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Report on Trends in Communication Technologies

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Abstract:
This document contains the results of the first year of activity of WPI.6 Integral. The document starts from an analysis of Personal Needs and of the landscape for Information and Communication Technologies (ICT) in Europe. Then, we produce our own view and interpretation of the (r)evolution caused by the introduction of ICT technologies into our society. We introduce the concept of the "DNA of ICT evolution", built upon two major meta-trends, identified as personalization and distribution. We then show how these two filaments support, and are supported by ten major trends. Finally, we show how the WPs of NEWCOM++ are contributing to these major trends. This is based on the results of a Survey conducted among the NEWCOM++ WP Leaders, to identify the major goals, requirements, users, impact, and risk of their corresponding research activities.

Keyword list: ICT, Information Society, Personal needs, services, ubiquity, flexibility, complexity, cognitivity, opportunism, cooperation, security, miniaturization, convergence

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LIST OF ACRONYMS

3D	Three Dimensional
3G	Third Generation
AAL	Ambient Assisted Living
AFGC	Analyzing Factor Graphs with Cycles
API	Application Programming Interface
BAN	Body Area Network
CAGR	Compound Annual Growth Rate
CPM	Continuous Phase Modulation
CSI	Channel State Information
DCAS	Design of Code-Aided Synchronization
DSNBC	Design of Short Non-Binary LDPC Codes
DSP	Digital Signal Processing
DVB-C2	Digital Video Broadcasting – Cable
DVB-H	Digital Video Broadcasting – Handheld
DVB-RCS	Digital Video Broadcasting – Return Channel via Satellite
DVB-S	Digital Video Broadcasting – Satellite
DVB-SH	Digital Video Broadcasting – Satellite Handheld
DVB-T	Digital Video Broadcasting – Terrestrial
ELPD	Efficient Linear Programming Decoder
FPGA	Field Programmable Gate Array
GIID	Geometrical Interpretation of Iterative Decoding
Glonass	Global Navigation Satellite System
GPS	Global Positioning System
JRRM	Joint Radio Resource Management
ICT	Information and Communication Technology
IIC	Innovative ICT Concept
IoH	Internet of Humans
IoT	Internet of Things
IPTV	IP television
IT	Information Technology
LCCID	Low-Complexity Components in Iterative Decoding
LOS	Line of Sight
MIMO	Multiple Input Multiple Output
MAC	Medium Access Control
MOB	Multibeam Opportunistic Beamforming
NBIC	Non-Binary Information Combining
NET	Network level
NoE	Network of Excellence
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
P2P	Peer To Peer
PDPC	Practical Design of Polar Codes
PHY	Physical level
PSN	Pocket Switched Networks
QAM	Quadrature Amplitude Modulation
QDIRC	Quantized Design for Iterative Receiver Components
QoS	Quality of Service
RFID	Radio Frequency Identification
RRM	Radio Resource Management
SaaS	Software as a Service
SNR	Signal-to-Noise Ratio
SOA	Software Oriented Architecture
TVS	Time-Varying Synchronization
UWB	Ultra Wide Band

VoD	Video on Demand
WLAN	Wireless Local Area Network
WPR	Work Package on Research
WSN	Wireless Sensor Network

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SECTION 1 – INTRODUCTION

This document contains the results of the first year of activity of WPI.6 Integral.

WPI.6 is NEWCOM++ workpackage aiming at *Information Society Trends and General Requirements Analysis*. According to the WPI.6 aims, the present document attempts to depict the scenario for ICT technological trends providing an original framework that starts from the individual needs and extends to considering the current evolution in the ICT sector, with a special focus on the European context, testified at first by the actual topics under investigation within NEWCOM++.

This deliverable represents a first interface through which NEWCOM++ can receive inputs and interact with stakeholders and users in the information society at large, with the objective to draw from the outside those requirements, constraints, and inspiration that can help enhancing integration among the Research WPs of the JPA. Accordingly, specific objectives of this report are to analyse the foreseen medium-long term evolution in Communication Technologies, and to identify major trends in applications, services, and system architectures, keeping in due consideration the constraints given by economic, regulatory, and standardization contexts, with an eye to extract common theoretical and practical challenges. In doing so, a large variety of advanced, ubiquitous wireless communication systems and networks are embraced in view of their possible exploitation in consumer, professional, and institutional markets.

To tackle this challenging aims, the first input for the present deliverable has been obtained through the collection of potential R&D innovative concepts from NEWCOM++ Research workpackages, with the corresponding goals, potential users, requirements (both general and specific, on services, applications, architectures, networks, links, equipment), constraints (in terms of technology, economy, regulation and standardization), foreseen impact and risk. This has been achieved through a survey of ideas conducted within the WPRs leaders, the result of which is reported for completeness in the Appendix to this deliverable. The collection of Innovative ICT Concepts resulting from the survey has formed the basic material to be shaped in identifying the overall ICT trend panorama.

The document starts from an analysis of Personal Needs and their potential satisfaction through Information and Communication Technologies (ICT). The ICT trends in Europe are reviewed, with emphasis on future Internet aspects and wireless technologies. We consider information and learning, environmental fitness, social interactions, working life, transactions, entertainment, security, privacy, and health and wellness. We discuss the view of the European Commission, with focus on the Future Internet and the Internet of Things, as well as the underlying technologies. In essence, Section 2 serves as a reference framework, based primarily on information coming from outside of the project.

Then, in Section 3, we enter into the heat of the game by producing our own view and interpretation of the (r)evolution caused by the introduction of ICT technologies into our society. We introduce the concept of the “DNA of ICT evolution”, built upon two major meta-trends, identified as *personalization* and *distribution*. We then show how these two filaments support, and are supported by, ten major trends: *ideal performance, ubiquity, flexibility, complexity, cognitivity, opportunism, cooperation, security, miniaturization*, and *convergence*.

Finally, in Section 4 we show how the WPs of NEWCOM++ are contributing to these major trends, which gives a clear picture of the potential impact that the scientific research endeavours in NEWCOM++ really have.

SECTION 2 – PERSONAL NEEDS AND THE ICT EUROPEAN CONTEXT

A good starting point to describe the overall picture of the ICT European context is to consider the society conditions in which the ICT evolution and innovation are taking place. Thus the focus is firstly put on the individual, in line with the approaches undertaken in parallel by other policy programmes in Europe, among which it is worth citing the AAL (Ambient Assisted Living) programme as the champion for focused attention on the human being [1].

Indeed, the individual person is always at the centre of any societal development, because any transformation translates necessarily into modifications of personal habits, and often is actually resting upon their intrinsic nature. Re-interpreting in a more modern key the classical approach by Maslow [2] who modelled the personal necessities through a universally famous pyramid, needs can be grouped into 8 major categories as described in the map in
Figure 1. Of course, classification of human needs under these discrete classes is not a simple task, with the unavoidable result that often an overlap between different needs can be detected, a fact that is inherently related to the complex nature of human beings coupled with the degree of subjective interpretation that is different for different people.

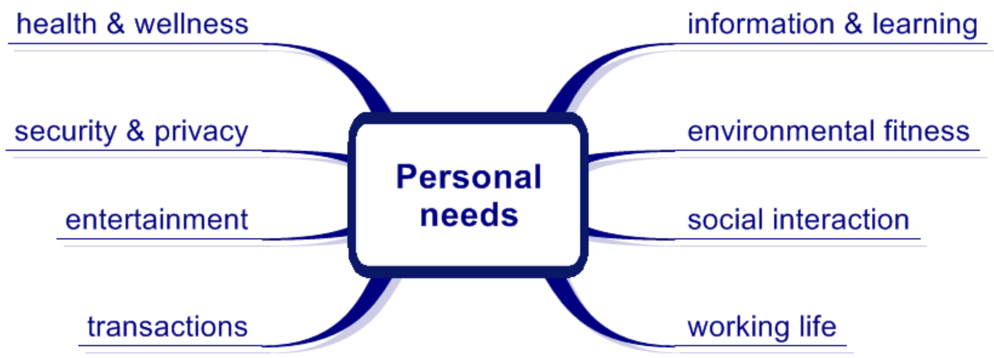

Figure 1 – The map of personal needs

It is interesting to note that each of these 8 categories of needs can be linked to a series of clear trends in the current ICT European arena. Accordingly, insight into this classification is a useful starting point to guide us towards the identification of the ICT trend roadmap, as described in the following.

2.1 Information and Learning

Information and Learning is the natural need for knowing, being up-to-date and informed anytime and anywhere, which has assumed a particularly compelling connotation in recent years with the rapid and capillary diffusion of Internet applications. In the digital era, the person is more and more eager to reach rapidly and efficiently all contents he/she needs in a precise moment, at home, at work, on the move. This trend is confirmed by the interest towards the creation of *digital libraries* in the current European research framework programme, and by the advent of new applications aiming at satisfying the user thirst for receiving information and learning in remote areas, in the form of e-learning. Notably, these trends are first responses to the social challenge of inclusion, which contributes in avoiding person isolation from society through e-inclusion mechanisms. As broadband becomes a necessity of daily life (*broadband for all*), the impact of information exclusion for citizens that do not have broadband access or who cannot afford it will be dramatic. Today’s digital divide may become tomorrow’s social-exclusion.

2.2 Environmental Fitness

Environmental Fitness is a broad interpretation of the necessity for any human being to adapt the surrounding ambient to its habits in order to allow comfortable living. This need is mapped onto a series of ICT trends that can be identified in the current picture. First of all, *mobility* reflects the possibility for the user to communicate, work, be entertained, and more generically reach the outside world while being on-the-move, a very popular and wide-spread tendency among users of all kinds (from consumer to professional and institutional). Ubiquitous multimedia communications have been the key to third generation cellular standards, and foreseen to become even more attractive in the next future. The current trend towards *info-mobility* is a specification of the wider mobility concept, consisting in the distribution of information to passengers of various transport means. The most relevant example is that of car passengers, which opens the way to more sophisticated applications such as Automatic Vehicle Monitoring or *intelligent cars* (the Intelligent Cars Initiative, i2010 [3]). *Ambient awareness* is another form of environmental fitness, integrating aspects of ambient intelligence into context awareness systems. A key role is played by navigation systems, such as GPS or the European Galileo, which enable location-based services. In this scenario, ambient awareness consists in computer mediated communication systems that help people maintain a peripheral awareness of others, translating into connections between households and mobile individuals, with automatic capture capabilities of awareness information and with a pervasive topology in the environment. Finally, the process of adaptation of the surrounding environment to the user ICT experience should avoid to forget the environmental footprint, identifying solutions to exploit resources efficiently and favour sustainability, in line with the *Green IT* and *energy efficiency* requirements.

2.3 Social Interaction

Social Interaction is the natural need of humans to belong to some form of society, from a small scale (a family, a group) to a larger scale (a community, a Country), in response to the continuous search for support, discussion, comparison and opinion exchange with other persons. This need takes a completely new connotation with the recent technology advances. In particular, it is worth mentioning here the tendency for *social networking*, so highly popular nowadays amongst younger generations, and the trend towards virtual interactions in *cyber-realities* where all aspects of life can be artificially re-constructed, through the creation of virtual identities or avatars (Second Life). The web is now used in a participative mode, as testified by the success of a number of applications such as Wikipedia, blogs, MySpace, Facebook, YouTube, GoogleMaps, etcetera. In this framework, other foreseen trends are *enhanced reality* (with brain electrochemical stimulation), and *augmented reality* (combination of real and digitally modified identities and environment). Of course, although we focus here on the more technologically oriented evolutions, this does not mean that real interactions among human beings should ever be replaced by their artificial counterparts.

2.4 Working Life

Working Life is the need for self-fulfilment and self achievement realized through working activities, which enables to exploit talents and education, contributing fundamentally to self-esteem. The need for a satisfactory working life is reflected in an important ICT trend, that we can identify as *e-Business*, comprising home-based or mobile-based teleworking, broadband connection between different enterprise premises, remote training, videoconferencing, etcetera. The nomadic use of ICT will challenge the meaning of ‘being at work’.

2.5 Transactions

Transactions are the need of humans to be supplied with services and goods in order to satisfy material/immaterial desires. ICT can be of help here with the supply of a host of *e-commerce* tools, that can be used in business, private, or consumer contexts. Home banking is but one example.

2.6 Entertainment

Entertainment is the need for amusement and hobbies, to aliment the innate human tendencies towards recreation. In partial overlap with the social interaction need when applied to the personal sphere, the necessity for entertainment is one of the most typical goals of ICT services, taking on various forms such as on-line gaming, portable consoles, mobile TV, P2P downloads, MP3 players, social networking (YouTube, Facebook, SecondLife), etcetera. Indeed, social networking is a direct response to the entertainment need.

2.7 Security and Privacy

Security and Privacy are primary needs of any person to feel protected during any aspect of life. In particular, this translates into the need for preserved secrecy on private data, which becomes a real social challenge in an era where communication of personal digital data is at the centre of many applications, especially web-based Internet applications. The success of social networking websites is the most evident example of the dissemination of private data over the Internet; search engines get and store data after every query, the content of personal e-mails is stored in remote servers and in some cases scanned for commercial and security reasons. Moreover, the user-friendly tools typical of the new, second-generation Web have made the Internet a platform for a growing number of financial transactions, ranging from purchases of goods to money transfers between electronic bank accounts. In the digital economy, public authorities have the responsibility to make sure that citizens can trust the use of the Internet, combating cybercrime, avoiding episodes of personal identity theft and of malware (malicious software) dissemination via spam and website attacks, and improving at the same time the authentication, validation and *digital identity management* for high level transactions (Internet banking).

