METIS Research and Standardization

A path towards a 5G system

Hugo Tullberg[1], Heinz Droste[2], Mikael Fallgren[1], Peter Fertl[3], David Gozalvez-Serrano[3], Eiman Mohyeldin[4], Olav Queseth[1], Yngve Selén[1]

[1]Ericsson Research, [2]Deutsche Telekom, [3]BMW Group, [4]Nokia Solutions and Networks

***Abstract*— METIS has been conducting research on 5G-enabling technology components the last two years and the METIS 5G system concept is being developed. Concurrently the 5G requirements are being developed in ITU-R. Standardization of relevant technology components is the next step towards the deployment of 5G systems. In this article we outline the METIS 5G concept and how it will be further refined in Horizon 2020 projects before being brought to 3GPP and other relevant standardization bodies.**

Keywords—5G; METIS; FP7; H2020; System concept; Standardization; 3GPP; ITU-R; ETSI; CEN; ISO

I. Introduction

Mobile communication has evolved significantly from early voice systems to today's highly sophisticated mobile broadband that support countless applications used by billions of people around the world. The rapid growth of mobile communication and equally massive advances in technology are moving technology evolution and the world toward a fully connected information society. The next generation mobile communication – 5G – is a technology solution for 2020 and beyond that will make access to information and data sharing possible anywhere, anytime, to anyone or anything. The key difference between previous generation and 5G is that 5G will extend beyond people and also support connectivity for anything that may benefit from being connected. A diverse range of devices can be connected, from massive deployments of low-cost battery-powered sensors and actuators, remote-controlled and remote-read utility meters, body-area networks of personal devices, to remote driving, and haptic communication enabling remote work in e.g. hazardous environments. In comparison to today's networks, 5G systems will integrate mobile broadband and machine-type communication, and support a much wider range of use-cases.

The overall purpose of the EU FP7 project METIS is to develop a 5G system concept that meets the requirements of the beyond-2020 connected information society and extend today's wireless communication systems to support new usage scenarios [1]. METIS is part of a long term vision, and the roadmap of this long term vision is divided into three phases: the exploratory phase (which consists of laying the foundation for the future wireless and mobile 2020 system), the optimization and trial phase (which consists of system optimization, contribution to standards and field trials of the system concept), and the implementation phase (which consists of pre-commercial trials)

METIS is an exploratory project that is investigating new technology components and paradigms. The most promising technology components and paradigms will be integrated into the METIS 5G concept. METIS is committed to contribute via partners with individual or joint contributions to standardization and regulatory bodies in particular in CEPT, 3GPP, ITU, ITU-R, ETSI, and IEEE.

Global standardization is necessary to take the most promising research results closer to implementation and deployment. Standards provide requirements, specifications, guidelines or characteristics that can be used consistently to ensure that products, processes and services are fit for their purpose. Interfaces and procedures need to be agreed to allow cross-vendor operations.

METIS and other EU research projects can contribute to regulation and standardization in different ways. In some cases EU research project can have direct liaisons, e.g., METIS has a liaison relation with ITU-R concerning the IMT Vision document. This is usually not the case with the standardization bodies, where the work takes place through contributions of the individual partners.

Since the research projects are time-limited, the standardization may continue after the project has ended. Large enterprises and organizations will continue their presence in relevant standardization bodies and ensure the continued impact of research on the standardization through the ordinary standardization mechanisms. For academic partners and Small and Medium-sized Enterprises (SMEs) the situation is different. Here, the end of the research project often makes the universities and SMEs stop investing funds towards the standardization. This raises the question if and how follow-up research projects can continue contributing research results towards the standardization bodies.

3GPP covers cellular telecommunications network technologies, including radio access, the core transport network, and service capabilities, and thus provides complete system specifications. The specifications also provide hooks for non-radio access to the core network, and for interworking with Wi-Fi networks [2].

3GPP is the main body for the standardization of cellular systems. METIS will contribute to the 3GPP evolution and vision work providing technical guidance on promising radio technologies, their evolution and related system concepts.

However, since 5G will broaden the use of mobile communication systems, other standardization bodies may be relevant as well. For example, Vehicle-to-Anything (V2X) communication addressing traffic safety may need to be addressed in vehicle manufacturer-specific standardization bodies as well, e.g. ISO and CEN. It is foreseen that in the future, the 3GPP "hooks" will be extended to include also hooks for non-3GPP standards necessary to realize 5G networks.

II. 5G Definition

There is work ongoing in ITU-R Working Party 5D (WP5D) to address the future development of International Mobile Telecommunications (IMT) technology. This includes technology trends, IMT above 6 GHz, and IMT-2020 vision. The technology trends have a shorter time-scope and are of limited interest for METIS and the subsequent Horizon 2020 (H2020) projects [3]. The IMT-2020 vision document will point out the 5G key capabilities at a high level. Detailed technical specifications for 5G systems are expected in later forthcoming documents.

