Strategic Research Agenda for Wireless Connectivity, Networks & Communication

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EXECUTIVE SUMMARY

Radio access network technology has been in the core of building the current information society. The most important and rapid advances in the information networks during the past 20 years have been based on the explosive growth in the adoption of new wireless technologies, systems and services. A major part of the Finnish economic success currently is based on various forms of radio access networks and technology. The expertise in the companies, universities and research institutes is on a top global level. The purpose of this Wireless Connectivity, Networks & Communication strategic research agenda (SRA) is to guarantee the maintenance and enhancement of the top technological expertise also in the future.

The major drivers in future information and communication technology (ICT) will be related to future internet technologies and architectures. One key dimension therein will be the wireless access component to enable smooth ubiquitous connectivity of a user or device. The smart environments of the future are envisioned to wirelessly connect trillions of devices. At the same time, the climate change and increasing energy cost call for particularly power and energy efficient solutions for the wireless access. Therefore, novel design of wireless networks and related radio technologies is a necessity. To guarantee the competitiveness of the Finnish ICT industry, service provides and application users, investments in the long term research and medium and shorter term development are needed.

The mission of this initiative is guaranteeing the competiveness of the Finnish radio network technology also in the future. The goal is to smoothen the adaptation to the paradigm change in the network technology to enable the continued success of the business in the area. The target of the technology development is to enable the practical provisioning of the anticipated and envisioned services in a sustainable manner in economic, societal and environmental sense.

This strategic research agenda contains several themes to achieve the targets stated in the mission. The fundamental themes elaborated to a higher level of detail in this document include but are not limited to

- Network Topologies and architectures
- Cognitive and Cooperative Networks
- Spectrum Sharing and Channel Access
- Ubiquitous Connectivity
- Fundamentals Behind Multiple Radio Technologies
- Transceiver Technologies
- Antenna technologies for future radio access networks
- Layerless Communications
- Radios as sensors and actuators
- Radio channel modeling

It can be said that the ICT sector has become the key industrial sector in Finland, and its main future prospects are in the development and deliveries of the telecommunications equipment. The current positions, however, cannot be maintained without strong investments in the research of the mobile communications. The transition from voice to data-driven networks is ongoing and will get more speed in the future. This will have major implications on the mobile industry. It has to develop such Radio Access Networks, which will meet the requirements of the future applications and services.

The key rationale for this Research Agenda is fundamentally to create technology that will enable economic growth and prosperity for Finland. Good technology resulting from research, if pulled through with appropriate business applications, will result in economic growth, and prosperity for a wide range of Finnish industries, not only the communications or ICT industry.

1. INTRODUCTION

Radio access network technology has been in the core of building the current information society. The most important and rapid advances in the information networks during the past 20 years have been based on the explosive growth in the adoption of new wireless technologies, systems and services. A major part of the Finnish economic success currently is based on various forms of radio access networks and technology. The expertise in the companies, universities and research institutes is on a top global level. The purpose of the Wireless Connectivity, Networks & Communication strategic research agenda (SRA) is to guarantee the maintenance and enhancement of the top technological expertise also in the future.

The major drivers in future information and communication technology (ICT) will be related to future internet technologies and architectures. One key dimension therein will be the wireless access component to enable smooth ubiquitous connectivity of a user or device. The smart environments of the future are envisioned to wirelessly connect trillions of devices. At the same time, the climate change and increasing energy cost call for particularly power and energy efficient solutions for the wireless access. Therefore, novel design of wireless access networks and related radio technologies is a necessity. To guarantee the competitiveness of the Finnish ICT industry, service provides and application users, investments in the long term research and medium and shorter term development are needed.

2. VISION AND MISSION

2.1. Application Vision

By the year 2020, mobile and wireless communications will play a vital role in all aspects of the lives of the industrialized countries' citizens. More and more devices will be networked to form smart environments to enable the realization of the ubiquitous information networks. The overall goal of the evolving networks is to improve the quality of life and productivity of human operations. The current financial turbulence and the technology enhancements needed by energy efficiency challenges have a major impact also on the information and communication technology (ICT).

