The foundation of the Mobile and Wireless Communications System for 2020 and beyond

Challenges, Enablers and Technology Solutions

Afif Osseiran[*1],Volker Braun[^1], Taoka Hidekazu[#1], Patrick Marsch[*2], Hans Schotten[^2], Hugo Tullberg[*1], Mikko A. Uusitalo[#2] and Malte Schellmann[*3]

[*1]Ericsson, [^1]Alcatel-Lucent,[#1]DOCOMO Euro-Labs, [*2]Nokia Siemens Networks, [^2]University of Kaiserslautern, [#2]Nokia, [*3]Huawei

***Abstract*— In 2020, mobile and wireless traffic volume is expected to increase thousand-fold over 2010 figures. Moreover, an increase in the number of wirelessly-connected devices to counts in the tens of billions will have a profound impact on society. Massive machine communication, forming the basis for the Internet of Things, will make our everyday life more efficient, comfortable and safer, through a wide range of applications including traffic safety and medical services. The variety of applications and data traffic types will be significantly larger than today, and will result in more diverse requirements on services, devices and networks. METIS is set up by leading global players to prepare the migration towards tomorrow's multi-purpose global communication infrastructure, serving humans and things. The main objective of METIS is to lay the foundation for this future global mobile and wireless communications system, and to generate a global consensus here. In particular, METIS will provide new solutions which fit the needs beyond 2020.**

Keywords—Future Mobile and Wireless Commnication System, Connected Devices, Device-to-device communication, Massive Machine Communications, Ultra-dense Networks, Moving Networks, Ultra-reliable Communications

I. Introduction

Societal development will lead to changes in the way mobile and wireless communication systems are used. Essential services such as e-banking, e-learning and e-health will continue to proliferate and become more mobile. On-demand information and entertainment will be delivered over mobile and wireless communication systems. The wirelessly connected Internet of Things will make our everyday life more efficient, comfortable and safer. As shown in Fig. 1, the societal development will lead to an avalanche of mobile and wireless traffic volume, predicted to increase a thousand-fold over the next decade. More precisely, in the already highly-developed communication societies of Western Europe there are predictions that the traffic in cellular systems will increase by roughly a factor of 70 until 2020 [1]. Other forecasts by telecom players [2-4] predict even more massive traffic growth, with forecasts in the order of 1000 times larger global wireless-traffic volumes in 2020 than seen in 2010, and primarily driven by increased usage of mobile multi-media services.

Further, it is generally predicted that today's dominating scenarios of human-centric communication will, in the future, be complemented by a tremendous increase in the numbers of communicating machines. There are forecasts of a total of 50 billion connected devices [5] by 2020.

The coexistence of human-centric and machine-type applications will lead to a large diversity of communication characteristics imposing different requirements on mobile and wireless communication systems, e.g. in terms of cost, complexity, energy dissipation, and service requirements. As a particular example, it is expected that the uptake of machine communications in many fields such as healthcare, security, logistics, automotive applications etc. will pose far higher reliability requirements on connectivity than communication does today. In terms of quality of service, a future mobile and wireless communication system must support a wide range of user data rates. For example, it must provide multi-Gbps data rates in specific scenarios, be able to guarantee tens of Mbps data rates with very high availability and reliability, and also be able to provide low data rates for machine-type communication in a cost-efficient and energy-efficient manner.

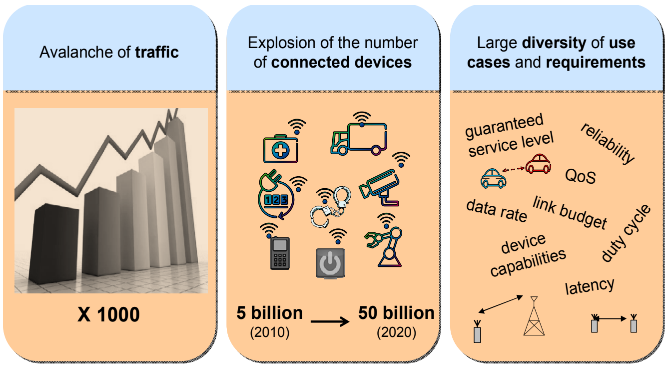

Figure 1. Forecast for the development of communication and connectivity needs in the next 10 years.