2.8 Health and Wellness

Health and Wellness is the last but fundamental need of humans for truly satisfactory livelihood, which should be provided anywhere and anytime thanks to the ICT enablers. As a prominent example, *e-health* applications remotely assist patients, for example exploiting body area networks capable of monitoring vital parameters. E-heath ICT is the response to critical social challenges such as *home care* (or domiciliary care), i.e. health care or supportive care provided in the patient home by healthcare professionals, and *independent living*, i.e. supporting assistance to disabled people. All of this at a significantly reduced social cost.

2.9 The ICT role in satisfying the personal needs: the future Internet

ICT can indubitably be considered as an enabler for satisfying these user needs via different forms of response, as outlined above. Europe is investing considerably in research activities in these fields, to devise novel and efficient applications in response to the user primary needs and to solve the social challenges posed by continuous evolution and innovation.

However, scientific research is not the only measure. For the first time, a conspicuous effort is being directed towards investing on ICT infrastructures, via the so called European structural funds. Indeed, 20% of the overall budget for 2007-2013 must be devoted to the introduction of ICT innovation. This European cohesion policy aims at ensuring that less developed regions, and regions confronted with serious structural change, can improve and contribute to European competitiveness. This fact will be essential to support the major investments needed to create the basic ICT backbone able to sustain the entire ICT evolution in the next future, i.e. the high-speed Internet architecture and telecom infrastructure. Founding the Internet of the future is one of the main challenges of the European i2010 strategy, which will contribute in accelerating the pace of change. Indeed, the sheer scale and complexity of nomadic computing and the new forms of the future Internet, will place the existing Internet architecture under strain, requiring quantum leap progress in terms of scalability, mobility, flexibility, security, trust and robustness. Considering the 8 personal needs described above, we can observe that the concept of *future Internet* can be seen as a *common denominator* for their satisfaction, since:

- it provides the platform for applications and data storage for information and learning,
- it provides the most part of the contents that the user may want to receive while on-the-move and the reference structure for environmental fitness
- it is the central stage for ICT social interaction via the social web
- it is a new unavoidable platform for professional tele-work

- it is the new digital enabler for e-commerce transactions
- it provides new means to entertain, such as IPTV, communities, chats, on-line gaming
- it embodies the need for security and privacy
- it provides the platform and enabling data storage for remote health and wellness applications

It is very interesting to note that this technological evolution is very much felt also at the highest political levels, as testified for example by the recent communication of the Commissioner for Information Society and Media, [4]: "*The Internet of the future will radically change our society” […]providing “seamless 'anytime, anywhere' business, entertainment and social networking over fast, reliable and secure networks. It means the end of the divide between mobile and fixed lines.*"

The concept of pervasive Internet is the cornerstone of the network-based society, as foreseen in the European i2010 priorities [3][5]. This is achieved through widespread provision of low-cost, wired and wireless, broadband connectivity, merging fixed and mobile communications. Convergence is blurring the market boundaries between telecoms, consumer electronics, media services and Internet companies, posing a new socio-economic challenge: keeping the Internet open with competition while remaining effective. Besides strongly impacting on societal innovation via its obvious economic effects on markets and the involved enterprise realities, the Internet of the future will transform user lifestyles.

Of course, the definition for the “Internet of the Future” is far from being obvious, and certainly not unique. Instead of attempting at this exercise, we can at least describe some of the most significant aspects that find broad support as important elements of this future network of networks [6], [7]:

- *participative web*, i.e. transformation of the Web from a network of separate applications and content repositories to a seamless and interoperable whole, with Social Network Sites at its basis;
- *semantic web*, whereby data is enriched by meta-information to allow efficient content search and filtering, in a common framework that allows data to be shared and reused across application, enterprise, and community boundaries, with semantic application platforms and statement-based data-storage (distributed semantic databases);
- *intelligent applications*, consisting in natural language processing, machine learning, machine reasoning, and autonomous agents that process meaning to enable the semantic web;
- *open technologies*, i.e. open APIs (Application Programming Interfaces) and protocols, widgets (portable code that any user can install and execute on its webpage), open data formats, open-source software platforms, and open data;
- *network computing*, i.e. Software-as-a-Service (SaaS) or cloud computing, the shared use of distributed computing resources as an alternative to in-house IT applications using local servers and personal devices (offering scale flexibility and cost-efficiency), which translates into Web services and distributed computing (for example, grid computing is a form of distributed computing whereby a "super and virtual computer" is composed of a cluster of networked, loosely-coupled computers, acting in concert to perform very large tasks);
- *portable identity* (to allow Internet users to log on to many different web sites using a single digital identity) and roaming of portable identity and personal data;
- *ubiquitous connectivity*, i.e. broadband adoption and mobile Internet access via mobile and portable devices.

It is worthwhile noting that also in the business arena social networking tools, collaboration, together with the emergence of the SaaS concept, will lead to a new generation of computer services available on demand and with much reduced overheads. Internet-based enterprise software is expected to grow worldwide at a rate of about 15% in 2006-2011.

It is evident that these expected developments of future Internet applications and services will generate unprecedented volumes of IP traffic, requiring significant strengthening of transport capacity both in the core and at the edges of the network. To fix ideas with numbers, it is useful to quote a recent Cisco white paper [8], focusing on estimates of IP traffic in 2012.

- *Annual global IP Traffic will exceed half a zettabyte (10^{21} bytes) in four years.* At just under 44 exabytes per month, the annual run rate of traffic in late 2012 will be 522 exabytes per year. A zettabyte, or 1,000 exabytes, will be the new milestone to look for beyond 2012. IP traffic includes both Internet traffic and traditional telecom/broadcast traffic transported over IP. The Internet itself in 2012 will be 75 times larger than it was in 2002. Internet traffic will generate 28 exabytes per month in 2012, the equivalent of seven billion DVDs each month.
- *Global IP traffic will nearly double every two years through 2012.* Total IP traffic in 2012 will be four times larger than it is in 2008. Growth will be driven by high definition video and high-speed broadband penetration, at a compound annual growth rate (CAGR) of 46 percent.
- *P2P is growing in volume, but declining as a percentage.* P2P file sharing networks in June 2008 are carrying 600 petabytes per month more than they did in June 2007, which means there is the equivalent of an additional 150 million DVDs (1 DVD contains approx 4 Gbytes) crossing the network each month, for a total monthly volume of over 500 million DVD equivalents, or two exabytes. Despite this growth, P2P as a percentage of consumer Internet traffic dropped to 51 percent at the end of 2007, down from 60 percent in 2006, and is estimated to drop to 44 percent by the end of 2008. The decline in traffic-share is due primarily to the increasing share of video traffic. A secondary factor in the decline is a trend toward web-based file sharing in place of P2P file sharing in some regions.
- *Internet video is now approximately one-quarter of all consumer Internet traffic,* not including the amount of video exchanged through P2P file sharing. Internet video was 22 percent at the end of 2007, and will reach 32 percent by the end of 2008.
- *The sum of all forms of video (TV, VoD, Internet, and P2P) will account for close to 90 percent of consumer traffic by 2012.* Internet video alone will account for nearly 50 percent of all consumer Internet traffic in 2012.
- *YouTube is just the beginning. Online video will experience three waves of growth.* Even with a six-fold increase between 2007 and 2012, current Internet video growth is in its initial stages. Internet video to the PC screen will soon be exceeded by a second wave arising from the delivery of Internet video to the TV screen. Beyond 2015, a third wave of video traffic will result from video communications.
- *Video communications and dynamic video content will ultimately test the Internet more than pre-recorded video content.* Service providers have a host of options available to help ease the burden of on-demand video traffic. Real-time video communications, on the other hand, will be a bandwidth burden with few remedies.
- *Mobile data traffic will double each year from now through 2012.* Mobile broadband-enabled laptops are creating sharp increases in mobile traffic. Mobile operators in many parts of the world are offering mobile broadband services at prices and speeds comparable to fixed broadband. Though there are often data caps on mobile broadband services that are far lower than those of fixed, some consumers are opting to forgo their fixed lines in favor of mobile. This has a familiar ring to it from the mobile voice substitution effect that began in the late nineties and is continuing today. As a result of the mobile broadband substitution effect, mobile data traffic in 2012 will be over twenty times what it is today.
- *Business IP traffic will grow at a CAGR of 35 percent from 2007 to 2012.* Increased broadband penetration in the small business segment and the increased adoption of advanced video communications in the enterprise segment will result in a CAGR of 35 percent for business IP traffic from 2007 to 2012.
- *TelePresence will start to be a significant driver of enterprise IP network traffic by 2012.* In 2012, the amount of TelePresence traffic on enterprise WANs will be more than five times the volume of the entire U.S. Internet backbone in 2000.

But this is not the end of the story. In fact, all of the above can be considered as an **Internet of Humans** (**IoH**), where the presence of the human element is always very close to the network and to the application. A whole new picture opens up when the main objective becomes the interconnections of objects, in a so-called **Internet of Things** (**IoT**). IoT entails seamless and self-configuring connection of devices, sensors, objects, rooms, machines, vehicles, etc. through fixed and wireless networks, based on *machine-to-machine* communications and RFID smart tags. The use of electronic tags and sensors will serve to extend the communication and monitoring potential of the network of networks, as will contribute to the introduction of computing power in everyday items. Advances in *nanotechnology* (i.e. manipulation of matter at the molecular level) will serve to further accelerate these developments [9]. The IoT concept finds particular relevance in a host of applications, such as for example:

- transportation through intelligent cars, logistics and traffic systems
- environmental fitness through smart buildings
- security systems
- health monitoring

IoT will represent an unprecedented challenge in terms of scalability, connectivity, security of the network.

2.10 The enabling technologies

We conclude this Section by a quick overview of the available **technologies** that must be leveraged upon to realize the practical implementation of the described ICT evolution in the pursuit of user needs satisfaction.

- *Broadband core network technologies.* Here, the undisputed queen will be the optical communication technology, the only capable to sustain the immense traffic offer that the future Internet will generate. Advances in optical fiber process, laser characteristics, dense wavelength division multiplexing techniques, optical switching and signal processing will bring enormous benefits in handling Tera-bps flows with sustainable power consumption.
- *Access technologies.* This will be the arena for fierce competition among several technologies, such as xDSL, fiber-to-the-home, wireless, and satellite, with broadband data rate that will range from 30Mbps up to 10Gbps. Wireless technology, the focus of the NEWCOM++ NoE, may be seen as the more flexible and economic of all the alternatives. The network of the future will be prevalently constituted by an optical core network terminated at the edges by broadband wireless access.
- *Media and broadcasting* of digital content via satellite (DVB-S2, DVB-RCS with mobile extension, DVB-SH), cable (DVB-C2), and terrestrial networks (DVB-T2, DVB-H), along with the advent of high definition and 3D standards, and IPTV delivery via the Internet.
- *Software technology*, through the already discussed concepts of network computing, SaaS, Web Services, Service Oriented Architecture (SOA), Semantic Web, Distributed databases, open source.
- *Embedded systems* and *sensor networks*, to embed sensing and intelligence in materials and environment, in line with the IoT and ambient intelligence trends. An example is provided by the deployment of passive RFID tags. Miniature wireless chips are being embedded in objects, such as security passes or medical devices, to provide broad access to digital content in the physical world (e-health). Ultra wideband (UWB) technology is also worth to be mentioned, often used in conjunction with RFID technology for high precision e-health applications.
- *Nano-technologies*, providing the necessary electronics and miniaturization to enable a myriad of new applications, including the embedded utilization of tags and sensors. Indeed, advances in nano-technologies will imply that smaller and smaller objects will have the necessity to interact and connect to the network, from local area networks to homes and offices, further down to personal and body area networks, and conceivably down to networks of nano-systems.
- *Location and positioning technologies*, exploiting a combination of satellite-based navigation systems (GPS, Galileo, Glonass, etcetera) and of terrestrial positioning methods, exploiting cellular and wireless networks.

SECTION 3 – MAJOR TRENDS IN THE ICT WORLD

We must now take on an original point of view and try to give a fresh reading of the above discussion on the European ICT context, identifying what we believe are the underlying and unifying major trends. We have seen that there exist many trends, in response to various personal needs, and it is difficult or even unnecessary to give a ranking, but it is possible and useful to try to classify them in order to make the discussion more interesting and organized. It is clear that from the point of view of NEWCOM++, we will always have to specify clearly where and how each specific trend has a bearing onto wireless systems.

We elect to say that the two main forces which are governing the revolution brought in by ICT technologies are *personalization* and *distribution*. Using a biological metaphor, we can think of *personalization* and *distribution* as the two strands, the two filaments, in a DNA structure, upon which and through which other trends are formed. This is what we call *The DNA of ICT evolution*, represented pictorially in

Figure 2. The two filaments generate and are linked by the bases, each one corresponding to a major ICT trend. Therefore, in the following we will identify *personalization* and *distribution* as meta-trends, or "trends of trends".

