering, temporary numbering, and roaming subscriber numbering. Also in the light of the proposed “one network cloud” per country, it is important to investigate benefits of keeping the current different network numberings. For instance, a roaming customer should not have to worry about the changes of name/address during handover operations between different networks with different naming/address spaces.

- Technologies for simultaneous support of packet and circuit switching and optimized routing protocols

In the One-network, the architecture consists of packet switching (including IP packets), circuit switching of 3G, B3G and 2G networks respectively, it is vital (for optimum and efficient routings, load balancing) to find appropriate interfaces and interworking when a traffic flow traverses different networks of different technologies.

Networks infrastructures are heterogeneous in nature; thus, one routing protocol will not be optimum for all types of networks sizes and network densities. Given the requirement that of different networks, each network may run its own routing protocol, will need to be interconnected together according to the “One-network” architecture, routing across network boundaries will become a technical challenge. Suitable and efficient solutions are required which allow heterogeneous routing protocols to be deployed inside each physical network. In addition, due to the high dynamicity in traffic pattern of mobile networks, the underlying routing configuration, even within a single network, should allow adaptive reconfigurations on the fly, according to the variations of the external conditions. For instance, how paths can be intelligently re-established or reselected at short timescale in order to regain optimised resource utilisation and QoS assurance is a distinct technical challenge.

- Self-organising and autonomous One-network cloud

Currently, different mobile networks have different levels of usage of their network resources over different hours of a day and weeks. In One-network concept, network resources are pooled together to efficiently serve the dynamics of demands for each service provider and charged based on the usage. This model will be like in the utility services (gas and electricity networks) and charged according to the usage. There is a need to investigate efficiencies gained when adopting different approaches to the resource sharings: 1) complete sharing and 2) part-sharing and part-reserved by each service. Designing proper schemes and protocols for such environments will put forward many interesting and challenging research and development problems.

- Business models for seamless mobility

Enabling ubiquitous mobility over the One-network infrastructure will require a carefully designed framework of business models that provides incentives for global collaboration amongst existing stake holders and in particular the current mobile network operators. Such a framework should facilitate this without any administrative overhead. This will necessitate definition of a set of coherent policy-based business models for global roaming and billing operations. These models should provide fair frameworks for revenue sharing among different operators, and affordable services for the network users. This will be a definite deviation from the current "walled garden" model of the mobile network operators that restricts network users and potential service providers. Such models need to provide sufficiently transparent cost structures to the network users in order to ensure consumer protection. On the other hand, any business model should provide reasonable incentives for the mobile network operators. Since mobile Internet providers will naturally operate in different countries with different set of regulatory systems, for example, policy based business models should provide some flexibility to account for variations of government regulations in different administrative domains, as well. Economic disparities also should be taken into account to adjust the usage costs according to the affordability of the users in different countries that might enjoy different levels of GDP per capita figures.

- Business models for infrastructure sharing

The One-network paradigm raises many questions with respect to the currently practiced business models, where each operator is responsible for its own network deployment, maintenance, and operation, even though there is evidence of major shifts from this model. In such scenarios, ultimately all the current actual operators can be regarded as virtual mobile operators. Considering this, relevant questions are: how do the mobile operators differentiate and distinguish themselves from each other, and on what basis they can compete for a share of the market? Who will be responsible for network maintenance, upgrades, operation, user security/privacy and billing?

Other important question is how the mobile operators are charged for usage of the network resources, and from a mobile service provider's point of view what mechanisms are available to support fairness of business models, while guaranteeing the QoS and SLA agreements.

11.3 Approach to Future Internet

The One-Network approach is proposed based on the following commercial and technical requirements expected of the Future Internet. It is a pragmatic approach based on the Networks of Future (NoF);

- Efficiency of the technical solutions on mobility, QoS and security;
- Commercial viability; offering better chance of being adopted by industry;
- Building on European industry strength;
- Considering the current trend of changes towards new business models of full infrastructure sharing.