The mobile and wireless systems such as HSPA, LTE/LTE-A, and the IEEE802.11 family of technology are expected to dominate the wireless-communication arena for the next decade. In particular, LTE/LTE-A [6-7] and its evolution is more and more emerging as the global choice to which essentially all mobile-broadband operators are expected to migrate. In addition, there are other radio-access technologies available or under development targeting specific usage scenarios, such as Bluetooth and ZigBee for very-short-range communication between different devices, and IEEE 802.11p for communication directly between vehicles (cars, buses, trucks, etc.) or between vehicles and fixed infrastructure.

Although the existing wide area mobile and wireless communication technologies are evolving, they have been primarily designed having human-centric mobile-broadband services and applications in mind. As a result of this, they are not able to respond sufficiently well to the diversity of application requirements and use cases foreseen for time-frames beyond 2020. They do also not provide the efficiency and scalability needed to respond to the expected explosion of traffic and number of connected devices.

In this paper, we will describe the approach taken by METIS (Mobile and wireless communications Enablers for the Twenty-twenty Information Society) [8], an integrated project partly funded by the European Commission under the FP7 research framework. METIS was set up by leading telecommunications companies in order to address the above described technical challenges of the information connected society beyond 2020. The "technology components" as well as the "horizontal topics" needed to build the next generation mobile system, "5G", which form the major brick stones of METIS, will be outlined.

II. APPROACH & OBJECTIVES

The anticipated traffic explosion, emergence of massive amounts of communicating machines and the correspondingly diverse requirements and use cases have to be taken into account in the design, development, and deployment of future mobile and wireless communication systems. As illustrated in Fig. 2, these future systems will have to

1. Be significantly more efficient in terms of energy, cost and resource utilization than today's system, in order to allow for a constant growth in capacity at acceptable overall cost and energy dissipation,
2. Be more versatile to support a significant diversity of requirements (e.g. availability, mobility) and use cases,
3. Provide better scalability in the way that the system is cost, energy and resource efficient while responding to a wider range of requirements regardless of whether a large or low amount of traffic is to be supported.

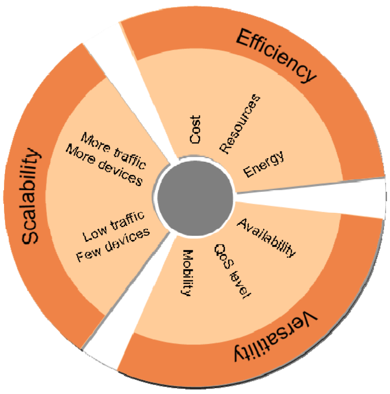

Figure 2. Key aspects of future mobile and wireless communication systems beyond 2020

METIS will lay the foundation for the future mobile and wireless communications system. METIS will develop a system concept that delivers the necessary efficiency, versatility and scalability, and it will carry out research on technology components supporting the concept. METIS intends to take a leading role on the development of the future mobile and wireless communications system, and it will ensure an early global consensus here. METIS also plans to play an important role of building consensus among other external major stakeholders prior to global standardization activities. This will for example be done by initiating and addressing work in relevant fora such as the ITU-R (to prepare for WRC-15), as well as in national and regional regulatory bodies.
In general, the objectives of METIS can be divided into three categories: the analysis and specification of requirements; the development and integration of new technical solutions; and the dissemination of results to ensure the required impact. Further details on these categories will be given in the following:

A. Requirements

The first category consists of a quantitative specification of requirements that covers new application domains, such as automotive and public transportation, public safety and emergency services, transport and logistics, and machine type communication.
A set of assumptions regarding usage scenarios, requirements, and key performance indicators (KPIs) in 2020 and beyond is established in scenario definition work, to ensure consistent basic assumptions in the technical-research works and system concept-development work. The focused scenarios of METIS are those not readily solvable by straightforward evolution of current systems. The assumptions provide a framework which would enable the technical works to develop a comprehensive system concept, into which the selected key technological components and solutions can be integrated.

B. Technical

The second category will be to develop technical solutions in order to provide a system concept that supports

- 1000 times higher mobile data volume per area,
- 10 to 100 times higher number of connected devices,
- 10 to 100 times higher user data rate,
- 10 times longer battery life for low power massive machine communications (MMC), and finally
- 5 times reduced End-to-End latency.

C. Impact

The third category aims to ensure METIS global impact through dissemination of studies, standardization and regulatory engagement, contributing for example to CEPT, ITU-R, and towards WRC-15.