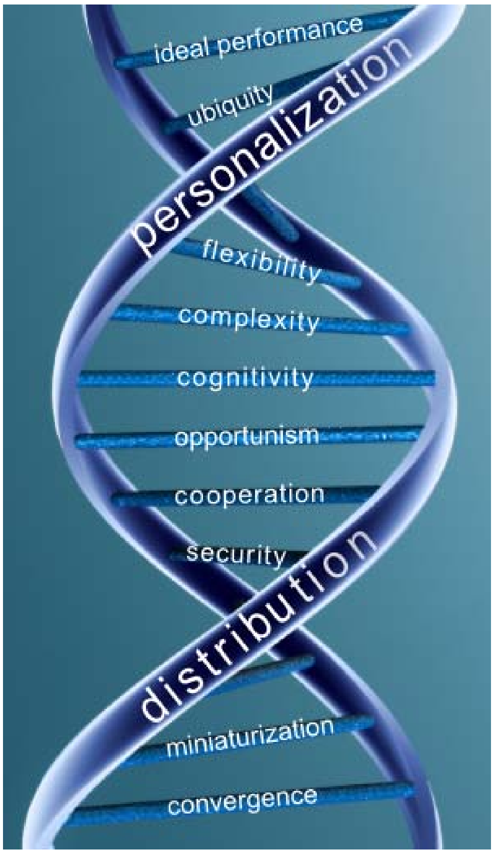

Figure 2 – The DNA of ICT evolution

Before we get into the more specific elements of the DNA of ICT evolution, let's dwell on *personalization* and *distribution* to give a rationale to our statement on their importance.

3.1 The Personalization meta-trend

The success of the industrial society was based on the mass production of goods at low cost, to be sold to a consumer market with homogenized tastes and desires. This paradigm today is completely reversed. The strategy is to go to the person, produce for the individual, satisfy specific needs, segment the market into small niches each tailored to a particular group of persons. This is all made possible by the fact that today it is feasible to produce at low cost with flexibility and modularity. Now, this trend is clearly reflected in the world of communications. Since the advent of mobile telephony, also identified as *personal* communications, we do not call a location, but an individual. We are now used to see the number that is calling us, associated to a person in our phonebook, and we decide whether to take the call or not. We select a specific tariff structure, suited to our calling profile, and we may even have lower tariffs when we call specific groups of people. In terms of accessing the Internet, we start from our preferred home page, we can browse over portals shaped according to our own profile, we can select our favored content from a huge offering, we can even become content producers by uploading pictures and movie clips. The individual has become a source of information, and not only a sink to be filled with advertisement. Even when watching TV, we now have at our disposal a growing number of on-demand offerings, from which we can freely select. The individual is more important, enjoys more freedom, is much more active than it was in the past.

3.2 The Distribution meta-trend

Another fundamental ingredient of the industrial society was the concentration of resources and intelligence into a few centres. This made interactions and investments more efficient, while also increasing the risk associated to losing a centre, and caused large movements of people (the first of which was the move out of the country into cities). The structure of companies was based on rather rigid pyramids, with very specific work functions and descriptions, and linear work flow procedures. Again, also this paradigm is reversed in the information society. Today, there is a clear trend towards the distribution of resources. In the world of manufacturing, it is customary to have parts produced in geographically distant premises. This reduces costs and creates a global economy where effects propagate unboundedly. Intelligence is distributed and decisions are obtained through a network of interactions. This adds greatly to the responsibility of each person in the organization, and the work functions become ever more flexible. This also creates a need for continual education, for it is not possible to adapt to the fast dynamics of the current societal evolution if one considers that his/her training ended in school. Companies' structures evolve from pyramids into networks of intelligent nodes, and the structure may evolve on a per product basis. The more futuristic version is the virtual company, where different entities join into specific ventures which only have the lifetime of a product life cycle. It can be stated, without the minimal shade of doubt, that all of this is resting upon ICT technologies. The network of people relies on the telecommunication network, and in the future, the same will happen for the network of *things*, also known as machine-to-machine communications. A distributed society, a distributed company need to find the necessary information anywhere they might reside. This is only possible thanks to the Internet and the associated search engines which allow to have nearly all the information in the world at one's fingertips. Intelligence is pushed to the edges, which reduces the risk associated to the loss of any network node, but at the same time requires a new ethical code, as well as security in communications. Networks evolve from heavy infrastructures to lightweight ad-hoc self-organizing topologies, where the role of operators needs to be defined anew.

As in the DNA structure, the two fundamental strands of *personalization* and *distribution* are actually running into opposite directions, i.e. they are the anti-parallel support of the ICT DNA double helix. In fact, while personalization implies a local view, distribution naturally translates into a global reality. Therefore, ICT is imposing on society a complex organization, whereby the global truth is formed through belief propagation from individual nodes which intelligently work within their local boundaries. As we will see later, this has much to do with the concepts underpinning iterative processing algorithms.

3.3 The trends of ICT evolution

The two meta-trends of personalization and distribution can be combined in various ways to form the *trends of ICT evolution*, which in our DNA metaphor correspond to the bases, the sequence of which identifies the genetic code. The following is our elected list of ten trends: Ideal performance, Ubiquity, Flexibility, Complexity, Cognitivity, Opportunism, Cooperation, Security, Miniaturization, and Convergence. Let's dwell on each in turn.

3.3.1 Ideal performance

The search for the ultimate ideal performance is the major force behind the evolution of any technical or technological system. It appears to be in the nature of the human kind to strive for the extraction of the maximum possible output, the optimal exploitation of resources, with the largest possible efficiency. This requires knowledge of the ultimate performance boundaries. In the case of communications, the boundaries are the object of Information and Communication theories, which in many instances do indicate where these limits are. The trend is therefore towards achieving the performance limits set by Information Theory. How does this link to the two meta-trends? The optimization of performance requires perfect fit to the specific communication conditions (propagation channel, interference, transmission format, etcetera), which can be interpreted as matching the individual user needs and constraints. This is part of *personalization*. On the other hand, the limits set by Information Theory are not restricted to a single link, but can and should be extended to the more complex case of networks. In this case, achieving the optimal limits requires global optimization, to balance fairness and overall throughput, with distributed intelligence. This is evidently part of the distribution meta-trend.

3.3.2 Ubiquity

The trend towards ubiquitous communications, the overused “Anywhere, anytime” motto, has been the driver for the evolution of cellular communications since the 70’s. Coverage is today extremely good in most urban areas, and surprisingly good in unexpected locations, even though obviously gaps remain in developing parts of the world. What is yet necessary is to sharply increase the geographic spectral efficiency (in bit/s/Hz/km^2), to provide ubiquitous *broadband* wireless access. Associated to ubiquity, we find mobility and pervasiveness. Mobility is the trend towards communication systems which can interconnect terminals moving at any speed, including all types of vehicles, trains, airplanes, ships. Pervasiveness is the trends towards finding connectivity all around us, in a truly *wireless ambient*. This concept has many important social implications, as already discussed in Section 2. Essentially, by living into a collaborative wireless ambient, the individual can benefit from optimized environmental fitness, which satisfies a basic human need. This is clearly a specification of the *personalization* meta-trend. At the same time, this personal fitness can be carried along in any location, becoming ubiquitous fitness, an evident derivation from the *distribution* meta-trend. Even though ubiquity and distribution may seem very similar concepts, we separate them by limiting the interpretation of ubiquity to the pervasiveness of wireless networks, and by attributing to distribution this and all other implications related to social aspects, work organization, global economy, etcetera.

3.3.3 Flexibility

Along with the search for Ideal Performance, this is also a major trend in the evolution of any technical system. All engineering systems start as rather simple and rigid, performing but a few functions, with limited scope for modifications in response to user needs. In the course of its development, the system acquires more and more functions, more and more options, which can be selected flexibly depending on instantaneous necessities. This is a very strong trend in wireless communications. Transmission systems, protocols, and terminals, are being designed as reconfigurable entities, with capabilities that can be flexibly adapted to the conditions set by the propagation channels, the transmission buffers, the spectrum availability, the interference environment, the desired quality of service, etcetera. Dynamic spectrum assignment strategies are being devised and starting to find their way into regulatory policies. Digital electronics capabilities are exploited to design software radios and flexible radios. Even analog electronics is now being bent to the requirements of designing flexible RF front-ends, with reconfigurable filters over large bandwidths. It is an easy task to map the trend towards *flexibility* as a direct son of the *personalization* meta-trend. In fact, it is obvious that flexibility is only useful if it is used to accommodate individual conditions and needs. On the other hand, it may be harder to describe the connection with the distribution meta-trend. However, *flexibility* at system level requires knowledge of all local conditions, in order to find a global optimum satisfying the requirements of the entire user population. Therefore, we can say that *global flexibility* is related to the trends towards *distribution* of intelligence, where as a minimum each user must sense its own environment and feed back this information to peers or to base stations. Also, the trend towards flexible network topologies is clearly out-spinning from the *distribution* meta-trend.

3.3.4 Complexity

Technical systems always evolve towards increasing levels of complexity, as functionalities increase and performance improves. On the other hand, technological complexity can become a major hurdle in its usability. Therefore, while internal complexity increases monotonously, there is a contextual trend towards the simplification of the human-to-machine interface. Complexity and simplicity must live together in harmony. As complexity grows, we must face the danger of increasing energy consumption, which could make entire systems unsustainable. A clear trend towards the design of "green" technical systems is growing powerfully nowadays. We could say that energy consumption is to complexity as energy saving is to simplicity. Mapped onto the world of wireless communications, complexity is visible in systems, protocols, terminals, network equipment, essentially in every element. The need to simplify is stringent for user terminals, but also for network management. And we can say that "green" communications are emerging as very hot area of research and development. The relationship between complexity and the *personalization* meta-trend is inherent in the fact that we do not accept standard and rigid solutions, but rather we always look for configurations which are adapted to individual needs. A personalized solution is always more complex than a standard item. The key enabler for the realization of complex systems is the fact that today we are able to produce personalized objects in a very cost effective manner. It is also true that, in many instances, personalization is perceived by the final user, but it is in reality a specific combination of a few standard objects. In view of the *distribution* meta-trend, it should be apparent that distributing intelligence, responsibilities, management functions, all translate into a more complex system. In this case, complexity also brings in the concept of *emergence*: the arising of novel and coherent structures, patterns and properties during the process of self-organization in complex distributed systems. Emergence can be weak when it can be reduced to its elemental parts, or strong when irreducible. Irreducible emergence can be thought of as an independent system, living a life of its own.

3.3.5 Cognitivity, self-organization and bio-inspiration

As complexity of systems grows larger, control becomes more and more difficult. At a first inspection, it would be desirable to be able to set rigid rules to which all system elements should abide. This has worked in the past and still does today. However, this can only be pushed to a limit, when exceptions to the rules become frequently necessary, but difficult to handle, and the overall efficiency is severely degraded. Also the system may become extremely large, and scalability of control becomes a major issue. Or, finally, flexibility demands may pose tremendous challenges to setting correct and efficient rules. In front of all of these difficulties, we are turning our observations to nature, where incredibly complex beings live apparently without any form of rigid control. This is the source for bio-inspired algorithms, techniques, and protocols. We see that life in nature is self-organized, and we can try to apply self-organization into devices, networks, and systems. And clearly, the most beautiful and powerful example of self-organized system is the human brain, with its capability of cognition. Therefore, the extreme finalization of this trend is to endow devices, networks and systems with cognitivity, i.e. the cognition capability. Hence the example of cognitive radio, where radio spectrum is not assigned a priori, but is cognitively selected based upon observations of the wireless environment. Seen through the light of the *personalization* meta-trend, we can see that we are actually turning our network nodes and devices into primitive forms of "persons", with a certain amount of artificial intelligence that allows them to "think" and make decisions with a certain degree of autonomy. In the Internet of Things, the human element largely disappears, and the network is completely populated by artificial beings, or agents, which carry out functions to achieve specific objectives. The *distribution* meta-trend is related very closely to the concept of self-organization, where local realities and decisions contribute, through message passing, to the global behaviour. This can be brought to the extreme where the overall objective functions, such as for example the estimation of a parameter, are elaborated only in a distributed manner, and the final result is not necessarily collected at a fusion centre, but can itself be distributed into the network.

3.3.6 Opportunism

With increasing degrees of distributed intelligence, flexibility, and complexity, it becomes crucial to execute operations not at any generic time instant, but when and only when the conditions are optimal.