The key objective of the One-network is to enable an Internet-scale mobile inter-network infrastructure. The main advantage of this approach is that mobile networks inherently supporting efficient and purpose-designed; mobility, strong security, and QoS. Thus, any successor that evolves from these networks will inherit those important features. In term of its evolution it is continually providing similar capacities as that offered by the fixed network.

Requirements and salient features expected of Future Internet:

- Extent of Connectivity
  - This is important to choose right network(s)as starting point towards FI to minimise required new investments. This justifies the proposed One-network approach as there is already extensive level of connectivity is provided by 2G, 3G, and B3G with more than 5 billion customers and wide-spread availability in the world.
- Business model- neutral, cater for different business sizes, and different business interfaces
- Self-managed/organised
  - Minimise cost of operation/maintenance and manage complexity on behalf of operators
- Fast response to dynamics of service providers demand
- Evolvability and future proof
  - Allowing independent evolution of both network and services
  - Energy efficiency
  - Greener environment and cost
- Purpose designed QoS, Security, Mobility
- Mix of packet and circuit switching support
- Open and simple service/user interface
  - Easier Innovation, hide underlying complexity, agnostic to underlying network architecture/protocols
  - Networking of Information (not just networking of networks)

11.4 Recommendation

R1). Europe should adopt an approach to Future Internet based on Networks of Future and current.

R2). European approach to the FI should be unique, distinct and pragmatic and based own its industry strength rather than following the USA, and far-east approaches.

R3). One architecture for FI is not politically, technically or commercially viable. Europe should invest in research on Mobile Networks Virtualisation technologies that enable creation of different virtual architectures based on needs

R4). Researchers should be encouraged and mobilised to research on "One-Network" paradigm in creation of a parallel internet and identify solutions for the research priorities outlined in this document as well as identifying new regulatory and technical challenges.

12. Green Wireless Communications

12.1 Rationale

In its communication "Addressing the challenge of energy efficiency through Information and Communication Technologies" the European Commission states :

"Information and Communication Technologies (ICTs) have an important role to play in reducing the energy intensity and increasing the energy efficiency of the economy, in other words, in reducing emissions and contributing to sustainable growth. In order to achieve the ambitious targets set and meet the challenges ahead, Europe needs to ensure that ICT-enabled solutions are available and fully deployed, but efforts should be made so that ICT leads by example and reduces the energy it uses — ICT industry accounts for approximately 2% of global CO2 emissions, but is pervasive throughout all kinds of economic and social activities, and increasing its use will result in energy savings from the other industries"

The European Commission acknowledges the opportunities ICTs have to offer in reducing the energy intensity of the economy but also points out that ICT needs to lead by example in increasing its energy efficiency. When assessing the energy efficiency of a product, the energy consumed for its manufacturing, distribution, use and end-of-life treatment needs to be considered.

Currently, data volume transmitted through networks increases approximately by a factor of ten every five years, which corresponds to an increase of associated energy consumption by approximately 16% – 20% per year. Gartner estimates that the use phase of ICT equipment is responsible for 2% of the annual carbon emissions. Other studies indicate that the share of the use phase of ICT in the worldwide energy consumption is closer to 3 %. This is comparable to the energy consumption of the aviation industry. When incorporating the entire life cycle, the share of ICTs is closer to 4%. The exponential growth of ICTs, which will be required for reducing the energy intensity of the entire economy, is currently not sustainable.

According to a study of ABI Research, base stations and backhaul networks of the cellular communications networks operators consume approximately 60 billion kWh per year. This corresponds roughly to 0.33% of the global electricity consumption . Note that the above investigations take into account only the use phase of the equipment. The GSM association estimates that this operational fraction is 90% of the total use phase energy consumption of mobile communications. Based on these numbers mobile communications entail 15% – 20% of the entire ICT energy footprint.

When tackling the problem of the increasing energy consumption, instead of looking just at different isolated aspects of the overall problem, a global optimization approach is required in order not to compromise the quality of the networks. A holistic approach should be considered. This energy efficiency view is relevant not only for networks in developed countries, where it contributes to decrease the electricity bill of operators, but also in developing ones, where the access to power networks is difficult in remote areas (implying alternative solutions). Improving energy efficiency can thus foster the deployment of wireless networks in these regions and help to close a potential "digital divide".