III. CONSORTIUM

METIS is a consortium of 29 partners spanning telecommunications manufacturers, network operators, the automotive industry and academia. Among these, the METIS consortium comprises five major global telecommunications manufactures, five global operators and 13 academic partners.

IV. Technology Components

In order to develop the connectivity solutions and mobile communication system for the beyond 2020 society with its broad range of service and application requirements, METIS will address the following technology components where significant progress beyond state of the art is required:

- radio-links, by considering advanced transmission technologies, including the use of new transmission waveforms and new approaches to multiple access, MAC and RRM;
- multi-node- and multi-user level, by having multi-hop communications, and network coding as an integrated part of the future mobile and wireless communications system; and by considering new technology research areas such as advanced inter-node coordination and cooperation schemes, and massive antenna configurations;
- network dimension, by considering the demand, traffic and mobility management, and novel approaches for efficient interference management in complex heterogeneous deployments;
- spectrum usage, by considering extended spectrum-band-of-operation, as well as operation in new spectrum regimes;

These technology components are briefly described hereafter.

A. Radio Links

Radio-Links (see Fig. 3) will develop and investigate new radio-link concepts, tailored to meet the demands of future applications arising from the identified scenarios. Further, it will create an understanding of the implications for the overall system design. Air-interface technologies will be designed to support the identified use cases and scenarios and address their requirements. A particular challenge is the efficient support of a broad range of data rates going from low-rate sensor applications up to ultra-high rate multi-media services. For this purpose, new waveforms, coding & modulation and suitable transceiver structures will be designed, aiming at improving spectral as well as energy efficiency, enhancing coexistence capabilities and increasing the robustness against imperfections in the transmission chain.

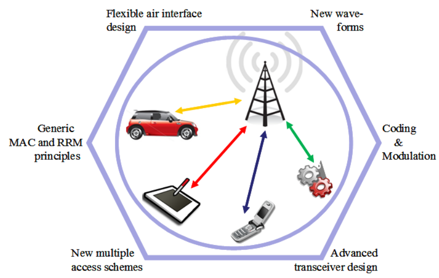

Figure 3. Air Interface Design, Waveforms and Multiple Access

Scalable link reliability will for example be supported by optimizing retransmission protocols; energy efficiency and battery stand-by time, in particular for machine type devices, will be increased by introducing new paging concepts. In general, new solutions will be developed for multiple access, Medium Access Control (MAC) and Radio Resource Management (RRM) to increase the system efficiency, whilst meeting the diverse needs of new classes of devices and services arising from future applications

B. Multi-node/Multi-antenna Transmission

Multi-node/multi-antenna technologies will be designed to achieve the performance and capability targets for future wireless communication systems. It will address the performance limits, the architectural impact, and the design of algorithms and enablers. Moreover, it will target new scenarios such as ultra-dense networks and MMC.

Massive antenna configurations will be assessed in order to deliver very high data rates and spectral efficiency, or enhanced link reliability, coverage and/or energy efficiency. The study targets techniques based on beam-forming, space division multiple access and spatial multiplexing, and it will take into account novel channel models and radio-link solutions, also in frequency bands above 3 GHz. The increased spatial dimensions require solutions with a limited computational complexity and signaling overhead such as e.g. reduced complexity algorithms for channel estimation and signal detection, or efficient design of pilot signals, pre-coding and feedback solutions.

Advanced inter-node coordination is expected to achieve significant increases in spectrum efficiency and user throughput and improvements for users with unfavorable radio conditions. An innovative wireless communication system is expected to fully integrate inter-node coordination so as to ultimately exploit its performance benefits. The studies will take into account the design of a novel air interface and new types of coordination, e.g. solutions that build upon the concept of interference alignment, solutions based on a joint design of transmit and receive strategies, or solutions designed for providing robustness against imperfections. Enablers for integrating advanced inter-node coordination techniques into a practical system will also be investigated, e.g. design of pilot signals, channel estimation and/or feedback solutions.

Multi-hop communications/wireless network coding using intermediate relay nodes between the sources/destinations will provide efficient means for backhauling, to extend coverage and reliability, or to transfer the processing/energy burden from the MMC devices to the network. Wireless network coding, where multiple communication flows are jointly coded, is expected to lead to tangible benefits in terms of throughput or improved link diversity. Emphasis will be put on developing innovative and practical protocols to support multiple interfering communication flows, along with the signaling needs and the correspondent resource allocation.