In other words, it becomes necessary to catch the opportunity for performing a specified task in the most efficient manner, and with the largest associated benefit. Indeed, all systems are dynamically varying in several dimensions (as a minimum, time), which means that conditions will fluctuate and opportunities will be created. To use a dimension or another, depending on the underlying conditions, can be interpreted as a form of diversity. Therefore, opportunism is a way to exploit diversity, choosing from time to time the path which offers the minimum resistance to our action, and thus optimizing the use of resources. In a sense, opportunism can be seen as the opposite of the brute-force approach, where exploitation of resources is total and completely independent of the ensuing conditions. The beauty of this is the fact that, in a network (be it technical or social) the total amount of resources is limited, so if each one use the minimum necessary to achieve its own purposes, then the overall efficiency is maximized. In other words, the use of brute force from any single individual hurts the entire network. In wireless systems and networks, and particularly in the family of Beyond 3G cellular networks, opportunism has become a major flagship for resource assignment, scheduling, and multiple access. Resources are given dynamically to those terminals which are at a particular instant enjoying the best channel conditions, which will allow to serve them with the minimum effort and maximal efficiency. In order to avoid that some terminals are always left out of the game, opportunism should always go along with fairness, implemented in one of its several possible embodiments. In this specific case, the *personalization* meta-trend materializes in the fact that we go after the opportunity which is occurring for a specific individual, knowing that it will only last for a limited window of time. On the other hand, we want to be fair to all users, and as such protocols and strategies are ready to consider also the needs of those for which opportunities do not seem to happen, at least not with sufficient frequency. In terms of the *distribution* meta-trend, we observe that opportunities may also be visible at a local level. This is because, to enable scalability, it is not conceivable that all information be collected in a single decision making node. Therefore, decisions to seize specific opportunities should be taken locally, with feedback on instantaneous conditions transmitted only when and where necessary, possibly on short legs to minimize latency and thus maximize network reactivity. Hence, opportunism must go along with distribution.

3.3.7 Cooperation

Cooperation can be seen as the virtuous consequence of awareness. If an individual, or an entity, is isolated, it can only work for its own specific goals. On the other hand, even if the entity is not isolated, but is unaware of the needs, or even the sole presence, of other entities around it, it will behave exactly as it did in isolation, working undividedly towards the achievement of its objectives. Only when an entity becomes aware of the presence, requirements, and needs of other entities around it, then it can realize that working in isolation may not be the most efficient way. Even the objectives are modified, at least because one sees not only its own objectives but also those of others, thus creating the notion of global objectives. Awareness generates a change of perspective, which can lead to various forms of cooperation amongst the individuals. Cooperation requires trust, fairness, and regulation, in order to ensure that all individuals benefit from the process. Cooperation in wireless communications can, for example, take the form of relaying the information sent by another user, in order to help it reach the final destination. In this way, the cooperating node is spending part of its resources not to achieve its own objectives, but rather to help another node do so. In return, it will trust that the situation will reverse when its own opportunity comes along. It is clear then that cooperation and opportunism go together, as the mechanism for cooperation will adapt itself to the underlying conditions which will vary dynamically over time. Other interesting forms of cooperation can be envisaged for virtual beamforming, virtual MIMO, collaborative positioning, etcetera. Cooperation is an act between individuals, and as such it possesses intrinsically the character of the *personalization* meta-trend. The personalized network entity is aware of the other entities, cognitively decides that it is useful to cooperate, trusts the other entities, and expects to receive mutual benefits and to achieve its own goals while contributing to the global goals. This comes very close to the description of the behaviour of a person in a social network. On the other hand, the exploitation of cooperation means, once more, that the operations in the network do not belong to a single terminal and a single central control entity, but rather require the involvement of a multitude of actors, distributed of the area of service, whereby decisions and operation occur as the result of the overall interaction. This is clearly in line with the distribution meta-trend, and we can say that cooperation without distribution is impossible, and distribution without cooperation is less effective and not exploited to its fullest.

3.3.8 Security

We must also recognize that, in front of all the positive aspects brought in by the personalization and distribution meta-trends, there is also an associated increase in the risk of misuse of ICT technologies. Centralized control may be bulky and in some cases unfair, but it can also serve as a guarantee for secure transactions, which can be protected more easily by various kinds of threats. On the other hand, when organizations become distributed, when decision making is the result of consensus, when resource management requires information from the edges, then it is clear that there are so many more possibilities for an alien to come in and disturb or deviate the process far from its intended objectives. And since there is a trend for personalization, any individual or any entity is up front with all of its features, which can be stolen or misused in many ways. Therefore, the meta-trends of *personalization* and *distribution* require that much attention is paid to ensure security, guarantee privacy, defy malicious attacks, propagate trust. This applies to society in general, and certainly it does also to wireless communications, which traditionally have been the weak side of network security. One special word for trust: it is not just a matter of making sure that content is encrypted, that access is conditional to authentication, that sensitive data is not exchanged (or at least not frequently). It also a matter to make sure that the final user *perceives* that using ICT technologies is secure. In other words, there must be trust in ICT technologies, or else the uptake will always be below expectations, and the impact much more limited than the potential.

3.3.9 Miniaturization

In the evolution of technology, we always see a trend towards miniaturization, as the results of improvements in the processes and in the understanding of the underlying physics. This has held marvellously in the case of digital electronics, where the scale of integration of ICs (Integrated Circuits) has grown exponentially through the years. Digital ICs are horizontal enablers for the progress in wireless communications, not only from the technical point of view, but also from the economic side, given that the cost of ICs has also decreased steadily through the years. And the end is not in sight: with the rush for nanoscale devices, unprecedented improvements are yet on their way. Also, circuits built on organic materials promise to change forever the notion of “hardware”, as we will be seeing and use devices in plastic and even softer materials. Nanotechnologies will produce entire nanosystems, which can be distributed as smart dust for a multitude of distributed sensing applications. Here comes the relationship with the distribution meta-trend. On the other hand, the trend towards miniaturization can also be seen in a more general way. In terms of cellular mobile networks, there is a clear trend towards the miniaturization of cells, which went from macro to micro, pico, and now femto-cells. The femto-cell is intended to be installed by and individual in a home or a small office, and as such we can see the connection with the *personalization* meta-trend. We can also see the miniaturization of networks, as for the case of the body area network, interconnecting different parts of the body for various applications for the benefit of the individual, such as e-health.

3.3.10 Convergence

Last but not least, convergence. It is placed at the end because in a way it connects all previous trends. In a general sense, convergence can be seen as that process according to which concepts which used to be separated come together to form new meaning. The process eliminates barriers and distinctions, and creates larger classes. Since we use classification as an instrument for clarification, it is indeed true that convergence always causes a certain amount of confusion, as previous certainties are questioned and new approaches must come in. In economic terms, convergence is an earthquake that shakes market shares and inevitably increases both opportunities and threats. From the point of view of scientific research, convergence can be seen as the uprising of interdisciplinary research, where competences from different areas are merged. The major benefit is that different frames of mind coming together have the potential to produce breakthrough innovation. From the point of view of wireless communications, convergence plays a major role in at least two ways. First of all, the distinction between mobile and fixed telephony is vanishing, with operators offering bundles which include also Internet access and TV (the so-called quadruple play). Considering also the fact that IP

(Internet Protocol) is rising as the common network protocol for all services, we can see clearly the incredible force of service convergence. Secondly, there is also convergence in the world of wireless terminals, which more and more become phones, computers, cameras, organizers, etcetera. Let's interpret the trend for convergence in view of the *personalization* meta-trend. No matter where the person is, we want to provide the same access conditions, the same service profile, as if the person was virtually at home. Convergence of networks and terminals can enable this concept. On the other hand, this can also be seen as the famous "anywhere, anytime" motto, i.e. the fact that we are always surrounded by a converged (albeit heterogeneous) network infrastructure, of which we don't want to know the details, as long as we can use it for our purposes. Therefore, convergence can be seen as an enabler for the *distribution* meta-trend, because without it we would not see a seamless wireless ambient but rather a jigsaw puzzle of technologies.

SECTION 4 – NEWCOM++ RESEARCH: IMPACT ON ICT TRENDS

It is interesting to note that the scenario described in Section 3 is reflected, in a significant part, by the research activities currently on-going within the NEWCOM++ project.

In a completely dual approach, we can map the 10 ICT trends onto the activities initiated or planned within NEWCOM++, or we can associate each activity to one or more ICT trends.

In the following, we select the first approach and accordingly we list the 10 ICT trends with a different objective: to outline the degree of involvement that the NEWCOM++ research work packages present in their respective, trying to provide practical example of concrete actions taken by the consortium towards these trends. The content of this section is in part the result of the post-processing of the responses received by WPR leaders to a survey issued by WPI.6, aimed at identify the goals of the WP, i.e. the activities also called **innovative ICT concepts** (**IICs**), and the associated users, requirements, constraints, estimated impact and foreseen risk. The complete survey result is listed in Appendix for the sake of completeness.

4.1 NEWCOM++ towards the Ideal Performance trend

The match between the Ideal Performance trend and the activities carried out within **WPR1** on “Modelling, calibration, and validation of multi-dispersive, multi-link channels” is very clear. In fact, *channel models are the instrument to describe the ultimate limits on performance,* essential means for quantify the reference boundaries that cutting edge research is trying to approach. The first IIC of WPR1 is to design radio channel models (considering broadband, mobile-to-mobile, and body area), which incorporate all relevant features and *impairments affecting performance*, such as multi-channel correlation, multi-dimensional dispersion, polarization, fast time-variance, localization, near-field conditions, etcetera. Moreover, the focus is on the design of *efficient and robust channel estimators*, which is of primary importance to avoid that all effort spent in the design of efficient air interfaces and protocols become fruitless due to inefficient channel estimation.

This consideration suits perfectly also to **WPR2** on “Feedback and Resolution of Channel State”, the work-package with the objective to explore the *role of feedback* to optimize performance in wireless communication networks and its relation to the resolution of the time-varying channel state. In particular, WPR2 aims at assessing the effect of imperfect channel knowledge at the receiving end due to the time-varying nature of the wireless channel and methods to encode it for the return channel as a function of the allocated bandwidth for feedback.

While **WPR3** is more oriented towards unifying paradigms and descriptions, in order to design flexible receivers with limited complexity, we can say that it also contributes to the Ideal Performance trend through its strife for *adaptively reconfiguring the air interface* to optimize performance under all propagation conditions.

The push towards the Ideal Performance trends is clear for **WPR4** on “Iterative Receivers for Wireless Communications”, where *iterative processing* is investigated to optimize performance (often with the price of complexity), with a look on practical design, from imperfect channel knowledge to fixed point implementations and down to synchronization problems and joint receiver design. All WPR4 IICs (see Appendix) are oriented towards the Ideal Performance trend.

WPR5 on “Coding for Multi-Hop Wireless Networks” pursues the Ideal Performance trend by designing coding at network and physical layers for multi-hop wireless networks, aiming at providing *better throughput*, energy efficiency and resource utilization both in unicast and multicast communications.

One of the IIC reported by **WPR6** on “Relaying and cooperation in networks” aims at setting the reference *bounds for performance in the case of cooperative networks*.

Similarly, the activities within **WPR7** (on “Joint Source and Channel Coding/Decoding”) are also explicitly in the direction of *reaching ideal performance*.

WPR10 on “Network Theory” is inherently involved in the Ideal Performance trend, being devoted to the analysis on the fundamental theoretical aspects and ultimate performance limits at network level, in terms of *capacity, throughput, and delay*, with the aim of devising techniques to closely approximate and even achieve them.

Finally, the last WP we feel to mention under the Ideal Performance trend is **WPRA** on “Security in Wireless Networks”. In this case, the accent on performance is testified by the attention given to the *equivocation concept*, i.e. on the measure of secrecy, and by the activities aiming at the definition of its theoretical limits in fading channels.

4.2 NEWCOM++ towards the Ubiquity trend

All NEWCOM++ work-packages are in some way linked to the Ubiquity trend, with a special mention for WPs related to network aspects. In particular, in these WPs the ubiquity requirement is achieved through distributing the intelligence centres and easing the mobility, portability, and pervasivity aspects. In addition, we find a clear synergy between the ubiquity and cooperation trends, since cooperation is often instrumental to achieve ubiquity.

Accordingly, **WPR5** approaches ubiquity through the study of *distributed channel and network coding***,** and *geographic routing*.

WPR6 exploits the concept of ubiquity through *distributing synchronization, localization, interference mitigation. Cooperation* itself is a concept that has a clear connotation of ubiquity since collaboration arises to allow connectivity anywhere anytime.

WPR8 on “Scheduling and adaptive radio resource assignment” *distributes scheduling capabilities* to optimize efficiency for distributed wireless networks, which is a rather new concept since typically in distributed environments random access is implemented. The approach followed for distributed scheduling is game-theory based.

WPR9 on “Joint RRM and Flexible use of radio spectrum” optimizes the *radio resource distribution* strategy to improve network efficiency.

WPR10 on “Network Theory” is towards Ubiquity through *the distributed implementation of the back pressure* resource allocation algorithm. Back pressure is a routing, scheduling and resource allocation policy that is based on the simple principle of performing resource allocation decisions based on queue backlog differentials. It is named after the corresponding natural property of fluid flows. The decentralized architecture of wireless ad hoc networks and the lack of central controller in some cases limit the applicability of centralized algorithms such as the back-pressure policy. Accordingly WPR10 is investigating its extension in a distributed context.

WPR11 on “Opportunistic networks” focuses on *wireless sensor networks***,** marrying the Internet of Things trend towards environmental fitness, and introducing algorithms and design solutions to cope with nodes and user equipments on-the-move. This paradigm encompasses features and methods that are especially suitable in both disconnected environments, in which islands of connected devices suddenly appear, disappear and reconfigure dynamically, and pervasive networking scenarios, where epidemic data exchanges occur among mobile devices in temporary proximity. Further, WPR11 is devoted to the mobility concept through the *Pocket Switched Networks* (PSNs) as a communication paradigm that relies on both occasional transmission opportunities and user mobility to carry the data to the destination, with the purpose to reflect the reality faced by the mobile users.