A first step requires increasing individual energy efficiency of equipments. Power consumptions of the most relevant equipments are listed on Table 12-1. Evidently, by migrating from 2G to 3G, power consumption has multiplied by a factor of 5. Moreover, the radiated power of a BTS or Node B is maximally 50 Watts maximum. This demonstrates that drastic reductions in power consumptions are required and should be feasible.

2G Networks			**3G Networks**		
Equipment	Power Consumption	Share in cellular network	Equipment	Power Consumption	Share in cellular network
BTS	1200 W	97 %	Node B	6000 W	98%
BSC	500 W	2.2 %	RNC	2500 W	1.5%
MSC	4000 W	0.8 %	UMSC	4000 W	0.5%

Table 12-1. Cellular 2G and 3G network consumption data[2]

Furthermore, it is a fundamental goal to extend the equipment's lifetime. This will lead to a lower impact of the production phase in the overall footprint.

Although the network itself needs energy efficiency optimization, it never got too much attention from the energy efficiency viewpoint, as it was easy and relatively cheap to get power fed to the equipments. This view is changing quite fast, and the inclusion of environmental approaches, namely energy efficiency, into the design of networks, is becoming a factor for increasing competitiveness. Many ideas can already be found, some of them implementable with current technologies, like switching off a base station during the night when traffic is low or non-existent. More generally, flexible networks that adapt their capacity to the requested requirements can lead to significant energy savings. Also new network paradigms that assure all components are used at their fullest capacity will need to be introduced.

Way forward:

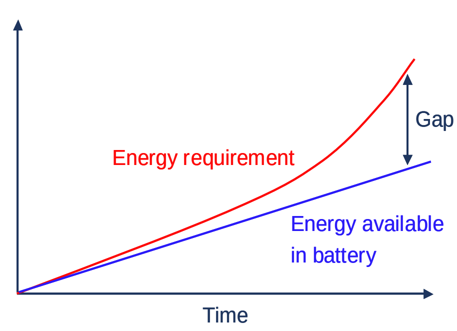
- To significantly increase the energy efficiency of wireless communications systems, a global optimization approach is required considering equipments and networks.

12.2 Green radio

The combination of mobility and connectivity has become a commodity in today's society. We have seen a continuous accelerated deployment of broadband personal communications and increasing demand for higher data rates over the last decades. In parallel, silicon technology has become ever smaller and faster. These two evolutions have reinforced each other so far, offering 'more (bandwidth) for less (area/cost, power)'.

12.2.1 Conflicts on essential resources

The gigantic success of wireless communications is however forming a threat to itself. The spectrum gets crowded, and increased service requirements are draining mobile devices batteries (Figure 12-1).



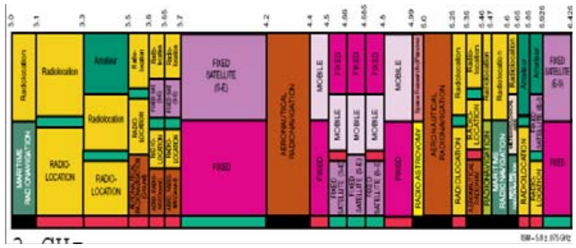


Figure 12-1. Growing energy gap (top) and over-allocation of the spectrum (bottom) hamper progress in mobile communications

The proliferation of radios and the intensification of their usage, is leading to a massive increase of 'wireless activity in the ether', increasing the risk of bad communication quality.

In addition to the emerging communication problems mentioned above, technology scaling also is reaching its limits. Indeed, CMOS scaling has arrived at the point where parasitic problems are becoming dominant: variability, reliability, and last but not least leakage, can not be resolved anymore at the technology (transistor) or circuit level only, and will have their impact on the system level performance. Even more important, the leakage may become the dominant component in power consumption, and this challenge has to be tackled thoroughly in order to provide energy efficient solutions for future designs. Leakage cannot be totally handled anymore at transistor level. Appropriate measures at design and even at system level (e.g. through intelligent control) are needed.