A. *ITU-R process of defining 5G*

ITU-R WP5D has the responsibility for IMT systems, which is the umbrella name for 3G (IMT-2000) and 4G (IMT-Advanced). WP5D does not write technical specifications for IMT. However it defines IMT in cooperation with the regional standardization bodies and maintains a set of recommendations for IMT-2000 and IMT-Advanced. In the development of 4G (IMT-Advanced) ITU-R first conducted studies of services and technologies, market forecasts, principles for standardization, estimation of spectrum needs, and identification of candidate frequency bands. Thereafter evaluation criteria were agreed, where proposed technologies were to be evaluated according to a set of minimum technical requirements. Technologies meeting the requirements are referred to as 4G technologies. It is anticipated that the process for defining 5G will be similar: first creating a vision document and thereafter detailed technical requirements on 5G systems.

As a first step ITU-R WP5D has initiated a new recommendation, "Framework and overall objectives of future development of IMT for 2020 and beyond", with the working name "IMT-2020". This will look at the development of IMT technologies beyond what is defined for IMT-2000 and IMT-Advanced. The recommendation is a first step for defining developments of IMT in the future, looking at the future roles of IMT and how it can serve society, looking at the market, user and technology trends, and spectrum implications. METIS is actively involved in the Vision work and has provided several inputs to the visions document.

In addition to the 5G vision and requirements documents the ITU-R spectrum regulatory aspects affect the 5G development. METIS is investigating suitable frequency bands for different applications, different spectrum access methods and sharing methods [4]. METIS will end in April 2015, but ideas should be carried on by suitable projects and/or METIS partners and should be included in input to WRC19.

B. *5G Requirements*

Future IMT systems need to support new usage scenarios and applications, as well as continuing growth in traffic volumes and data rates. The key design principles for 5G systems are flexibility, versatility, scalability and efficiency to serve diverse use-cases and scenarios [5].

Societal development will lead to an avalanche of mobile and wireless traffic volume. Even though we cannot predict the next "killer application" it is predicted that the traffic volume will increase a thousand-fold over the next decade. METIS envisions three main service directions: Extreme Mobile Broadband, Massive MTC, and Ultra-reliable MTC [6].

Extreme Mobile BroadBand (xMBB) provides the capabilities, e.g. traffic volume and data rates, required by new applications as virtual reality and augmented reality, extreme-resolution 3-dimensional TV. Improved user Quality of Experience (QoE) and smart content delivery will also be necessary.

New use-cases include the wide range of applications related to Machine-Type Communication (MTC). The traffic characteristics and requirements of MTC often deviate substantially from those of human-centric communication. The various kinds of MTC will enable the wireless Internet of Things (IoT) encompassing tens of billions connected devices.

Massive MTC concerns massive deployments of e.g. low-cost battery-powered sensors and actuators, remote-controlled and remote-read utility meters. 5G systems must provide up- and down-scaling connectivity solutions for tens of billions of network-enabled devices since it is expected that there will be 10-100 connected devices for each human user of communications systems (for human interaction, connected machines owned by the user and devices owned e.g. by the city the user lives in).

Ultra-reliable MTC relates to the capability to provide a given service level with very high probability. Ultra-reliable MTC also includes applications where low delay is a critical factor, such as remote driving, industrial control, and haptic communication enabling remote work in e.g. hazardous environments or remote surgery. The various kinds of MTC will enable the wireless Internet of Things (IoT) encompassing tens of billions connected devices.

The coexistence of human-centric and machine-type applications, as illustrated in Fig. 1, will lead to a large diversity of communication characteristics imposing very different requirements on 5G systems. Considering also other not yet identified application areas and use-cases poses a strong requirement on system flexibility.

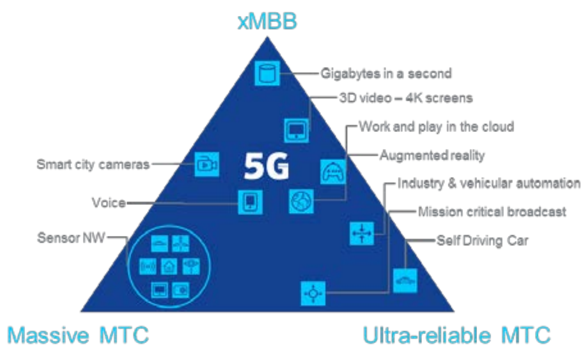

Fig. 1. Development from today's Mobile BroadBand (MBB) services to the beyond-2020 mix of xMBB, Ultra-reliable MTC and Massive MTC. Additional use-cases enabled by 5G systems are to be expected.