In addition, **WPRB** on “Localization and Positioning Techniques” reflects the Ubiquity trends in focusing on *location-based services and cooperative positioning strategies*.

Finally, considering that cognitivity relies on the ability of devices to adapt their behaviour to decisions based on environment changes, we can state that there's a strong synergy between the Ubiquity trend (in the sense of environmental fitness) and the *cognitivity* trend.

4.3 NEWCOM++ towards the Flexibility trend

The Flexibility trend is also present in a massive way within the research activities of NEWCOM++.

WPR3 on "Adaptive coding/modulation for the wireless channel" implements flexibility in terms of transmission format, through *adaptive selection of modulation and coding* scheme in a dynamic fashion, according to the channel conditions. In particular, this trend towards adaptation is investigated within NEWCOM++ via the IIC on OFDM systems.

Focused on cooperative networks, **WPR6** is naturally linked with flexibility because *cooperative networks* are the opposite of rigid networks, with an inherent flexible, dynamic, and reconfigurable topology and protocols. In particular, WPR6 investigates on *adaptive relays*.

WPR8 is also inherently flexible, being devoted to the design of scheduling techniques with *adaptivity at resource management level*. In particular, we mention here the IIC on Scheduling Techniques for Heterogeneous Networks, where the heterogeneousness further stresses the degree of flexibility object of research.

Similarly to WPR8, **WPR9** has the concept of flexibility already in its name: "*Flexible use of radio spectrum*", with several IIC on this topic: joint radio resource management (JRRM) for heterogeneous networks. Adaptivity is also selected for algorithmic computation of the optimal parameters to be adopted by RRM.

WPR10 follows the flexibility trends through IICs such as the *back pressure* based resource allocation, the main objective of which is to push the capacity limits of wireless through decentralized network control with minimum overhead.

WPR11 is focused on the emerging paradigm of opportunistic communications to enable nodes and user devices to *self-configure and exploit resources in extremely dynamic networks*, such as Wireless Sensor Networks, Underwater Sensor Networks, Pocket Switched Networks, Delay-Tolerant Networks, Autonomic Networks.

Finally, **WPRC** achieves flexibility through the "*Flexible Radio Platforms*" it is based upon. In the view of WPRC, flexibility is expected to be a must in transceivers that will have to cope with an ever increasing multitude of air interfaces and radio technologies in the future. In this sense, flexibility is a means to achieve real-time processing in various radio environments with limited transceiver complexity and reasonable power consumption. Another aspect of flexibility is its ability to provide easy maintenance or upgrade of transceivers by adjusting through adequate parameters or software updates. A specific IIC of WPRC is on "Define flexible radios able to implement several modes and/or standards with limited overhead in terms of reconfiguration time, computing overhead and power consumption".

4.4 NEWCOM++ towards the Complexity trend

The Complexity trend is a central topic with its wide interpretation. Almost all WPR activities and IICs proposed have set requirements and forecast risk often linked with the complexity issue.

WPR3 is focusing on the design of new algorithms for specific challenging system scenarios, such as Coded-OFDM, Non-orthogonal multicarrier, CPM, and Coherent QAM systems. This IIC has the specific requirement to offer a wide range of choices in terms of the *performance/complexity trade-offs*.

Similarly, for all IICs set by **WPR8**, the main *requirement and, at the same time, constraint is set by the complexity of implementation*. Indeed the approaches to be used often require application of complex design procedures, accounting for many separate aspects (channel model, physical layer issues, the type of radio resources, network topology, application level requirements, buffer management strategies, etc). Such complexity in many cases prevents from using mathematical approaches and requires heavy simulations which are time and effort consuming.

Interpreting the current Energy saving tendency under the Complexity trend, we can cite here **WPR10** because *energy consumption* is a central topic in wireless sensor networks, with the constraints provided by finite battery life, traffic characteristics, topology and mobility. In this sense goes also **WPR11**, with a specific IIC dedicated to design and develop new *forwarding/routing algorithms that match the energy-saving requirements* of emerging networks where opportunistic techniques are expected to be exploited.

WPR4 on coding is for nature careful towards the complexity theme being the need for *low complexity receivers* the basic requirement, with *reduced power consumption of handsets and extended battery life*. Some explicit examples are the IICs on Quantized Design for Iterative Receiver Components and on Low-Complexity Components in Iterative Decoding. Also **WPR6** has strong attention towards the requirements of power decrease and length of battery life and for reduced complexity of routing in highly volatile/mobile networks.

Complexity is also a central requirement for all RRM activities carried out within **WPR9**.

Further, because all cooperation systems can be seen as complex systems, we can signal under the Complexity trend all those WPRs that are related to *cooperation*.

Finally, a special mention towards the trend to minimize complexity must be done for **WPRC**, which handles with *computationally intensive communication tasks* and aims at defining flexible radios able to implement several modes and/or standards with limited overhead in terms of reconfiguration time, *computing overhead and power consumption*.

4.5 NEWCOM++ towards the Cognitivity trend

The Cognitivity trend is present in **WPR3** through *adaptive coding and modulation*, i.e. proper real-time adjustment of transceiver parameters, based on the environmental and operational conditions for better spectral utilization.

A cognitivity influence can also be found in all network related WPs. In particular, **WPR6** through the self-configurability, related to the surrounding environment, that is characteristics of the relay and cooperative networks it tackles.

WPR8 has set a specific IIC on this direction on the design of *scheduling in Cognitive Radio Networks*, with the objective of optimizing performance with contained complexity.

WPR9 introduces the interesting IIC on the "*Sensorial Radio Bubble*" concept for Cognitive Radio Equipment. In a cognitive behaviour, the perception of the stimulus is the means to react to the environment and to learn the rules that permit to adapt to this environment. WPR9 proposes to define a volume around the equipment, called the "sensorial radio bubble", the diameter of which is at the scale of the sensing possibility of the equipment. It will be the responsibility of a cognitive radio equipment to be aware and interact with all the pertinent information available in the area that can help the equipment to match its functionality to the global state of its environment.

WPR11 exploits cognitivity through the *dynamism associated with the networks* characterizing opportunistic communications, dynamism related to the surrounding environment where several groups and islands of connected devices suddenly appear, disappear and reconfigure dynamically.

In **WPRB**, cognitivity is addressed via the concept of *Cognitive Positioning*, i.e. foreseeing adaptive terminals sensing free bands and placing suited signals on those band for optimal (i.e., highest accuracy) localization.

Finally, **WPRC** provides enabling technologies for cognitivity since the main concept on which it is based, i.e. *flexibility*, is a must whenever cognitive radio is considered, since cognition relies on the ability of the transceiver to adapt its behaviour to decisions based on environment changes. As such, flexible hardware is a key component of a cognitive radio terminal or system.

4.6 NEWCOM++ towards the Opportunism trend

The Opportunism trend is the essential entity of **WPR11** on *Opportunistic communications*. The main IICs in this context are to devise and develop new models and tools for user and node mobility that really fit the characteristics of Opportunistic Networking environments; to design and develop new forwarding/routing algorithms that match the energy-saving requirements of emerging networks where opportunistic techniques are expected to be exploited; to design and develop a transport layer protocol that supports and fully exploits the potential of Opportunistic Networking; to design and develop a middleware system that facilitates application development within Opportunistic Wireless Sensor Networks (WSNs); to develop radio resource management algorithms for management of heterogeneous wireless mesh networks; to design topological structures that are not only based on the relative distance between nodes, but also on their intrinsic properties and to allow the existence of several of these topological structures simultaneously; to devise new technology-agnostic schemes to describe resources within the node and the (wireless) network, so they can be managed more easily.

WPR2 investigates *opportunistic beamforming* strategies which have proved that the sum rate due to complete CSI can be asymptotically achieved using only partial CSI. In particular, with Multibeam Opportunistic Beamforming (MOB) only the channel modulus information is sent through the feedback channel from each user so decreasing the feedback load in comparison with the full CSI (phase and modulo with respect to each antenna) by a factor higher than 2, depending on the feedback strategy. The MOB scheme benefits from the partial CSI that is available from all the users, to extract the system multiuser gain, as an implicit users selection is included in its performance.

WPR7 and **WPR8**, among other techniques, put some focus on *opportunistic scheduling*. The aim of this algorithm is the maximization of system throughput by serving always the user(s) with the best channel conditions, realizing the so called multiuser diversity, i.e., the independence of random channel fluctuations experienced by each user in the system. However, it is worth noting that this gain can be realized only if link adaptation techniques are available to take advantage of the improvement in channel conditions. This technique has the advantage of maximizing throughput and spectral efficiency, which is crucial in wireless systems due to spectrum scarcity, but it has an important drawback in its unfairness, since users affected by poor channel conditions may starve for long time.

WPR8 is also focused on *Opportunistic Spectrum Access techniques*. An opportunistic frequency channel skipping protocol is proposed for search of better quality channel, where the channel decision scheme is based on Signal-to-Noise Ratio (SNR). The key mechanism is that if the SNR is not favourable, mobile nodes can opportunistically schedule better quality frequency channels enabling data transmission at higher rates.

WPR9 has also some reference to opportunism, through algorithms such as *Opportunism Sub-Carrier Allocation* and opportunistic spectrum usage.

WPR10 focuses on opportunistic transmission and multi-user diversity (traditionally used for providing high throughput efficiency and fairness) to provide high quality estimation by appropriately coordinating sensor node transmissions towards the fusion centre.

4.7 NEWCOM++ towards the Cooperation trend

The Cooperation trend is widely present in NEWCOM++ WPRs.

WPR6 is of course centred on Cooperation, as its title immediately reveals, in the view of obtaining significant capacity and multiplexing gain in wireless communications. This encompasses strategies and codes (including error correcting codes, linear precoders or both), which exploit relaying diversity in order to realize seamless communication and reduce complexity of routing in highly volatile/mobile networks. In particular, the focus is on *cooperative techniques at both physical and network level*, considering algorithms, protocols and electronic device, and on the definition of bounds on the performance achievable with cooperation.

WPR5 can also be seen under the Cooperation trend, because it is linked with *P2P that can be seen actually as a cooperative application*.

Game theoretic modelling of node interactions in autonomous systems is the response of **WPR10** to the Cooperation trend, in particular with *the cooperative games*. Game theory represents a useful tool to model and try to counterfeit misbehaviour at wireless network nodes, and cooperative games are those games where some synchronization and collaboration among network nodes is allowed and, thus, more interaction between users is needed.

WPR11 is in line with the Cooperation trend via its opportunistic networks, where in many cases nodes may be required to provide their own resources (e.g., memory, bandwidth, battery power) for others to use, without getting any direct benefit from that, on a cooperation level.

WPRB follows Cooperation via its *cooperative positioning* to achieve “cooperation for ranging” in scenarios such as Cellular, Wi-Fi, Ad-hoc & Sensors networks. The interest towards cooperative positioning arises from the observation that all positioning systems must be energy-efficient and robust to imperfections in hardware, varying multi-path and fading propagation conditions, NLOS channels and possibly also strong interference. However, with the wide diffusion of WSN only few nodes are placed in known positions in order to reduce the installation costs, thus leaving several unknown-location devices out of the range of any reference node (due to the short transmission range). This is the case of ad-hoc network scenarios as well. Thereby, conventional positioning techniques employed in cellular mobile systems or WLAN are not appropriate and localization needs to be carried out cooperatively by the nodes, i.e. by allowing nodes in unknown locations to exchange measurements on a peer-peer basis.

4.8 NEWCOM++ towards the Security trend

The trend of Security is embodied by **WPRA** on “*Security in Wireless Networks*”, the transversal WPR specifically addicted to the privacy and security topics. Basically the goal of this WPR is to further formalize secrecy concepts for fading channels. A particularly intriguing opportunity is the security that is provided by the random channel. The random channel naturally provides a level of protection against wiretapping and similar attacks

4.9 NEWCOM++ towards the Miniaturization trend

The Miniaturization trend is reflected by **WPR1** through the *body area network* concept, exploiting the concept of miniaturization in the sense of “*network cells miniaturization*”.

In addition **WPR6** benefits greatly from the *miniaturization of devices*, which allows the design and fabrication of extremely powerful and complex ICs, FPGAs, DSPs.

4.10 NEWCOM++ towards the Convergence trend

The Convergence trend belongs to **WPR11** through the concept of *oppnet*, where it assumes in particular the meaning of *network convergence*. Oppnet can be seen as hoc networks where diverse systems, not originally employed as nodes of an oppnet, join it dynamically in order to perform certain tasks they have been called to participate in. They are used for emergency applications.

WPR7 implements the convergence trend through joining source coding with channel coding to optimize performance, implementing the *coding convergence***.**

WPR9 realizes the *convergence of resource exploitation*, by joint RRM and flexible spectrum utilization.