Wireless World Research Forum (WWRF) and eMobility communities have collected and integrated different views and visions about wireless systems. According to these visions in the future by 2020 users will be able to access anytime and anywhere services in a secure and trustworthy manner tailored by their preferences and environment. Applications also aim to provide relevant information about the users in order to supply services and applications that best suit their preferences and environment. Applications and services are pervasive and the number of wireless devices is increasing from the current one device/person to about 1000 devices/person. People, all their things, and nearly all things in their living and working environment will communicate with each other. The main tasks of a communication system will be to provide a cost efficient platform for smart space applications and delivery of entertainment and information to users.

A major objective of the networks of the future will be improving energy efficiency in all of its meanings. The future networks and technologies will be remarkably more energy efficient than the current ones. This calls for new paradigms for the network architecture and technology design. What is even more important, the future applications run over the networks will be serving the goal of energy efficiency and productivity. More and more devices will be connected (wirelessly) to be part of a global ubiquitous information network. Radio frequency identifier (RFID) tags will be placed on virtually everything in some time. This enables improved logistics in terms of sharing transportation of humans and various goods in much more efficient way than currently comprehendible. Other important applications include three-dimensional internet user interfaces enabling virtual reality and telepresence. Enhancing such applications may enable reduction in traffic and related energy consumption.

Smart environments will be pervasive in the future. That means that the users will strongly interact with the environment that surrounds them, e.g., by using devices for personal use, or by having the location as a basis for many of the services to be used. This implies a totally different structure for the networks. Also context recognised by the system and it acting dynamically on the information is a major enabler for intelligent applications and services. This also means that sensor networks and RFIDs are increasingly important and integrated into the local area and cellular networks. The number of devices that people carry (knowingly or unknowingly) will increase. Solutions to these challenges will enable vast new application areas beyond traditional communications including medical monitoring and diagnosis, mobile e-commerce, sensing and security, automotive industry and much more.

2.2. Technology Vision

The current third generation (3G) cellular systems and High Speed Packet Access (HSPA) provide data rates on the order of 10 Mbit/s and support for mobility. Wireless local area network (WLAN) or Wireless Fidelity (Wi–Fi) systems provide wireless connection to the Internet on local access basis. Wireless metropolitan area network (WMAN), like Worldwide Interoperability for Microwave Access (WiMAX) system standard provide coverage extension for wireless internet connection and enhance the WLAN service. Also mobility support has been recently introduced to WiMAX standard and the first networks start to emerge. The same is true for the 3G Long Term Evolution (LTE), which started as a study item in the Third Generation Partnership Project (3GPP) standardization forum in 2004. One of the targets is to provide data rates up to 100 and 50 Mbits/s in downlink (DL) and uplink (UL), respectively. The network is also optimized for packet access to provide a wireless connection to the Internet. The next step is currently being taken to standardize IMT Advanced (IMT-A) for which 3GPP is proposing an evolved version of 3G LTE called LTE-A. The future network will introduce new network topologies that are based on flat network architecture like mesh networks in local area and direct communications from user to user.

Local connectivity solutions for short-range communications in the form of Bluetooth standard family and various sensor network applications are gaining more and more importance in the future. Those technologies will be a key part in forming the smart environments and ubiquitous networked world.

Future communication infrastructure will be based on a system of heterogeneous access networks and cooperating and competing multimode terminals. Networks will be more autonomous by composing and managing themselves and more intelligence will be located in the end-points of the infrastructure such as terminals, access points, and servers. From the implementation point of view networking technology will become a transparent technology that will consume a minimal amount of energy and that everyone can afford, use, and deploy. All Open System Interconnect (OSI) layers need to be carefully designed. Because the lowest layers usually consume a major part of the total energy, their optimization is of utmost importance. The energy includes not only the transmitted energy but also energy used on all layers for algorithms and protocols. Especially, the high power amplifier in the transmitter takes a large amount of the total energy.

The extensive ubiquitous network cannot be managed with the currently established network infrastructure or with emerging ad hoc radio network technologies since the conventional radio access schemes will not scale to large collections of nodes and is destined to be plagued with interference, electromagnetic pollution, and network congestion. To develop such a scalable and dynamically pervasive network, we need fundamentally new methods to address spectrum sharing, radio frequency access, cooperative and adaptive link management, opportunistic access, information routing, and quality of service. What is more, new materials and technologies for future radios, modems and antennas are needed to enable smooth integration of various networks with low energy and power consumption. The new internet paradigm may change the current OSI layering paradigm in the future. So called layerless communication is envisioned to be reality after 2020.