C. Multi-RAT

Multi-layer/Multi-radio access technology (RAT) Networks will investigate network-level aspects related to the efficient deployment, operation and optimization of the future wireless communications system, with an emphasis on heterogeneous multi-layer and multi-RAT deployments. The following topics (see also Fig. 4) will be addressed:

Co-existence, collaboration and interference management. Here, efficient and reliable schemes will be developed addressing the detection of interference and its origin, the autonomous clustering of network nodes to jointly address interference, and actual interference management schemes considering mid- to long-term resource and power allocation as such. A particular challenge will be to develop solutions for ultra-dense networks, where interference dependencies between communicating entities are especially complex. As the future wireless system will also encompass the option of direct D2D communications and MMC, this leads to increased degrees of freedom that have to be considered for interference management, and demands solutions that are highly scalable.

Demand, traffic and mobility management. These research activities are concerned with the smart mapping of services and devices to the multitude of available RATs and layers the future wireless communications system will consist of. In particular, it will be essential to predict and exploit the user or device location, its movement and behavior as well as the application context for a most efficient mapping. Further, novel mobility signaling concepts will be developed in order to ensure that the overhead associated with signaling remains in a reasonable relation to the communication payload. This is particularly challenging in the context of ultra-dense deployments, where highly mobile devices require frequent handovers, and in the context of massive machine communications, where any signaling burden on the device side should strictly be minimized. The full range from centralized to decentralized infrastructure-driven or device-driven mobility management will be explored.

Functional network enablers. Based on the interference and mobility management solutions developed in the activities stated before, it will then be determined which functional network enablers are required to facilitate these techniques. For instance, novel management interfaces may be needed, as well as the system capability to auto-integrate and self-manage a multitude of node types. Finally, efficient integration of nomadic cell concepts into heterogeneous networks will be investigated.

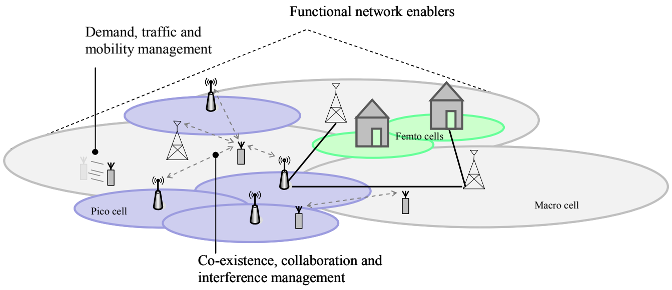

Figure 4. Heterogeneous multi-layer and multi-RAT deployments

D. Spectrum

METIS will investigate ways to enable and secure sufficient access to spectrum for beyond 2020 wireless communication systems by developing innovative spectrum-sharing concepts. This should lead to substantial improvements in the overall spectrum utilization and result in significantly increased spectrum usage efficiency from a spectrum-oriented as well as an economic point of view.

In the beginning, the focus will be, on the one hand, on frequency-band analysis in order to identify new spectrum resources and to understand their characteristics, and, on the other hand, on a scenario analysis of future wireless communication systems in order to understand spectrum requirements for beyond 2020 systems. Frequency band analysis will be open to look for opportunities even up to 275 GHz.

In a second step, innovative concepts and enablers for shared spectrum usage and flexible spectrum management will be developed. Here, some examples of novelty include identification of required enablers for ultra-dense network deployments operating at high frequencies as well as spectrum management for autonomous and network-assisted D2D communication supporting high mobility.

V. SYSTEM & HORIZONTAL TOPICS

METIS will use so-called *horizontal topics* to build the overall system concept. A horizontal topic (HT) integrates a subset of the technology components developed to provide the most promising technology solution to one or more test-cases which have been identified in the scenario work.

The concept development will direct the research work to consistently integrate the developed technology components into an overall system concept as illustrated in Fig. 5.