Finally, by discussing on cross-layer techniques, **WPR7** is towards a *layer convergence*. Cross-layer optimization offers many opportunities to improve end-to-end distortion without the need to redesign all components of the communication chain, but rather by exploiting information from one layer in existing optimization mechanisms in another layer. An instance of this is the use of feedback mechanisms provided by mobile communications standards in order to optimize the perceived quality of mobile video streaming, applied to *cross-layer scheduling*.

SECTION 5 – THE EUROPEAN PROJECT TOWARDS THE ICT TRENDS

A final insight on the ICT trends roadmap is provided here providing citation of relevant projects within the European framework that have been and currently are active towards the directions identified above.

Indeed, many European projects can be seen as central players in the definition and growth of the ICT trends forming the *DNA of ICT evolution*. Some examples are the following:

- The MAGNET and MAGNET Beyond projects are the reference for the *Personalization* meta-trend [11]. Some of the main focus areas of MAGNET Beyond are user-centricity, personalization and personal networking. MAGNET Beyond wants to improve the quality of life for the user by introducing new technologies that are more adapted to the needs of the user: the objective is to make environments smarter, more responsive, and more accommodating to the needs of the user, and this without jeopardizing privacy and security of the individual.
- The ORACLE project must be cited for the *Opportunism* and *Cognitivity* trends [12]. By providing novel mechanisms for enhanced and more efficient spectrum usage, ORACLE supports the i2010 initiative aiming at spectrum optimization via the development of agile terminals and mechanisms to facilitate access networks (i.e. the access points, base stations and/or Node-Bs) that can sense “holes” in used spectrum and adapt their transmission characteristics to use these “holes” in the radio.
- The objective of the FIREWORKS [13] project is to design and validate a prototype of the next generation Broadband Wireless Access (BWA) systems based on IEEE 802.16 Standard, including cooperative communications together with mesh network architecture, flexible relay-based deployment cross-layer optimisation, In pursuing its objectives, the project can be seen as a joint expression of the *Cooperation*, *Flexibility*, and *Convergence* trends.
- The ROCKET project [14] is an example of application of the Cooperation trend. In fact, it aims at providing a ubiquitous wireless solution to reach bit rates higher than 100Mbps with peak throughputs higher than 1Gbps, based on Reconfigurable OFDMA Cooperative Networks enabled by agile spectrum use.
- The CODIV project [15] is another expression of the *Cooperation* trend, pursuing the objective of developing and optimizing diversity techniques (at both physical and network levels) to increase network capacity, robustness and fairness, and demonstrate their feasibility, through cooperation.
- The MAESTRO project [16] is an example of the *Ubiquity* and *Convergence* trends. Indeed, it aimed at the development of the Satellite Digital Multimedia Broadcast (SDMB) concept, paving the way for effective Satellite and Terrestrial network convergence. The SDMB system aims at complementing mobile networks with broadcast and multicast capabilities for a spectrum effective delivery of multimedia services on mobile devices. Taking advantage of the natural assets of satellite systems and of the full interoperability with terrestrial standards, the SDMB system aims at facilitating the successful deployment of UMTS, minimising geographical discrimination and fostering multimedia usage adoption in Europe, effectively bridging the digital divide, towards Ubiquity.

SECTION 6 – CONCLUSIONS

In this deliverable, we have attempted to depict the complex picture of the ICT trends that are moving the society, with special focus to the European arena, towards technological innovation basically aiming at satisfying the basic personal needs. Accordingly, after a detailed identification of the personal needs guiding any form of evolution, the current evolution waves in Europe in the ICT field have been investigated.

Inspired and fully integrated with the research activities carried out within the NEWCOM++ project, we have then identified the main ICT trends and we have classified them through a novel metaphor that exploits the biological concept of DNA, yielding what we have indicated as the DNA of the ICT evolution. In particular, two major ICT meta-trends, identified as personalization and distribution, form the structure of the DNA itself. Then these two filaments support, and are supported by, ten major trends: ideal performance, ubiquity, flexibility, complexity, cognitivity, opportunism, cooperation, security, miniaturization, and convergence, which are described in detail in the deliverable.

Finally, thanks to the contributions received from NEWCOM++ WPR Leaders in response to a survey set out by WPI.6, we have organized the ICT activities currently under research within the project, underlining their synergies with the identified ICT trends.

The following list of observations summarizes the essence of the deliverable and provides the reader with our concluding messages:

- There is an evolution in society, which affects the personal needs of each individual, and as a consequence opens up opportunities for the provision of new services.
- Information and Communication Technologies are main drivers in this transformation from the Industrial Society to the Information Society.
- Europe wants to play a primary role in this evolution, and is investing significantly in research, development and innovation.
- The major trends that can be extrapolated from the societal evolution are Personalization and Distribution. We claim that these are also the meta-trends in the evolution of ICT.
- Out of the two meta-trends, we have identified ten specific trends in the evolution of ICT, specifically: the search for ideal performance; ubiquity; flexibility; complexity; cognitivity, self-organization and bio-inspiration; opportunism; cooperation; security; miniaturization; convergence.
- The research activities carried out in NEWCOM++ WPs can be mapped over these trends.
- Observing the above mapping, it can be stated that NEWCOM++ is contributing significantly to all of the major trends in the evolution of ICT technologies. We can expect significant impact out of this research endeavour.

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[15] EC FP7 CODIV project (Enhanced wireless communication systems employing cooperative diversity) https://projects.av.it.pt/codivdir/Default.aspx

[16] EC FP6 MAESTRO project (Mobile Applications and sErvices based on Satellite and Terrestrial interworking)

APPENDIX 1 – THE NEWCOM++ CONSORTIUM SURVEY ON ICT TRENDS

Within the activities of WPI.6, a survey has been circulated among NEWCOM++ Research WP leaders with the aim of identifying the main research topics active in the project and providing the basis for ICT trends definition process. In particular, the results of this survey have been matched to possible evolution scenarios of the ICT world, in order to extract all the possible exploitation potential out of NEWCOM++'s scientific endeavours.

The survey was formulated to investigate on the goals, users, requirements, constraints, impact, and risks that characterize the activity of the research workpackages WPR.x in NEWCOM++, where

- The *goals* are the potential achievements of the research activity that should bear significant progress in the ICT evolution. For the purposes of the survey, these goals have been identified as *innovative ICT concepts* (*IICs*). An IIC can be an algorithm, a theorem, a methodology for analysis and/or design, a protocol, a SW or HW object, etcetera.
- *Users* are the categories towards which the IIC is directed and can be manufacturers, operators, service providers, citizens, members of the scientific community, educators, etcetera.
- The IIC *requirements* are intended in a broad sense, as seen from the point of view of all potential users of the innovative ICT concepts. Requirements can be posed on services, applications, architectures, networks, links, equipment, theory, etcetera. Requirements can be expressed in terms of performance, complexity, flexibility, cost, theoretical thoroughness, etcetera.
- The *constraints* are limiting factors that are normally outside of the direct control of the researcher. Constraints can be imposed by technology, economy, standardization, regulation, incomplete theoretical paradigms, etcetera.
- The *impact* is a qualitative perception of the bearing that a specific IIC can have. A tentative qualitative assessment goes from 1 to 3, where 1 indicates large impact, i.e. a breakthrough; 2 indicates a significant impact, i.e. considerable innovation; and 3 indicates useful extension of previous knowledge.
- The *risk* is measured in terms of the confidence that the WP leaders have in the achievements of the goals they have set. High risk-high impact activities are possible, and are balanced with high confidence-lower impact activities. A tentative qualitative assessment goes from 1 to 3, where 1 indicates high risk, i.e. IIC may not be achieved, but it is worth trying; 2 indicates that it is possible to achieve IIC within NEWCOM++ lifetime; and 3 indicates high confidence to achieve IIC, i.e. it will be delivered.

A massive response to the survey has been received form WPR leaders, and the detail of the answers is reported in the following for the sake of completeness, divided per WP.

Table 1 – WPR1 survey response

<table>
<tr><th>Innovative ICT Concept (IIC)</th><th>Potential Users</th><th>Main Requirements</th><th>Constraints</th><th>Impact</th><th>Risk</th></tr>
<tr><td>Design of radio channel models appropriate for advanced wireless networks (broadband, mobile-to-mobile, body-area). These models shall incorporate the relevant features affecting the performance of these systems (multi-channel correlation, multi-dimensional dispersion, polarization, fast time-variance, localization, near-field conditions, etc.).</td><td rowspan="3">• Manufacturers of advanced wireless networks and service providers
• Manufacturer of localization devices and context-dependent applications
• Manufacturers of channel sounders and simulators
• Academic institutions involved in research in radio channel investigations and localization, as well as in the design of wireless networks</td><td rowspan="3">• The models to be developed shall accurately mimic the features of real channels
• The designed models shall exhibit a tractable complexity
• The channel parameters estimators shall be robust, accurate, and exhibit a tractable complexity</td><td rowspan="3">No major limiting constraints are foreseen</td><td rowspan="3">Level: 2 – The insight gained into the features of the radio channels will enable to design systems or components of systems, like channel estimators and equalizers, which will significantly improve the overall performance of advanced wireless networks. Complexity can also be reduced by exploiting this knowledge</td><td rowspan="3">Level: 2 – We are highly confident that we will achieve most of the scientific objectives defined in the joint activities within WPR1 during the N++ lifetime. The success rate is expected to be around 75%.</td></tr>
<tr><td>Get insight into the features of the radio channels relevant for these advanced wireless networks by means of experimental investigations</td></tr>
<tr><td>Design of efficient, robust channel estimators of the parameters of the radio channel models and compensation of nuisance effects in channel sounders, e.g. phase noise.</td></tr>
<tr><td>To develop a channel model for Body Area Networks (BANs) that exploits the use of MIMO.</td><td>Potential users are the scientific community and service providers</td><td>Scientific community: theoretical model with well-defined parameters.
Service providers: quantifiable and realistic results (given by a user friendly simulator).</td><td>New technology and few researchers in this field.</td><td>2</td><td>3</td></tr>
</table>

Table 2 – WPR3 survey response

Innovative ICT Concept (IIC)	Potential Users	Main Requirements	Constraints	Impact	Risk
Develop a General modelling approach useful in AMC algorithm design in Coded OFDM systems.	Members of the scientific community in the field of AMC in wireless communications	• Wide Applicability: The model description should be able to accommodate selected current, emerging (e.g WiMax) or future standards employing MIMO-COFDM, in a variety of environment characteristics. • Backward Compatibility: The supported modes of operation should include at the minimum the mandatory modes of a selected standard (e.g. WiMax).	Incomplete theoretical knowledge, and implementational complexity: Complexity is an important limitation in the area of AMC design (for both A and B): In most cases of interest (current/emerging standards), a compact and accurate model description that includes all relevant parameters is hard to formulate. The resulting optimal AMC algorithms in most cases are extremely complex, thus usually suboptimal solutions are preferred.	2	2
Design of new algorithms for specific challenging system scenarios (Coded-OFDM, Non-orthogonal multicarrier, CPM, Coherent QAM systems).	Link-level designers of advanced wireless systems	• Trade-off capability: The proposed new algorithms should offer a wide range of choices in terms of the performance/complexity trade-off plane		3	2

Table 3 – WPR4 survey response

<table>
<tr><th>Innovative ICT Concept (IIC)</th><th>Potential Users</th><th>Main Requirements</th><th>Constraints</th><th>Impact</th><th>Risk</th></tr>
<tr><td>Geometrical Interpretation of Iterative Decoding (GIID)</td><td rowspan="10">Manufacturers – in particular those who design ASICS for 3G/4G, WiMax, DVB-S2 and related present and future standards.
Long term interest: AFGC, PDPC, ELPD
Short and medium term interest: DSNBC, QDIRC, LCCID, DCAS, TVS

Members of the scientific community and educators will be interested in all topics, in particular
GIID, NBIC.</td><td rowspan="10">• Efficient design of wireless receivers motivated by theory and provably optimal
• Reduced complexity receiver
• Reduced chip area usage due to simplified algorithms
• Extended transmission range of mobile due to efficient capacity-approaching information encoding
• Reduced power consumption of handsets and extended battery life
• Improved transmission quality for data and multi-media</td><td rowspan="10">• Much of the research defined is of theoretical nature and therefore of high risk
• This means that the potential yield if successful is greater than for more practical research
• It also means that the potential yield if unsuccessful is non-existant, unlike for more “applied” research projects where results can often be exploited one way or another
• Some algorithms developed require transmitter-side modification and must therefore be adopted in a standard before becoming relevant. It is expected that where great potential benefits can be obtained by implementing a new technique, all standards will eventually adopt it (as is now happening for turbo/LDPC codes) but it may take some time
• Some algorithms are receiver-side only and do not suffer from the standardization constraint</td><td>3</td><td>2</td></tr>
<tr><td>Analysing Factor Graphs with Cycles (AFGC)</td><td>2</td><td>1</td></tr>
<tr><td>Practical Design of Polar Codes (PDPC)</td><td>1</td><td>2</td></tr>
<tr><td>Non-binary information combining (NBIC)</td><td>3</td><td>1</td></tr>
<tr><td>Design of short Non-binary LDPC codes (DSNBC)</td><td>2</td><td>3</td></tr>
<tr><td>Efficient Linear Programming Decoder (ELPD)</td><td>1</td><td>1</td></tr>
<tr><td>Quantized Design for Iterative Receiver Components (QDIRC)</td><td>1</td><td>1</td></tr>
<tr><td>Low-Complexity Components in Iterative Decoding (LCCID)</td><td>3</td><td>3</td></tr>
<tr><td>Design of Code-Aided Synchronization (DCAS)</td><td>2</td><td>2</td></tr>
<tr><td>Time-varying Synchronization (TVS)</td><td>2</td><td>1</td></tr>
</table>