2.3. Mission

The mission of this initiative is guaranteeing the competiveness of the Finnish radio access network technology also in the future. The goal is to smoothen the adaptation to the paradigm change in the network technology to enable the continued success of the business in the area. The target of the technology development is to enable the practical provisioning of the

anticipated and envisioned services in a sustainable manner in economic, societal and environmental sense.

3. OBJECTIVES AND THEMES

3.1. Objectives

The radio interfaces for future systems for different application areas and deployment scenarios will be developed and optimized in terms of flexibility, peak data rates and granularity of data rate allocation, latency, power consumption and frequency range. As far as possible the different access systems should be based on a common platform in order to ease the implementation of multi mode devices. New spectrum efficient access technologies, deployment concepts and advanced signal processing methods are needed considering operation in various bands, and allowing the parallel operation of high performance radio interfaces in handheld devices.

Radio access network research is one part of the overall system design. It needs to be emphasized that radio interfaces for the future are designed jointly with the overall systems in order to enhance future network architectures to support applications that become enabled with the development of new radio networking technologies. However, achievement of major advances in radio access networks capacities, power efficiency, distributed network control, new network topologies etc. requires also independent and highly focused research at different layers. This results in an integrated and iterative design process, where the major difference with the past is that the overall system design is much more emphasized.

The flat network architectures have been introduced newly in order to meet better the future Internet driven networking requirements. The new high rate radio interfaces will enable end-to-end performance movement to a level that is hard to meet with the current network topologies. This will pose a challenge to enhance network architectures even flatter by supporting optimally routed user traffic, peer-to-peer communications and mesh networking in the future mobile broadband networks.

A huge challenge for the future radio access networks is to realize the co-operation of different networks in practice. Also the flexibility between ad hoc and structured network approaches must be fully supported. New spectrum efficient access technologies, deployment concepts and advanced signal processing methods are needed considering operation in various bands, and allowing the parallel operation of high performance radio interfaces in handheld devices. In longer run, this will lead to the larger scale deployment of cognitive radio technologies.

The development of frequency-agile terminals that can sense holes in the spectrum and adapt their transmission characteristics to use these holes may provide one tool to address and take advantage of the spectrum under-utilization. Although, some current adaptive radio systems already exhibit the feature of automatically adjusting their parameters for a given standard, the development of truly agile terminals requires to go much further, since it is not possible for the designers to foresee all the possible environment scenarios and then provide deterministic schemes for selection and reconfiguration.

Opportunistic communication challenges fit in the general framework of the Cognitive Radio research, focusing specifically on techniques exploring mainly the frequency dimension to find and use the best spectrum and space opportunities in a fair manner. Research needs to be conducted on concepts, mechanisms and architectures for cognitive radio terminals and networks. Socio-economical advantages of opportunistic spectrum usage in both time and space need also to be demonstrated.

The increasing data rates and numbers of network and access technologies call for sophisticated transceiver architectures and technologies. The computation solutions for the

baseband need to apply the newest computation paradigms to enable efficient software defined radio (SDR) implementations to provide the required flexibility and adaptability to varying technologies, frequency bands and applications.

The new internet paradigm may change the current Open System Interconnect (OSI) layering paradigm in the future. So called layerless communication is envisioned to be reality after 2020. Concrete examples towards that direction are already taken in the routing, joint source-channel coding and crosslayer optimization research. More activity towards the goal will be needed.

The radiation efficiency of the devices has a significant role in the energy consumption. The increasing number of radios in handheld devices sets challenging requirements for antenna design. It is important to find optimal antenna structures for multiradio systems. The progress of the research of new materials and artificial metamaterials provides good possibilities in antenna applications.

3.2. Themes

To reach the mission R&D efforts need to be focused in several different themes. Those are described in more detail below.