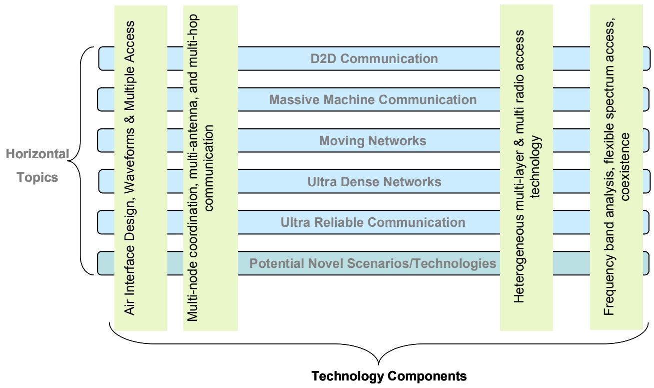

Figure 5. System Integration: Horizontal Topics & Technology Components

The HTs will be integrated into the overall METIS system concept. Potential overlaps between HTs, trade-offs and mutual interdependencies between technology components will be identified and analyzed with respect to their impact on the overall system design. The performance of the proposed concept will be evaluated according to the research objectives and KPIs.

Essential HTs identified so far in METIS (see Fig. 5) are described below. In addition to these HTs, architecture is identified as a fundamental, technology-oriented HT that must be addressed by any wireless communications system. Additional HT(s) can be added if necessary to capture emerging market, societal, technical, and economical needs.

A. *Device-to-Device (D2D)*

Direct D2D Communication refers to direct communication between devices, without user plane traffic going through any network infrastructure. However, under normal conditions the network is controlling the radio resource usage of the direct links and the resulting interference effects. The goals of this HT are to increase coverage, to offload backhaul, to provide fall-back connectivity, and to increase spectrum usage and capacity per area.

B. *Massive Machine Communications (MMC)*

MMC will be vital to the future mobile and wireless communications system where the goals of this HT are to provide up- and down-scaling connectivity solutions for tens of billions of network-enabled devices. More precisely, machine-related communication will be associated with a wide range of characteristics and requirements (e.g. data rate, latency, cost) that will often deviate substantially from those of human-centric communication in current use.

C. *Moving Networks (MN)*

Moving Networks will enhance and extend linking together potentially large populations of jointly moving communication devices. A moving network node (e.g. vehicles or buses with advanced networking capabilities) or a group of such nodes can form a “moving network” that communicates with its environment, i.e., other fixed or mobile nodes that are inside or even outside the moving entity.

D. *Ultra-dense Networks (UDN)*

Ultra-dense Networks will be the main driver to address the traffic demands of beyond 2020, where the goals are to increase capacity, increase energy efficiency of radio links, and enable better exploitation of under-utilized spectrum. Infrastructure densification is a path that has already been taken within, e.g., existing cellular radio-access technologies with inter-site densities going down to the order of 200 m.

E. *Ultra-reliable Networks (URN)*

Ultra-reliable Networks will enable high degrees of availability. In this context, METIS aims at providing scalable and cost-efficient solutions for networks supporting services with extreme requirements on availability and reliability.

F. *Architecture*

METIS will research and introduce a novel, beyond-cellular architectural concept that can take advantage of the novel component technologies described previously in a scalable way. The goal is to provide a consistent architectural framework integrating different kinds of centralized and decentralized approaches.

VI. IMPACT

Based on its findings and results, the METIS project will support an early consensus building process in industry and research on the long-term migration of mobile communications. METIS will in particular contribute to the harmonization of technology roadmaps in various standardization and industry organizations, provide guidance for standard evolution, and support regulatory discussions on European and international level.

In order to support the global dissemination of its results, METIS will initiate liaisons with other activities, projects, and fora addressing the long-term migration of mobile communications. It will also address stakeholder organizations of potential new application domains requiring support of METIS solutions in the future. Regulatory organizations and events as well as standardization bodies will be supported by the METIS member organizations.

VII. CONCLUSIONS

Mobile and wireless communication systems beyond 2020 will have to respond to the increase in traffic volume, by increasing capacity and by improving efficiency in energy, cost and spectrum utilization. Further, the numbers of devices and the variety of use cases and requirements will necessitate mobile and wireless communication solutions with significantly increased versatility and improved scalability.

METIS will lay the foundation for the next generation mobile and wireless system. METIS will develop a system concept that delivers the necessary efficiency, versatility and scalability. The project will research technology components such as network topologies, radio links, multi-node, and spectrum usage techniques. Horizontal topics such as Device-to-Device, Massive Machine Communications, Moving Networks and Ultra-dense Networks will be used to integrate the research results into a system concept that provides the necessary flexibility, versatility and scalability at a low cost.

ACKNOWLEDGMENT

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