Table 4 – WPR5 survey response

<table>
<tr><th>Innovative ICT Concept (IIC)</th><th>Potential Users</th><th>Main Requirements</th><th>Constraints</th><th>Impact</th><th>Risk</th></tr>
<tr><td>1. Erasure coding on the network layer (mainly for video transmission)
The main IICs are:
Guidelines to understand what erasure correction capability is needed in the case of wireless transmission.
A thorough comparison of decoding complexities of RS codes in a multitude of operational situations
A theoretical comparison of binary and non-binary, optimal coding schemes. This incorporates clear statements concerning the comparison of Digital Fountain codes and maximum distance seperable codes over larger alphabets.</td><td rowspan="4">The IICs within our workpackage are aimed at increasing the understanding of the optimal operation of wireless networks. As such the typical user of the IICs are members of the scientific community, network operators, services providers, in short anybody involved in the operation and design of a wireless network.</td><td rowspan="4">The main requirement for the IICs to reach its intended audience is a clear and proactive dissemination of the results. This will be achieved through the various industry partnerships available within the workpackage and other publication activities</td><td rowspan="4">Since the IICs in this workp[ackage are of research nature mostly leading to publishable material the outside constraints are minimal. However, it is essential that the results of this workpackage are being demonstrated in realistic scenarios, since otherwise they are too easily constraint to theoretical exercises.</td><td>2</td><td>2 - 3</td></tr>
<tr><td>The main IICs are answers to the following problems. The answers will be given in form of Theorems, protocols, statements and demonstrations:
What is the end-to-end delivery probability in network cding enhanced geographic routing
How large is the end-to-end delivery delay in network coding enhanced geographic routing
Estimation of the impact of mobility of the nodes on the the overall performance
How do integrated routing/MAC protocols compare to non-integrated ones
How can we provides specific opportunities for network coding in integrated routing/MAC protocols</td><td>2</td><td>2</td></tr>
<tr><td>An information theoretic analysis of network coding.
The IICs in this subpackage will be achieved in form of Theorems.
What benefits can network coding provably offer in terms of rate region , outage capacity, and correlated sources
Evaluate, in terms of capacity gain, the optimal trade-off between the benefits and limitations of cooperation in wireless communications, and including realistic constraints as delay and coordination requirements</td><td>2</td><td>2 - 3</td></tr>
<tr><td>Coding for relay networks
The IICs in this subpackage will be achieved in form of Theorems and design algorithms.
Propose a theoretical framework to solve the critical quantification issue of the intermediate (continuous) propagated messages at the relays
Propose new powerful network-channel codes on graphs able to approach the theoretically promised rates and diversity gains;
Investigate of the relationship between network topology and coding gain. This includes a mathematical characterization of the network coding performance in network models with dynamic topologies (random graph topologies, mobility, and propagation models) and the identification of favorable topologies for network</td><td>1 The high rating is due to the assessment that this IIC will provide an understanding of wireless network operation which has an enabling character, with the potential to make networks, and hence services and applications possible which in todays technology are impractical to realize.</td><td>1</td></tr>
</table>

Table 5 – WPR6 survey response

Innovative ICT Concept (IIC)	Potential Users	Main Requirements	Constraints	Impact	Risk
1. Cooperative techniques at PHY or NET level	1. Educators for training of students (1/2/3 above) 2. Manufacturers if techniques applied in a standard or a proprietary system (1 or 2 above) 3. Members of the scientific community (all from above)	1. For the manufacturers or telco, the techniques must show a benefit (rate, power decrease, length of battery life, etc) for particular scenarios 2. For a customer, could be motivated to offer his/her terminal for cooperation if bill advantage !	no points	I think the impact can be large if a benefit can be shown. Of course this would be reminiscent of MIMO and therefore can be ranked as 2 or 3.	The possibility exists. Mark 2. The question is more the impact on standardization and products
2. Algorithm or protocol or electronic device					
3. Bounds on the performance achieved with cooperation					

Table 6 – WPR7 survey response

Innovative ICT Concept (IIC)	Potential Users	Main Requirements	Constraints	Impact	Risk
Algorithms for robust reception of video compatible with existing standards	operators, service providers, and mobile receiver manufacturers, scientific community	Operators: compatibility with existing standards, contributions to standards, scalable videos robust to error transmissions Service providers: scalable videos robust to error transmissions Manufacturers of mobile handsets: compatibility with existing standards, contributions to standards, scalable videos robust to error transmissions (our work could allow to design better receivers compatible with existing emitted signals)	standardization can prevent some of our innovations to be used (but not all of them) the paradigm is also not fully understood, we often know partial answers	1 if we are successful 2 very likely	For some parts : 3 But for other ones : 1 The topic of WPR7 has been studied for a long time, and rejected by the possible users due to (i) complexity,(ii) lack of compatibility, and (iii) too small improvements on the performance of existing systems. The last two items should be solved within NEWCOM++ lifetime
Better design of video coders for a better transmission (more robust towards transmission errors)					
Computing bounds for the performance of video broadcasting					
Contributions to standards					
Application to scalable videos (interaction of the source coder with the channel coder)					

Table 7 – WPR8 survey response

Innovative ICT Concept (IIC)	Potential Users	Main Requirements	Constraints	Impact	Risk
IIC0- Identification of Design Techniques for Scheduling Algorithms	IIC0 is intended for members of the scientific community	IIC0 – not applicable, as the challenge is of abstract nature	The basic constraints are posed by the complexity of the approaches to be used, that often require application of complex design procedures, accounting for many separate aspects (channel model, physical layer issues, the type of radio resources, network topology, application level requirements, buffer management strategies, etc). Such complexity in many cases prevents from using mathematical approaches and require heavy simulations which are time and effort consuming.	2	For all IICs, risk is low. There is no intention to find global optima. Rather, to produce technical advancements. Risk is then estimated as 3.
IIC1- Scheduling techniques for Multi-Carrier and Space Division Systems	IIC1-4 aim at the design of scheduling and RR assignment techniques for specific (yet not necessarily standardised) types of wireless interfaces, therefore they are more targeted to members of the scientific community, and researchers/technicians of network operators and manufacturers	IIC1-4 – requirements are in terms of performance (delay, fairness, throughput) and complexity of implementation		2	
IIC2- Distributed Scheduling in Interference-Limited Wireless Networks				2	
IIC3- Scheduling in Cognitive Radio Networks				2	
IIC4 - Scheduling Techniques for Heterogeneous Networks				2	

Table 8 – WPR9 survey response

<table>
<tr><th>Innovative ICT Concept (IIC)</th><th>Potential Users</th><th>Main Requirements</th><th>Constraints</th><th>Impact</th><th>Risk</th></tr>
<tr><td>1.- New JRRM (including Radio Access Technology selection) algorithms for heterogeneous networks to increase the overall QoS.</td><td>Manufacturers, operators, members of scientific community, educators. (Comments: In general, all of the identified IICs are in the form of algorithms to be applied over either wireless networks or wireless devices, so that they can be potentially used mainly by manufacturers, and in some cases by operators. On a second position, all the concepts can be useful from a general perspective for the members of the scientific community, and for educators, in the sense that they can be incorporated in teaching courses, mainly in post-graduate research-oriented (e.g. doctoral) courses.)</td><td rowspan="10">Manufacturers: Requirements in terms of how introducing the algorithms in new equipment.
(1) to (10): Performance, complexity, flexibility, cost.

Operators: Requirements in terms of how configuring the different network elements in accordance with specific algorithms.
(1)(2): Performance, complexity, flexibility, cost, facility of use.

Members of research community and educators: Requirements in terms of how exploiting the algorithms to develop new research concepts.
(1) to (10): Performance, complexity, theoretical completeness.

Service providers: Architectures – complexity, flexibility, cost;
Services – performance

Citizens:
Networks and Services QoS; Cost</td><td>Application of the optimal algorithm can be limited by standardization constraints (e.g. some required signalling or procedures may not be supported by current technologies). Technology and incomplete theoretical paradigms, standardisation, regulation</td><td rowspan="8">At this point of time it is difficult to predict because in all the cases it will depend on the specific algorithm/solution that will be obtained, but potentially impacts of 1 or 2 can be achieved.</td><td>3</td></tr>
<tr><td>2.- Automated optimisation algorithms of (J)RRM parameters using intelligent and adaptive computational methods</td><td>Manufacturers, operators, service providers, members of scientific community, educators.</td><td>Application of the optimal algorithm can be limited by available technology and equipment (e.g. some equipments may not provide the necessary inputs to execute the optimisation). Technology and incomplete theoretical paradigms constraints</td><td>3</td></tr>
<tr><td>3.- New joint channel allocation and scheduling solutions for OFDMA based on utility maximization</td><td>Manufacturers, members of scientific community, educators</td><td rowspan="2">Application of the optimal algorithm can be limited by available technology and standardization constraints (e.g. certain equipment may not be able to execute certain procedures within desired delay constraints, or some measurements may not be available, etc.)</td><td>3</td></tr>
<tr><td>4.- Game-theory based dynamic spectrum sharing algorithms for OFDMA</td><td>Manufacturers, members of scientific community, educators</td><td>3</td></tr>
<tr><td>5.- The “Sensorial Radio Bubble” concept for Cognitive Radio Equipment</td><td>Manufacturers, members of scientific community, educators</td><td rowspan="4">Application limited by available technology and regulation constraints. (Note: In all the cases the identified limitations are more related with the application/implementation of the identified IICs rather than with the research itself towards these IICs.)</td><td>3</td></tr>
<tr><td>6.- New distributed algorithms for Cognitive Radio.</td><td>Manufacturers, members of scientific community, educators</td><td>3</td></tr>
<tr><td>7.- New blind sensing techniques.</td><td>Manufacturers, members of scientific community, educators</td><td>3</td></tr>
<tr><td>8.- New algorithms for making secondary use of spectrum</td><td>Manufacturers, members of scientific community, educators</td><td>3</td></tr>
<tr><td>9.- Introduction of advanced analysis and visualisation methods.</td><td>Manufactures, operators, service providers</td><td>Technology and incomplete theoretical paradigms</td><td>2</td><td>2</td></tr>
<tr><td>10. - Managing wireless parallel transmission of services and systems in heterogeneous networks.</td><td>Manufactures, operators, service providers and citizens</td><td>Technology and incomplete theoretical paradigms, standardisation, regulation</td><td>1</td><td>1</td></tr>
</table>

Table 9 – WPR10 survey response

Innovative ICT Concept (IIC)	Potential Users	Main Requirements	Constraints	Impact	Risk
[WSN-MODEL]: Analytical model for performance evaluation of Wireless Sensor Networks, featuring a unifying approach for considering access and connectivity issues.	1. Members of the scientific community. 2. Educators.	1. Regarding educators, every IIC should provide state of the art overview and analytical results and methodology in order to facilitate teaching and the comprehension of recent advances in networking science. 2. For the members of the scientific community, the WSN-MODEL should result in deriving algorithms with low implementation complexity, generality and ability to render a wide range of practical scenarios for wireless sensor networks.	1. All IICs are related to theoretical aspects of network theory and as such, it is difficult to derive optimal and directly implementable algorithms. 2. The trade off between sub-optimality and implementation requires extensive research and testing effort in order to be addressed. 3. There is a lack of tools/benchmarks suitable for testing in realistic scenarios the various algorithms. Especially, for large network settings, it is time and man-hour consuming to set up such experiments.	3	2
[BACK-PRESSURE]: Back pressure based Resource Allocation: The main objective is to push the capacity limits of wireless through decentralized network control with minimum overhead.	1. Members of the scientific community 2. Educators. 3. Industry members (manufacturers, operators and service providers)	3. For the members of the scientific community, BACK-PRESSURE based network control is crucial is order to transfer maximum amount of information from source to destination. Such policies should be implementable, i.e. with low computational complexity and amenable to distributed implementation. Likewise, the members of the Industry are interested in simple implementable algorithms which are able to (i) enhance the performance of their products, e.g. relaying switches, (ii) facilitate the design and the operation of large and complex networks. The manufacturers will adhere to the design of such policies.		1	2
[ESTIMATION]: A methodology for the deployment of a sensor network for estimation of an unknown quantity or parameter or process. Emphasis is given in using opportunistic transmission and multi-user diversity in order to optimize estimation quality.	1. Members of the scientific community 2. Educators. 3. Industry members (manufacturers, operators and service providers)	4. The ESTIMATION IIC is expected to introduce novel research directions for the members of the scientific community, and opportunities for the design and development of respective detection systems by the manufacturers.		2	2
[GAME THEORY]: Game theoretic modelling of node interactions in autonomous systems. The envisioned autonomic node operation necessitates developing game theoretic models that capture selfishness and node misbehaviour.	1. Members of the scientific community 2. Educators. 3. Industry members (operators, software developers and service providers)	5. Educators and the members of scientific community are expected to obtain insights in autonomic operation of networks through the GAME THEORY IIC. The results can be used for teaching game theoretic principles for designing future autonomous networks. Additionally, the results will trigger further research preparative to derive realistic models and thus predict behaviour of autonomous networks. The above hold for members of the Industry as well.		1	1
[PERCOLATION]: Use of percolation theory and properties to study connectivity properties of wireless networks. Emphasis is given in connectivity problems more specific to wireless sensor networks as well as ad hoc and mesh networks.	1. Members of the scientific community. 2. Educators.	6. The PERCOLATION IIC is expected to foster research within the members of the scientific community, for specifying fundamental performance limits and connectivity properties of wireless networks. Educators will identify useful bonds between physics-inspired principles (one of which is percolation) and networking that will lead to using physics methods for understanding the collective behaviour of large wireless networks.		2	1
[NETWORK-IT]: Use of network information theory to derive fundamental performance limits and scaling laws for wireless networks with a large number of nodes. The focus is on presenting existing results on fundamental performance limits on transport capacity, user throughput and delay, and on scaling laws underlying wireless networks in the asymptotic regime of a large number of nodes.	1. Members of the scientific community. 2. Educators.	7. Members of the scientific community and educators should expect NETWORK-IT IIC to lead to derivation of fundamental performance limits of networks with emphasis on the asymptotic regime of a large number of nodes.		1	2