Theme #1: Network Topologies and architectures

The future wireless networks will have novel network topologies to complement the legacy cellular topology. It is anticipated that fixed relay stations may be installed to improve capacity and coverage via improved link budget and increased diversity. Similar goals can be attained if user terminals act as relay stations to each other. Even more significant capacity and performance gains can be achieved via coordination between network nodes enabling so called virtual MIMO transmission in downlink direction even with single-antenna transmitters. In uplink, the same principle can be exploited to implement virtual receive antenna array. Looking the implications from the radio networking and higher layers poses even more significant challenges enabling peer-to-peer communications and mesh networking. A list of the most important research topics can be found below:

- Mesh networks
- User cooperation, cooperative MIMO networks
- Fixed and mobile relays
- Ad-hoc and mobile ad-hoc networks
- Implementation challenges
- Methods increasing spectral and energy efficiency, tradeoffs between energy and spectral efficiency
- Joint optimization of capacity, coverage, and quality of transmission
- Interference management
- Femtocells for open access
- Future Internet driven networking and flat network architectures, enhanced for optimal peer-to-peer communications in local area concepts

Theme #2: Cognitive and Cooperative Networks

In future communications systems, large numbers of different wireless devices and networks will coexist. The main challenges related to this system implementation are better use of available shared radio – especially spectrum – network resources and minimization of waste of energy. Use of resources can be improved with cognitive operation principles including; sensing of shared resources status, understanding the relevant features of wireless environment,

decision of resource allocations and operation principles (e.g. cooperation mechanisms) and practical adaptation actions. Cooperation between terminals and different network entities are needed for several purposes; identifying and exploiting underutilized spectrum in an efficient manner, controlling the interferences, to enhance link and network performance and efficiency in use of resources, ensuring connectivity and quality of services and experience, and establishing and maintaining a network of collaborative nodes. Understanding the time varying nature of the traffic and modelling it facilitates further improvement in finding and exploiting spectral resources. Cognition based on sensors can be improved by passive awareness where all existing information is exploited by cooperating for example with the base stations. Cognition based only on sensors, even if cooperative, may be unreliable and may lead to chaotic situations. A list of the most important research topics can be found below:

- Collaborative techniques for identifying and exploiting underutilized spectrum
- Policies for spectrum sensing, exploitation and sharing
- Methods for interference management and waveform design
- Techniques for cognitive radio transceivers
- Intelligent radio (e.g. power, frequency, time, space) and network (computing power, storage, batteries, displays) resource sensing and flexible management
- Cooperative communication techniques in different OSI layers; communicational, operational and social cooperation, network coding
- Communication system level energy efficiency optimization.
- Functionality and performance testing methods and tools
- Analyzing and modeling traffic in cognitive radio networks
- Resource allocation under fairness-efficiency requirements
- Admission control
- Network operating over 'extended multihop topologies' (topologies beyond simplest tree and star topologies)
- Multihopping from applications perspective
- Traffic and load balancing through multihop technologies
- Multihop technologies for hierarchical systems of cells of different sizes
- Distributed radio resource management
- Distributed control structures
- Cooperation between network elements, distributed antennas, and radio frequency sensors
- User collaboration under network control
- Collaboration in hierarchical systems of cells (e.g. macro/micro/pico/femtocells collaboration)

Theme #3: Spectrum Sharing and Channel Access

Currently there are basically two main principles for the spectrum allocation, namely license and un-license spectrum usage. In the first one there is allocated a certain spectrum band for each operator for a use of some specific radio technology. In the latter one the usage of spectrum is regulated by applying a certain transmit power mask for a specific spectrum band to which the equipment should fill. New approaches for spectrum allocation could be classified basically two classes; system assisted spectrum use and opportunistic spectrum use. The approaches in the first class try to find new ways to utilize licensed bands. In the second class, the aim is to find ways how spectrum holes could be utilized opportunistically, mainly using the primary/secondary usage paradigm. A list of the most important research topics can be found below:

- Interoperator / intraoperator spectrum sharing
- Identifying spectral opportunities in flexible spectrum usage
- Controlling co-channel and adjacent channel interference
- Multiple access schemes and related radio network control

- Infrastructure (network) perspective may adopted. Aim is to keep realistic system assumptions but contribute to networks beyond LTE-A and IEEE802.16m.
- Flexible Spectrum Usage (FSU) related to both conventional macro/microcell networks and local area systems of small cells.
- Network assisted device to device communication.
- Interference management
- Propagation models described in the C&A area can be used also to support the development of FSU