III. METIS 5G Concept

METIS foresees a multi-Radio Access Technologies (RAT) system, illustrated in Fig. 2, which efficiently integrates the following main fundamental services:

- Extreme Mobile BroadBand (xMBB): provides high data-rates and low-latency communications and improves Quality of Experience (QoE) through a more uniform experience over the area, and graceful degradation of rate and latency as the number of users increases. It is foreseen that xMBB can also be used for reliable communication in emergency situations.
- Massive Machine-Type Communications (M-MTC): provides up- and down-scalable connectivity solutions for tens of billions of network-enabled devices. Scalable connectivity, wide area coverage and deep indoor penetration are important, and compared to xMBB, we trade rate for coverage.
- Ultra-reliable/Critical MTC (U-MTC): provides ultra-reliable low-latency communication links for network services with extreme requirements on availability, latency and reliability, e.g., V2X communication and industrial control applications.

The key supporting enablers include:

- Dynamic RAN providing a new generation of dynamic Radio Access Networks (RANs). In dynamic RAN the wireless device exhibits a duality, being able to act both as a terminal and as an infrastructure node. Dynamic RAN incorporates Ultra-Dense Networks (UDN) and Moving Networks – Nomadic Nodes (MN-N) (mobile relaying does not exist up to now in 3GPP networks), and supports Device-to-Device (D2D) communication both for local traffic (off-loading) and backhaul.
- The spectrum toolbox contains a set of enablers (tools) to allow 5G systems to operate under different regulatory and spectrum access scenarios. The toolbox is divided into three layers called "spectrum regulatory framework", "spectrum usage scenarios", and "enabler domain", where the latter contains the different tools needed in a given spectrum scenario.
- New lean signaling/control information is necessary to guarantee latency and reliability, support spectrum flexibility, support large variety of devices with very different capabilities and ensure energy efficiency.
- Localized content/traffic flows allows offloading, aggregation and distribution of real-time and cached content. Localization reduces the load on the backhaul and provides aggregation of e.g. sensor information.

Detailed descriptions of the main fundamental services and enablers, and some key aspects are found in [6]. Descriptions of the Horizontal Topic (HT)-specific concepts leading up the overall METIS 5G system concept are given in [5, 7] and a first view on the METIS 5G system concept is given in [5].

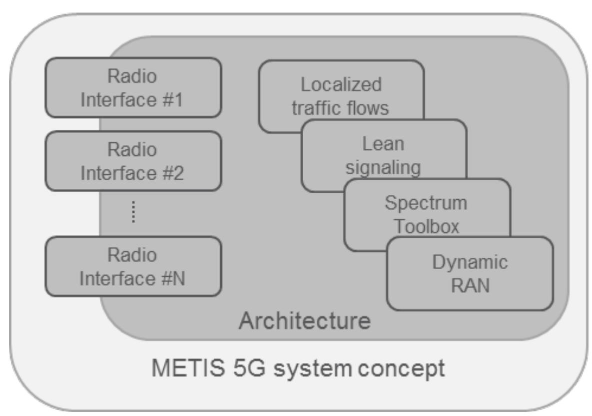

Fig. 2. Illustration of the METIS 5G system concept.

A. Radio Interfaces

The waveform design has been a main driver in the cellular evolution path. From FDMA/TDMA through WCDMA to OFDMA, different generations have been characterized by the choice of a single radio interface solution. However, METIS foresees not a single 5G radio interface, but several coexisting radio interfaces in the same technology where selection is done as a function of the scenario and the specific needs of transmitter and receivers.

The four identified main waveform candidates from METIS are Orthogonal Frequency-Division Multiplexing (OFDM)/Single-Carrier Frequency-Division Multiple Access (SC-FDMA), zero-tail Discrete Fourier Transform (DFT) spread OFDM, Filter-bank Based Multi-Carrier (FBMC), and Universal Filtered Multi-Carrier (UFMC). More information and details on the new air interfaces described in this section can be found in [8].

B. Massive MIMO

In massive Multiple-Input, Multiple-Output (massive MIMO) we see a very large antenna array at each base station and in general orders of magnitude more antenna elements as compared to conventional systems. Massive MIMO can be used for a more efficient backhaul wireless link or for the access link, in which a large number of users are served simultaneously. Essentially, massive MIMO implies multiuser MIMO with a large number of base station antennas. METIS considers massive MIMO both for access and backhaul links [6].

Massive MIMO and high gain beam-forming are perceived as crucial technical components for 5G MBB access going towards much higher data rates, much higher capacity and new and higher frequency bands up to millimeter waves (mmW) to get access to increased bandwidth.

C. Multi-hop communication

Multi-hop relaying in cellular networks, with the direct intervention of the infrastructure, is an intrinsic part of the METIS vision of the 5G. Multi-hop communications are to change the way connections are established, combining the traditional centralized schemes of connectivity with D2D communications.