Table 10 – WPR11 survey response

Innovative ICT Concept (IIC)	Potential Users	Main Requirements	Constraints	Impact	Risk
a) To devise and develop new models and tools for user and node mobility that really fit the characteristics of Opportunistic Networking environments;	a) IIC a) will be of interest to members of the scientific community, as they especially recognize the current lack of realistic and trustworthy mobility models;	a) To be an effective tool for scientific community, the models suggested in IIC a) should actually capture the essence of user and node mobility while keeping the level of complexity low;	Technology in this area has not yet experienced enough, and user penetration of mobile applications exploiting proximity is still low. As a consequence, research on opportunistic networking is still young.	a) 2 - Although several mobility models have already been developed, few take opportunistic properties into consideration. As such, IIC a) will most likely fall into the second category: a significant impact with considerable innovation;	a) 1 – IIC a) falls in the first categor: high risk;
b) To design and develop new forwarding/routing algorithms that match the energy-saving requirements of emerging networks where opportunistic techniques are expected to be exploited;	b) IIC b) is primarily target at perspective system developers that want to design energy-efficient techniques oriented to emerging network paradigms such as delay-tolerant networks, autonomic networks, socio-aware community networks, etc;	b) To justify the use of the forwarding/routing schemes in opportunistic environments, as suggested in IIC b), the energy saving gain that they provide will have to counterbalance the need of implementing new algorithms instead of the ones traditionally used in ad hoc and sensor networks;		b) 2 - Although several energy-efficient forwarding/routing schemes have already been developed, few take opportunistic properties into consideration. As such, IIC b) will most likely fall into the second category: a significant impact with considerable innovation;	b) 2 - IIC b) has a relatively reduced risk factor but is still in its initial stage, hence it should fall into the second category: possible to achieve within the NEWCOM++ lifetime;
c) To design and develop a transport layer protocol that supports and fully exploits the potential of Opportunistic Networking;	c) IIC c) is primarily targeted at veteran WSN software developers that want to design new applications, or extend existing ones, for use over Opportunistic Networks;	c) To justify the use of a dedicated transport layer protocol within opportunistic environments, as suggested in IIC c), the transport layer functionality that it provides and its ease of use will have to outweigh the additional computational and network resources that it uses;		c) 2 - Although some efforts have already been suggested that would transparently extend existing protocols for use within opportunistic networks, namely through the use of Bundle Layers, no dedicated transport protocols have been designed to fully exploit the potential of these networks. As such, IIC c) will most likely fall into the second category: a significant impact with considerable innovation;	c) 2 - IIC c) has a relatively reduced risk factor but is still in its initial stage, hence it should fall into the second category: possible to achieve within the NEWCOM++ lifetime;
d) To design and develop a middleware system that facilitates application development within Opportunistic Wireless Sensor Networks (WSNs);	d) IIC d) will mainly be used by WSN users that want to quickly and easily create new applications that work within Opportunistic environments, without having to go through the complex WSN software development process;	d) To justify the use of a specialized middleware system for Opportunistic WSNs, as suggested in IIC d), the flexibility that it provides as well as its ease of use will have to greatly decrease the effort of application development, while also not overly limiting its usefulness;		d) 2 - Although several middleware solutions have already been developed for WSNs, few take Opportunistic properties into consideration. As such, IIC d) will most likely fall into the second category: a significant impact with considerable innovation;	d) 2 - IIC d) has a relatively reduced risk factor but is still in its initial stage, hence it should fall into the second category: possible to achieve within the NEWCOM++ lifetime;
e) To develop radio resource management algorithms for management of heterogeneous wireless mesh networks;	e) IIC e) may be used by manufacturers, operators, citizens or members of the scientific community;	e) To provide opportunistic meshed connectivity to users, in IIC e);		e) 3 - IIC e) will have, at the start, a useful extension of previous knowledge.	e) 1 - IIC e) has a relatively reduced risk factor but is still in its initial stage, hence it should fall into the second category: possible to achieve within the NEWCOM++ lifetime;
f) To design topological structures that are not only based on the relative distance between nodes, but also on their intrinsic properties and to allow the existence of several of these topological structures simultaneously;	f) IIC f) will mainly be used by WSN users who wants to set the network topology for a specific scenario or application and tune it in real-time for new situations;	f) To justify the use of several topological structures, as suggested in IIC f), the flexibility and functionality that it provides will have to outweigh the additional computational and network resources that it uses.		f) 2 - IIC f) may be considered to have a significant impact with considerable innovation.	f) 1 – IIC f) falls in the first categor: high risk;
g) To devise new technology-agnostic schemes to describe resources within the node and the (wireless) network, so they can be managed more easily.	g) IIC g) will be of interest to operators and service providers as they have a technology independent mechanism to manage resources, as well as to members of the scientific community, as they can easily incorporate new mechanisms into the newly defined structure.	g) IIC g) allows the user to manage the resource of the node or network, without requiring deep inner knowledge of each of the employed technologies.		g) 2 - IIC g) will have a significant impact and the proposed method of defining the resources can be considered innovative.	g) 2 – IIC g) is mainly a scheme for defining resources and new technologies should be adapted to it, therefore it should be possible to achieve within the NEWCOM++ lifetime, but adaptations or changes could be expected after the NEWCOM++ project has finished.

Table 11 – WPRA survey response

<table>
<tr><th>Innovative ICT Concept (IIC)</th><th>Potential Users</th><th>Main Requirements</th><th>Constraints</th><th>Impact</th><th>Risk</th></tr>
<tr><td>1)Demonstrate theoretically the achievable secure rates in mobile environments.</td><td rowspan="2">The potential users are manufacturers, operators, service providers, citizens, militaries.</td><td rowspan="2">Manufacturers: The complexity and cost on devices will be a requirement.
Operators: The complexity and cost.
Service operators: Having protocols that can be used without a central entity may turn out to be a problem for operators (as there service role ,which includes security, may be diminished).
Citizens: Performance and battery lifetime
Militaries: Robustness and reliability of the protocols in any environment (and not in rich scattering environment or for some particular cases of the different channels)</td><td rowspan="2">Standardization: existing computationally (not provably) secure algorithms exist and comply already with the user’s request for civil application. However, with the increase of processing power (which make these techniques less appealing), physical layer security may become a real competitive approach.
Technology: The technology is still in a very early stage. Many hypothesis are unrealistic (things are partially known on the eavesdropper channel) and hard to meet (perfect channel reciprocity)</td><td rowspan="2">It can have a significant impact on wireless ad-hoc networks with little infrastructure where end to end security can not be guaranteed by an entity.</td><td rowspan="2">Some important theoretical results can be achieved during the lifetime of the project. As far as the practical and protocol aspects are concerned, there is a risk but it is more than important than trying. It is the only project in Europe which considers this new paradigm of physical layer security whereas in the United states, several projects have been accepted on this topic.</td></tr>
<tr><td>2)Provide protocols and algorithms for wireless secure communications.</td></tr>
</table>

Table 12 – WPRB survey response

Innovative ICT Concept (IIC)	Potential Users	Main Requirements	Constraints	Impact	Risk
Seamless positioning (SeaPos): the objective is to study Integration and interoperability to attain to the ultimate goal of ever-available indoor/outdoor localizazion services. This can be achieved trough: - Advanced data fusion techniques that integrate different indications (at the level of (pseudo-) ranges from the sensors or final user position) coming from different systems - Particle Filtering (Monte-Carlo sequential estimation), Bayesian estimation, for inter-operation of different positioning systems (GNSS and/or UWB) - Integration of non-radio-based positioning devices such as inertial sensors	Due to the wide-spread field of this topic, the potential users of the workpackage are manifold: they can be final users of location-based services (emergency, tourism, infotainment etc.), as well as manufactures and operators that deal with optimization of network resources, or "pure" navigation for transport and guidance. Moreover potential users can be identified in final users (such as citizens) that can take advantage of the applicability to heterogeneous networks that can gain in the use of "seamless positioning" with ever-available indication of the user and object's position.	SeaPos: Smooth handover between indoor/outdoor and/or urban/rural positioning systems using different technologies. The application should not perceive any discontinuity in the indication of the terminal position. This requires the development of "handover" procedures between different systems.	SeaPos: Lack of standardization. Whilst satellite navigation is already ubiquitous and standard worldwide, the different systems for local positioning are extremely heterogeneous in terms of technology and radio bands. Therefore, the development of universal procedures for inter-system handover has to face this huge variety of approaches.	1	1
Cooperative positioning (CooPos) in UWB and/or in vehicular networks. The objective is to study array processing, cooperative positioning, multi-sensor positioning in order to achieve "cooperation for ranging" for scenarios such as Cellular, Wi-Fi, Ad-hoc & Sensors networks.		CooPos: Triggered by military application, research on cooperative communications and positioning is reaching maturity. An example of application for CooPos is at the moment a vehicular communication network for cooperative driving based on high-accuracy relative positioning. Of course, cooperation for positioning needs by definition communication capability among the different terminals to communicate. The requirement is thus to develop signal and terminal architecture that can support in the same band and/or with the same signal joint navigation and communications.	CooPos: The constraint here is similar to the one concerning SeaPos. Cooperative positioning might be applied in a variety of environments, but optimization and applicability are constrained by the limited capability of intercommunications between nodes.	2	2
Environment characterization (EnviChar) (scatterers, scattering spread, cluster identification etc.)		EnvChar: Positioning techniques may be based on some kind of fingerprinting or environmental mapping of a certain area where the service is deployed and operational. The requirement is finding mapping techniques (for instance, techniques to characterize the statistical behaviour of a radio channel) that summarizes the huge amount of data usually intrinsic to such techniques into manageable databases or simple reconstruction algorithms can be handled by low-complexity terminals.	EnvChar: The HW that is needed to validate the diverse approach to perform fingerprinting and/or EnvChar is expensive and can be accessed only in very few labs in Europe. So the constraint here is given by limited availability of such resources.	3	2
Cognitive Positioning (CogniPos): adaptive terminals sensing free bands and placing suited signals on those band for optimal (i.e., highest accuracy) localization		CogniPos: The FCC has very recently released in the USA some bands for cognitive radio applications. The same bands may be used intermittently for positioning applications, provided suited cognitive algorithms to exploit the available spectrum in an optimum way are developed	CogniPos: Cognitive Positioning techniques are transversal, in that they can be applied to basically all wireless communication systems whenever a certain band is available. The constraint here is the availability of regulated bands to such services that has to be revised at a regulatory level	1	3

Table 13 – WPRC survey response

Innovative ICT Concept (IIC)	Potential Users	Main Requirements	Constraints	Impact	Risk
1.Propose multi-processor architectures to implement digital communication algorithms. This involves static and dynamic partitioning of processing tasks. 2.Define efficient communication on chip between processors. This include the analysis of Network on Chip technology 3.Define flexible radios able to implement several modes and/or standards with limited overhead in terms of reconfiguration time, computing overhead and power consumption. 4.Define specific architectures to handle computationally intensive communication tasks.	1. Communication system manufacturers, including handset and base station manufacturers 2. Microelectronic industry, as for instance chip or chipset vendors having customers in the telecommunication industry.	1. Consider state of the art or future communication standards 2. Consider real implementation constraints while considering advance technology capabilities, such as advanced silicon technology nodes 3. Benchmark the proposed solutions with the ones available in the industry.	1. Architecture exploration is a long task and evolution of standards as the exploration goes along may compromise some of the choices made. 2. Hardware specification and design is a manpower consuming activity and the research being carried out in WPR.C may be too partial, though addressing key challenges. 3. Access to advanced technology, such as silicon vendor advanced design kits.	Impact can be large or even breakthrough since WPR.C research is at the heart of future hardware functionalities that will be compulsory in future transceivers.	Risks are mainly related with the constraints mentioned