Theme #4: Ubiquitous Connectivity

Future communication systems include many different types of access technologies – wireless sensor networks, personal area networks (PAN's), wireless local area networks (WLAN's), wide area mobile communication, broadcast – each optimized for its particular use scenarios. Access networks should provide adaptive and flexible allocation of data rates to users, high average aggregate throughput per area and low latencies. The most important research target is not necessarily only higher bit rates but high and uniform capacity in most of the network coverage areas with high spectral occupancy and spectral efficiency with reasonable energy consumption and implementation costs. Energy efficiency of large number of wireless devices is crucial for the success of these technologies. The integration and smooth utilization of a plethora of radio access technologies and network solutions needs to be guaranteed in the heterogeneous network environments of the future. This requires careful network design to provide ubiquitous connectivity and smooth handover or roaming from a network or technology to another. End-to-end quality of service guaranteeing is a key research target. A list of the most important research topics can be found below:

- Roaming and handovers in heterogeneous network environments
- Connection and co-design of wide area coverage, local coverage and sensor networks
- Vehicular networks and their integration to the future RANs
- Connection to future layerless communication paradigm
- Optimal access schemes and networks for different use scenarios; broadcast, cellular, metropolitan, WLAN, PAN, wireless car, very short range, high mobility, low energy consumption, and microwave links
- Functionality and performance testing methods and tools
- Impact of traffic and load characteristics to the energy efficiency in different network topologies.
- Energy efficiency requirements in network planning
- Network topology (relays, picocells etc) will have an impact on the overall energy consumption of the radio communication system. Current network planning methods are focused only on capacity and coverage. There is need for new design paradigm that allows the designer to make the right energy, capacity, coverage, cost tradeoffs.

Theme #5: Fundamentals Behind Multiple Radio Technologies

Future wireless access standards will apply scattered frequencies and multiple technologies. Concurrent use of a plurality of network and radio technologies is a reality which will remain. This requires deep understanding of new radio channel models, physical layer and radio access technologies and their impact on the overall access network design. Joint optimization of adaptive modulation and coding (AMC), radio resource management, routing, and transceiver processing across all the OSI layers is needed. A list of the most important research topics can be found below:

- Coding, modulation and other physical layer technologies
- Radio resource management
- Interference management and smart design of competing / interfering systems

- Flexible and adaptive access schemes
- Radio access schemes with high spectral efficiency
- Exploitation of available diversities in time/space/frequency/code domains
- Joint optimization of RF and baseband parts, management, and compensation of nonlinearities
- Joint optimization of transceiver algorithms and transmission protocols

Theme #6: Transceiver Technologies

To enable enhanced services and higher data rates with low enough implementation complexity and power/energy consumption. This requires application of the most advanced baseband (BB) computation solutions and algorithm tailoring for them. The co-design and joint optimization of radio frequency (RF) and baseband parts need to be addressed given the dispersed frequency band allocations of future wireless access networks. A key future challenge for transceiver technologies is posed by the network topology development, which integrates the role of a smart terminal and a network node. In other words, future terminals need to perform part of the distributed cognitive network control routing tasks. A list of the most important research topics can be found below:

- Computation platforms, circuits and design
- Signal processing algorithms, architectures and co-design
- Low power and energy consumption(green) solutions
- RF circuits, components and amplifiers
- Compensation of RF impairments in BB
- RF/BB interface and function partitioning
- Cognitive radio and network node implementation
- Spectrum sensor implementation
- Radio resource management, control and routing implementation
- Implementation of layerless communication
- Software and hardware techniques and solutions
- System software, operating systems
- Middleware architectures
- Parallel programming methods and tools
- Adaptive and self-reconfiguring transceivers and network nodes

Theme #7: Antenna technologies for future radio access networks

Radiation properties of antennas are essential for the communication quality and energy consumption of new radio systems. The increasing number of radios in a small volume of handheld devices causes challenges for the antenna design. In addition, the absorption and frequency detuning of the hand and head deteriorate radiation properties. More research is needed to minimize the human body absorption and to compensate the human body and other environmental effects in the near field of the antenna.

New materials and fabrication methods (for example printed electronics) provide possibility to produce small and cost-effective antenna structures. The research of artificial materials with extraordinary electromagnetic properties (so called metamaterials) is a subject of increasing interest in the electromagnetic community. These exotic materials have great potential for example in miniaturization of the patch antennas. Both theoretical considerations and practical implementation studies of those structures are needed.