Way forward:

In order to cope with the challenges explained above, we need disruptive solutions. The following essential paradigm shifts show the potential to enable green radios:

- We will need to design next generation radios aware of power dilemmas, to deliver services under constrained resources (energy, spectrum). 'Green challenges' will need to be integrated in the optimization criteria, while traditionally the design and operation goal of wireless systems has been to guarantee Quality of Service (QoS).
- More flexible use of the spectrum should be exploited to reduce overall energy consumption. Cognitive radio is investigated already, yet the goal so far has been to guarantee QoS, while the concepts could bring much greater value when addressing 'Green challenges'.

- The traditional link between a service and a network should be disconnected, as it leads to huge energy and spectrum wastes. For example, more than 30% of mobile phone calls are made from user's homes, thus generating unnecessary energy consumption.
- Optimal usage of scarce resources should be considered across (OSI) layers, cross the link, cross the implementation levels (functionality/algorithms, platforms, architectures, circuits). Mainly local optimizations have been carried out for energy savings so far, where gain at one point often is counteracted by the loss at another.
- Alternative energy sources should be considered and where possible designed for. E.g. for very low power radios energy scavenging can be considered, and for small energy efficient base stations or even terminals solar energy may be used.

The above listed challenges have to be addressed at the terminal as well as at the infrastructure side, as will be explained in the following section.

12.2.2 Terminals & Infrastructure

Multi-mode terminals integrating reconfigurable green radios, i.e. radios that are aware of energy, can enable radical energy savings in heterogeneous network environments.

Power consumption in infrastructure for wireless systems is already becoming an important design target, and is expected to become even more crucial in the future. Smaller and/or distant base stations will not be connected to the power supply net in the future. The overall need to save on scarce energy make it a bottleneck and will also impact the infrastructure which is connected to the power supply. Moreover, recent communication systems offering much higher capacity, unfortunately often do so at the expense of more power consumption at the base station, especially the power amplifier, as explained below.

In Figure 12-2, the power consumption of a typical medium power GSM base station is shown for a link with GMSK modulation serving three sectors with four carriers per sector. It can be seen that the power amplifier consumes the largest amount of power and converts more than 50 % of the total input power into heat. Compared to this example, new modulation schemes (e.g., OFDM used in LTE) aiming at optimum data throughput, suffer from even worse power efficiency. The reason is that the signal of such modulation schemes feature much higher peak-to-average ratios, thus requiring higher power amplifier back-off which in turn leads to lower power efficiency.

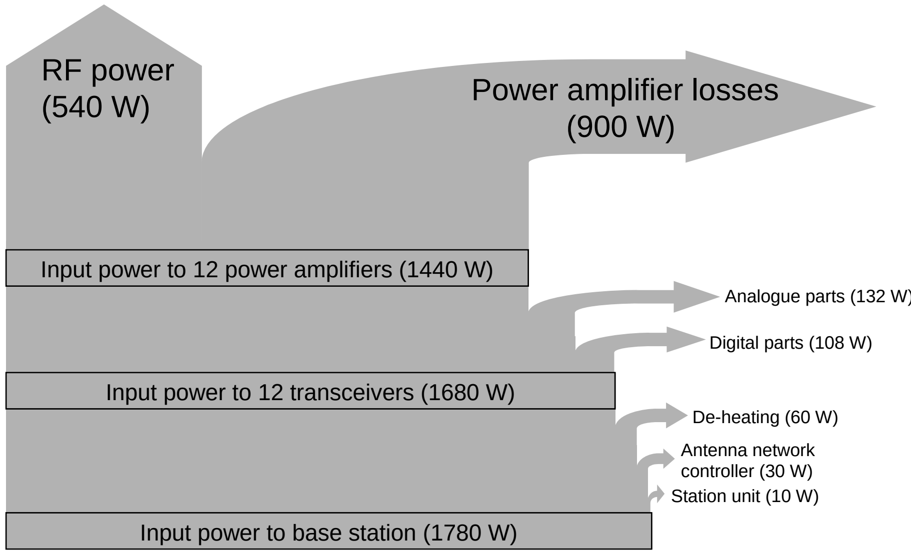


Figure 12-2. Power consumption of a base station (example: GSM medium power base station with GMSK modulation, serving 3 sectors with 4 carriers per sector).