A list of the most important research topics can be found below:

- Antennas for multiradio systems

- Functional materials and metamaterials for antenna applications, including tunable antennas
- Miniaturization of handset antennas using metamaterials or functional materials
- New materials and fabrication methods for mass-product antennas
- Printed antennas (conductive ink)
- Wearable antennas
- Interactions between antennas and humans

Theme #8: Layerless Communications

The OSI model for communication has been a great success in the current system design. However, it causes several bottlenecks and problems to the system design, because it is inherently suboptimal in particular for wireless networks and connections. Thus, a clean slate approach for communication system design could provide a remarkable efficiency boost and a change of complete engineering paradigm. In addition to the clean slate approach, an evolutionary research approach based on optimization across the layers of the existing OSI model and networks is needed to get practical backward compatible results and solutions. A list of the most important research topics can be found below:

- Communication network theory for system design with no layering
- Communication protocol optimization
- Crosslayer optimization
- Network information theory
- Source-channel coding and decoding for multiuser multimode wireless networks

Theme #9: Radios as sensors and actuators

Typical wireless terminal or device has multiple radios on board. These radios may be used for data transmission, local connectivity, wireless localization as well as sensors and actuators. Also wireless devices can form a self-configuring network. The potentially large number of nodes and the constraints for energy consumption makes design of such systems challenging. The sensor networks use IP based protocol solutions to ensure seamless communication between sensor systems and the rest of the internet. Various different radio solutions are to be used such as WLAN; Bluetooth, low energy; IEEE 802.15.4 "Zigbee" radios; RFIDs. Among the most important research topics are:

- Low power fast recovery radio technology, wakeup radios
- Co-existence and cognitive operation of the sensor radios
- Co-design of communications and data fusion to minimize transmission needs
- Network monitoring and fault recovery
- Security
- Using the radio as a sensor; tailoring existing radio technologies for lower power operation
- Using OFDM radio as radar: OFDM-based ranging and wireless localization
- Scalability issues of sensor networks
- Positioning in sensor nwtworks

Theme #10: Radio channel modeling

New requirements are set on the assessment of radio channel properties for the successful development of new radio access networks. This implies the need to identify the specific

scenarios, parameters, and system configurations which have an effect on the radio channel. A list of the most important research topics can be found below:

- Physical propagation mechanisms at specific bands of the radio spectrum in the micro- and millimetre-wave bands, including also satellite mobile communications
- Propagation modeling in cognitive radio systems and its implications to interference management and waveform design
- Channel sounding and modeling for MIMO and virtual MIMO systems
- Identification of the propagation specificities of multihop and relay networks,
- Frequency dependence of the propagation for multiradio systems
- Mobile-to-mobile and point-to-multipoint propagation channels
- Development of propagation tools and simulation methods for new radio access networks
- Human influence on the radio channel particularly for personal area networks (PAN)

Other themes

This document is still in its draft phase and some other topics may be added including techno-economical modeling to assess the future business environment as well as wireless-enabled services. Also security and trust in wireless networks is an open problem.

This document looks the challenges encountered regarding the topics covered, but more input is welcome and will be produced in the finalization of the document.

4. RELEVANCE AND IMPACT

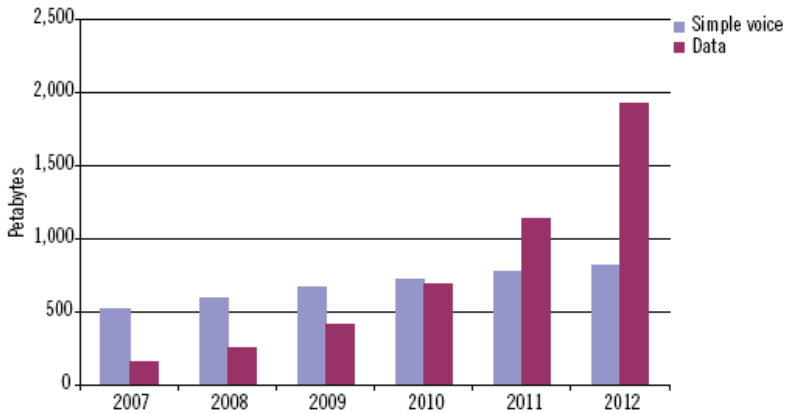
4.1. Commercial Relevance

Telecommunications has been, and is, one of the fastest growing industrial sectors. In 2007 the total revenue in the global market grew by an estimated 11.2%, reaching US$1.8 trillion and accounting for more than half of the total IT market. According to the Gartner forecasts, the global telecom market will show a compound annual growth rate (CAGR) of 4.0% between 2007 and 2012, reaching the value of US$2.3 trillion. In 2007, the total telecom equipment revenues reached the value of US$374 billion and will grow by 6.8% on average until 2012.

The values of the different segments of the mobile markets are, and are forecasted to be, as follows: total mobile markets US$865,775 million with CAGR 2007-2012 7.8 %; Infrastructure US$51,469 million with CAGR 2007-2012 3.0 %; Terminal devices US$162,389 million with CAGR 2007-2012 8.0 %; and Services US$651,917 million with CAGR 2007-2012 8.0 %. From the infrastructure markets, the equipment for the Radio Access Networks (RAN) represents the major share.

In Finland, the telecommunications boom, which started in 1990s, has changed the structure of the economy more than in other OECD countries. Finland, once a country with the forest industry as the key industrial sector, is today known as specialized in the Information and Communications Technology (ICT) industry. The share of the telecommunications sector of the Finnish GDP was already 2,8% in 2006. The telecommunications equipment represented 14,3 % of the Finnish export in 2007, and the total value of the export of the *electronics and telecommunications equipment* –category was 9.3 billions of Euros in that year (Tilastokeskus: Korkean teknologian tuotteiden ulkomaankauppa tuoteryhmittäin vuosina 2006 ja 2007).

It can be said that the ICT sector has become the key industrial sector in Finland, and its main future prospects are in the development and deliveries of the telecommunications equipment. The current positions, however, cannot be maintained without strong investments in the research of the mobile communications. The transition from voice to data-driven networks is ongoing and will get more speed in the future, see Figure 1 below. This will have major implications on the mobile industry. It has to develop, for instance, such Radio Access Networks, which will meet the requirements of the future applications and services.



Note: Simple voice excludes VoIP
Source: Informa Telecoms & Media

Figure 1: Global mobile network traffic, voice versus data 2007-2012 (source: Informa)

The change from voice services to non-voice services (data) will mean a kind of disruption point in the mobile communication markets, and will reshape the competition environment. The huge market potential will allure new players, and the existing market leaders, including the Finnish ones, have to make huge investments in the development of the new technologies and systems in order to maintain their positions. In some countries there is strong public sector financial support to communications and especially wireless access technology research and development. It is vital to have in Finland continued support to keep research in this economically important and still fast developing area at globally leading level.

4.2. Envisaged Outputs

Via this proposal the necessary knowledge will be developed to make sure that the Finnish radio access and network technology expertise remains at highest level globally. World leading wireless research ecosystem is vital for existing industry and new business startups. To ensure that the competitive edge of Finnish ICT industry is maintained it is imperative that state-of-the-art IPR is generated in creation of radio access and network technologies. This can be leveraged in standardization activities to reach favorable results. The programme contains also themes that will facilitate research that will eventually lead to new business opportunities. In summary, the outputs are competence, IPR (and not just for standards but also for differentiation), standards inputs, new products, networks, applications and system concepts. Also new features for existing products to enhance their performance are expected.

The key output for this proposal is fundamentally to create technology and services that will enable economic growth and prosperity for Finland. Good technology and innovative services resulting from research will result in economic growth, and prosperity for a wide range of Finnish industries, not only the communications or ICT industry.