Way forward:

Green radios should be targeted both in design of functionality and implementation, as well as in operation:

- Radio implementation: There is a need for innovative radio solutions (analog front-ends and digital platforms, antennas and antenna interface), which exploit the possibilities enabled by new technologies, while taking into account the problems they bring. With this regard, in future terminals the integration of RF MEMS (Micro-Electro Mechanical Systems) in RF front-ends and the co-design of some RF components (e.g, antennas and amplifiers) is promising.
- Reconfigurability and scalability are key to realizing a cognitive radio so that it can reconfigure itself according to spectral opportunities. These reconfigurable capabilities should be available from the transceiver level up to the resource management strategies. Important impact on energy saving wireless devices is also expected from new antenna design techniques such as:
    - RF MEMS base reconfigurable directive antenna.

  - Combining with indoor localization Positioning ID devices/tags or DOA estimators).
  - Using cooperative beam-forming.
  - Better understanding of indoor propagation.
  - Antenna LNA co-design approach .

- Radio functionality: Energy efficient modulation and coding schemes, including network coding and cooperative networks, can bring significant savings. Indeed, wasting energy due to high interference levels, need for packet retransmissions, or very long contention periods, can be avoided if the communication system and the air interface are designed with the goal of reducing energy consumption. Furthermore, new. sampling or sensing techniques such as "Compressed Sensing" that allows the faithful recovery of signals from what appear to be highly incomplete sets of data, typically using fewer data bits than traditional methods used to request, appear to be very promising. Indeed, following this approach would bypass the current wasteful acquisition process in which massive amounts of data are collected only to be in large part discarded at the compression stage and hence results in a significant saving of the transceiver processing power.
- Radio operation: Progress on the radio design alone will not be sufficient to cope with the green challenges. A need for holistic strategies exists, to enable energy aware and spectral efficient operation. Green intelligence can be brought in the radios through the cognitive cycle in which the analysis step considers the reconfiguration opportunities also in terms of global energy consumption (terminal & network) through an interaction between the terminal and network infrastructures (Figure 12-3). As such, future terminals should be context aware and their ultra low power communication aspect will be enabled by an appropriate joint combination of sensing, localization and identification.

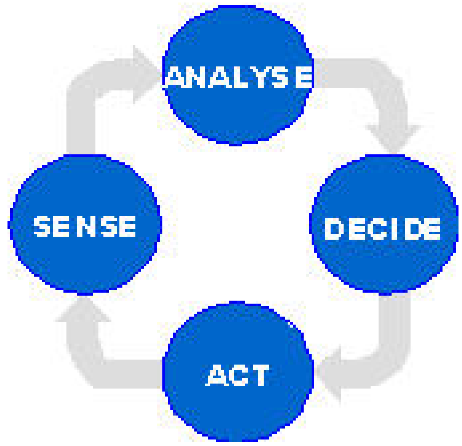


Figure 12-3. Cognitive cycle should target green operation

12.3 Green networking

It is expected that in the coming decade there will be an explosion of the number of wireless devices and, consequently, of the amount of wireless communication that takes place, e.g., WWRF foresees roughly 1000 wireless devices per capita by 2017 . Providing services and running applications on these devices, we will face the double challenge of (1) significantly reducing the energy consumed by these systems, and, (2) sharing the spectrum (licensed and unlicensed) in an efficient way among a huge number of indoor and/or outdoor devices. Energy consumption needs to be reduced for two reasons: to curb the growing share of energy consumption of ICT systems and to significantly extend battery autonomy of wireless devices, a necessary condition for providing dependable services on wireless devices, e.g., in telemedicine or ambient assisted living for the elderly.