4.3. Potential Impact

Mobile and wireless communication has seen a tremendous growth in the last years. The number of mobile subscribers worldwide has increased to about 3000 million today. It is predicted that by the year 2015 about 5000 million terrestrial mobile subscribers worldwide will be connected. Emerging markets are playing an important role in this growth with the biggest market share in Asia.
The future growth of mobile and wireless communication services in developed countries is expected mainly from data oriented services and applications. With the advent of the Future Internet, a critical infrastructure for businesses, governments and citizens, a wide variety and ever growing number of networked applications, business models, edge devices, networks and environments will emerge. The Future Internet will be the key enabler and cross functional technology for all business domains (e.g. machinery, automotive, banking, service industry etc.) and all areas of administration (governments, enterprise management). The increased expectations of users and many future services offerings will require systems that support higher throughput values per user with lower latency than in today's systems.
For these reasons, new and more efficient radio access technologies are needed. In addition, there is an ongoing paradigm shift driven by a user who expects ubiquitous communication providing higher performance at a suitable cost-benefit-ratio without having to take care of the underlying technology.
In mobile communications Finland is still in a leading position, see Figure 2 below. The Finnish industry has been the forerunner in developing and deploying the new mobile communications technologies, and has reached the position which was unimaginable 20 years ago. And this is especially the case with the radio access technologies and systems, which are playing the major role in the mobile communications business. However, the development pace of the new technologies and the competition, especially from Asia, is growing. This is leading to a situation,

where maintaining the current positions is under high pressure. The future success stories cannot be based on the successes in the past, and the basics have to be built again. As the research and development of the new technologies have already been launched in China, Japan and Korea, and in Europe, the similar activities and related investments are imperative also in Finland.

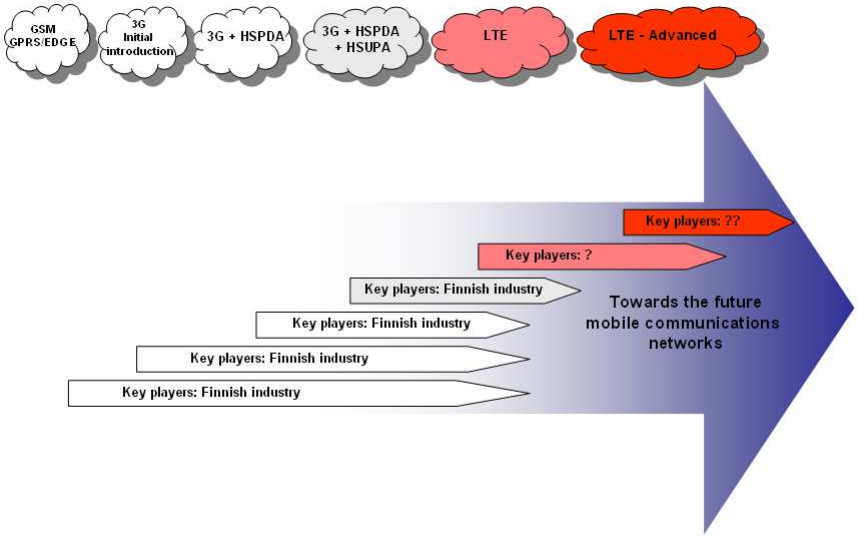


Figure 2: The roles of players in radio access networks with respect to maturity

The key rationale for this Research Agenda is fundamentally to create technology that will enable economic growth and prosperity for Finland. Good technology resulting from research, if pulled through with appropriate business applications, will result in economic growth, and prosperity for a wide range of Finnish industries, not only the communications or ICT industry. The expected impact can be concretized with the following items:

- Reinforce the Finnish leadership in the mobile and wireless communication systems; developing stronger synergies between various sector actors and contributing to new business models that take advantage of convergence and full interoperability.
- New and wider market opportunities for the Finnish industry in the mobile and wireless communication markets based on the created knowledge and IPR.
- Increased economic efficiency of the future mobile and wireless access infrastructures (cost/bit). This shall support new deployment scenarios for the radio access systems with reduced operator's CAPEX and OPEX. Accelerated uptake of the next generation of network and service infrastructures.
- Improved user experience for consumers, enterprises and other groups, enabling them to take advantage of a wider variety and totally new services at any place and time.
- Contribution to global standards of the future radio access technologies. These should support full interoperability with the existing radio access technologies, a significantly larger and diverse number of devices, new services and more complex user requirements.

Mobile and wireless communications is an important economic driver generating growth. Significantly improved transmission capabilities are increasingly required to support increased traffic originating from content-rich data services in order to connect people as well as machines to the information society. The involvement of the Finnish actors in the research and development of the future radio access technologies will strengthen their global competitiveness in this important field of economy.