Up to now these concerns played only a marginal role in the design of wireless networks and even less so in wireline networks. Present network architectures, protocols and implementations are to a large extent unable to face the new challenges. Therefore, there is great need for new approaches to the Green networking.

Green networking refers to techniques, mainly related to data link, network and transport layers, aiming at provisioning services to the communicating entities under the premise of minimizing the impact in terms of energy consumption, spectrum use and radiation while guaranteeing the QoS user profile. It requires a major rethinking of architectures, protocols and implementation techniques in the light of these concerns. Moreover, it should be part of an overall holistic cross-layer approach to address energy and spectrum concerns jointly at networking and radio levels.

Green networking is not just a new approach to classical networking issues. It has to deal with the drastically different nature of future networks. These networks will be largely hybrid networks, formed by the combination of wireless and wired infrastructure networks, and ad-hoc networks. We can distinguish two (related) domains with different focus regarding green networking:

- Green deployment
- Green operation of wireless networks.

12.3.1 Green deployment

Green deployment, relates to the establishment of a network infrastructure, dealing with, e.g., radio access, cellular, pico- and femto- cellular networks, WLAN infrastructures, and so on.

12.3.1.1 Integration of multi-hop solutions into cellular networks

Wireless Mesh Networks (WMNs) are an emerging two-tier architecture based on multi-hop transmission, forming a self-organised wireless backbone. WMNs have the capability of enhancing network coverage and reducing deployment costs. The fact that a wired infrastructure is not needed for interconnection of mesh routers makes WMNs a solution that provides connectivity to end users in a very efficient way. They can be deployed easily to optimise routes and minimise energy consumption. Furthermore, the usage of multi-hop solutions for the backhaul of heterogeneous networks leads to an efficient usage of radio resources in base stations and access point. It also minimises interference and hence requires lower transmission power. Furthermore, the use of a wireless backhaul in WMNs reduces the use of wireline transport networks, hence, reducing the natural resources needed for deploying these networks and the impact on the environment of the installation.

Way forward:

- Development of multi-hop mesh solutions for backhauling of heterogeneous networks to get a significantly more efficient usage of radio resources in base stations and access points.
- Development of multi-hop mesh solutions for reducing energy consumption from the terminals to the base stations and access points.

12.3.1.2 Tight-integration of network deployment (from macro down to femto)

With the upcoming roll-out of femto-cell architectures, future mobile communication will be even more characterized by a nested architecture where macro-, micro-, pico-, and femto-cells deliver wireless connectivity. In addition, in all these network topologies, different radio access systems are used (e.g., UMTS, HSDPA, LTE and WIMAX), which increase the problem of efficient resource management, the key anchor point to facilitate green wireless communication.

Delivering indoor coverage with femto-cells strongly reduces power consumption compared to the use of macro-cells. However, parallel operation of these networks may cause mutual interference. This clearly distinguishes the problem of managing different deployments from handling heterogeneous access networks since different access technologies usually operate in different frequency bands.

Way forward:

- Investigation into a unified resource management to significantly reduce overall power consumption of wireless systems with nested topologies. The mutual interference demands full integration of network deployment. It requires the design and development of new technologies and concepts ensuring such a full integration of several deployments.
- Research into novel advanced techniques for interference coordination and interference management between femto-cell and macro-cell base stations at levels from physical up to higher layers.
- New protocols and architectures for heterogeneous access and core networks aiming for a fixed mobile convergence of networks with a tight integration of several network deployments applying identical wireless access technologies.
- Mechanisms for handling increased complexity of the solutions. New energy-aware solutions for self-configuration and self-optimization technologies in the context of the variety of network deployments.

12.3.1.3 Resource sharing and resource management techniques for energy saving

In order to make optimal use of the limited resources when deploying a wireless network, an optimal combination of topologies, radio-interfaces, and protocols has to be selected, taking into account energy saving in the nodes and subsystems, spectrum use, radiated power, etc. The shape of the cost function will depend, e.g., on the desired model accuracy, the computational overhead allowed (very relevant when running over limited computational capability devices). Network load balancing and smart information storage in distributed networks could lead to substantial energy savings. Networks need environment sensing capabilities, where users are communicating, establishing a map of signal, interference, and other parameters. This will lead to the possibility of networks to predict the channel behaviour of users, hence, optimise the use of resources.

Way forward:

- Optimization techniques and tools are needed for optimizing resource sharing and resources management during the deployment of wireless networks.

12.3.2 Green operation

A number of different techniques can contribute to green networking in the highly-dynamic emerging networks. Besides some classical approaches like routing, cross-layer optimization, etc., new networking paradigms offer opportunities to save energy.

12.3.2.1 New networking paradigms

Cooperative networking is a strategy where network elements belonging to the same owner or across domains cooperate and assist each other, instead of competing in using resources in order to globally optimize spectrum usage and reduce power consumption. Cooperation is a logical way forward when network elements belong to the same owner, as for instance in home networks and personal networks. Considerable gains can be obtained through cooperation.

Cognitive networking refers to the use of artificial intelligence-like techniques to make better choices in operating a network or a set of networks. An example could be that a mobile network could predict time and access points to dock with another network or with the Internet. It could be possible to save energy by predicting when to transfer non-time critical data at the best possible moment via the best choice of access point.

Opportunistic networking is a technique applicable to networks where the connectivity is intermittent and, by extension, where the characteristics of the connectivity vary considerably in time. This is in particular applicable to moving networks, that intermittently dock with an infrastructure or other moving networks (e.g., vehicular networks). Opportunistic networking, in particular in combination with cognitive networking can be used to choose the best opportunity to transfer data.

Delay-aware and delay tolerant networking is applicable to the support of services where delay is not a key requirement. Instead of activating resources that consume energy but cannot be necessary because of the delay-tolerant nature of the service, the goal of this approach is to optimize consumption using minimum resources.

Virtualization implies flexible mapping of virtual communication resources, e.g., virtual gateway or router, onto real resources. It has the potential of sharing resources and consequently decreasing energy consumption. Moreover, decreasing the equipment deployed not only reduces direct energy consumption but also the energy and pollution that its recycling implies once equipment is replaced.

Way forward:

- Besides global optimization techniques, principles and techniques are needed to base cooperation on, e.g., incentive schemes.
- Apply cognitive techniques, in particular prediction, to choose network elements and access times for reducing energy consumption.
- Develop opportunistic networking techniques for minimising energy consumption.
- Develop decision-making techniques based on the conditions of the network and the type of services, e.g., when to transmit and to which node.
- Develop virtualization techniques to achieve energy-saving resource-sharing.

12.3.2.2 Classical networking issues

Typically routing algorithms use a single cost function, the number of hops, when selecting a route between two nodes. Green networking requires multi-criteria routing involving “green variables” weighted according to criteria agreed by the stakeholders.

Pattern-based optimization of network resources can be an energy-saving alternative to network over-provisioning. Aspects such as the use of the network by end-users, the location, the time, etc. are actions that exhibit patterns. A fully configurable network with the ability to envisage to some extent the requirements in terms of network use will optimize the necessary resources and consequently minimize the required energy.

Opportunistic interface selection by users can be used to improve the connectivity of users in flexible spectrum environments and, thus, help alleviate the problem of excessive energy consumption. This approach is applicable in scenarios where a user can connect to several networks using a multiple interface terminal or in a personal network where the user can select one of the many interfaces of different personal devices.

Energy efficient security and trust is crucial since most security protocols are energy hungry and resource consuming, and require many interactions between wireless devices as well as between wireless devices and fixed network elements. Solutions need to be investigated for providing the necessary security with less resources and energy.

Way forward:

- Multi-criteria routing techniques for optimizing energy usage need to be developed.
- Techniques are needed to recognize and predict patterns in network usage to optimize energy usage in conjunction with fully configurable networks.
- Develop techniques to allow opportunistic selection of air interfaces to achieve a best-connected situation from an energy point of view.

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