According to METIS studies, multi-hop communications can increase spectrum efficiency, fairness, and reduce energy consumption. Moreover, METIS foresees that, in order to further enhance spectrum efficiency, the wireless backhaul and wireless access might share the same spectrum.

D. Network architecture

The METIS 5G architecture development is driven by three key aspects; flexibility, scalability, and service-oriented management [6]. These three aspects are complementary to each other such that the diverse set of technology components accompanied with the broad range of service requirements can be efficiently supported. Flexibility enables dynamic configuration of the necessary network functionalities for the realization of a given main fundamental service. In this sense, flexibility may span a multi-dimensional space comprising time, frequency, and devices (referred to as network elements, NEs). Certain network functionalities may be necessary at a given time for a target frequency band in certain NEs, e.g., mmW support on the radio access link of a small cell during peak time.

The flexible architecture will enable the efficient cooperation among fundamental services. This can necessitate new or tailored functionalities that will be made available on-demand. Furthermore, scalability will be assisted by flexibility to fulfill the requirements of extremely contradicting use cases, e.g. low data rate MMC versus multi-user ultra-high definition telepresence. The anticipated flexibility and scalability will enable a future-proof architecture that can adapt to the requirements of the possibly emerging use cases that are unknown at present. Accordingly, the service-oriented management will make use of scalability and flexibility to provide the utmost quality for a targeted service. In addition, the METIS 5G architecture shall enable cost- and energy-efficient operation of mobile and wireless communication networks, and METIS is collaborating with the 5GrEEn project to develop solutions for improved energy efficiency [9].

Architectural trends such as Software Defined Networking (SDN) and Network Function Virtualization (NFV) will be taken into account to define the final METIS 5G architecture. Implementation of radio network and service functions in C-RAN environments in a localized and/or centralized way (dependent on infrastructure availability of the Mobile Network Operator and line delay limitations set, e.g., by CoMP schemes) will simplify the mapping of SDN and NFV features onto the RAN. NFV [10, 11] can be seen as highly complementary to SDN [12, 13], as it is relying on techniques currently in use in many data centers.

As illustrated in Fig. 3, from a functional point of view, the METIS radio access can be decomposed into:

- Network Management where all blocks that cover network overarching functionalities are arranged;
- Radio Node Management containing the building blocks (BBs) that provide radio functionalities that affect more than one node;
- Air Interface that includes all the functions that are directly related to air interface functionalities of radio nodes and devices;
- Ultra-Reliable Service Composition as well as Ultra-Dense Network Extension belongs to HT-specific overarching BBs.

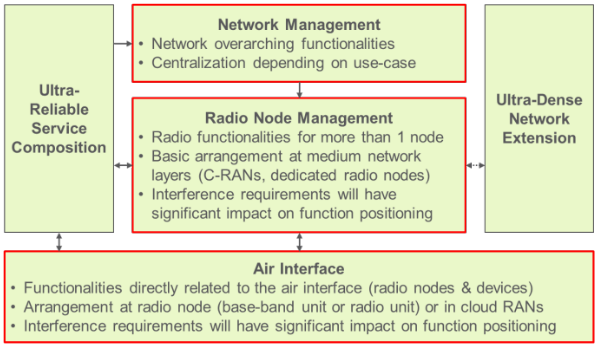

Fig. 3. Overall high-level functional architecture.

IV. 5G STANDARDIZATION

Research projects such as METIS should conduct the pre-standardization research work. They investigate novel promising technologies, and identify which technologies bring real gains. EU research projects have a good mix of partners that under ideal conditions can focus on conducting exploratory research and more system-oriented applied research. The latter helps in finding the promising topics that provide actual practical gains.

Mobile communication standardization predominantly takes place in 3GPP [2]. As 5G will include new application areas, not all standardization will necessarily take place within 3GPP, and some 5G components may be standardized by other standardization bodies. Already today other relevant bodies, such as IEEE (802.11 mobile/Wi-Fi integration, ITS G5 802.11p V2X, 802.15 Zigbee, wireless HART automatic control) are active. Integration of 3GPP technologies and Wi-Fi technologies is already taking place, and coordination between the standardization bodies or clear division between areas of responsibility will be necessary. This will likely be done on a use-case by use-case basis.

3GPP is foreseen to be the main 5G standardization body, in particular for xMBB and services tightly coupled to xMBB. xMBB extends the capabilities of today's MBB in terms of supported data rates and frequency ranges, and adds new features including increased reliability and service equalization. The technology components enabling xMBB, e.g., massive MIMO, mmW communication, D2D are already being considered by 3GPP, though the 5G versions of the technology component may be significantly different and not necessarily backwards compatible.

3GPP standardization separates between Study Items (SIs) and Work Items (WIs), but currently the trend is that also WIs have initial study phases. Properly executed, EU research project can mitigate the trend of standardization discussions becoming discussion on research topics.

3GPP Release 8 was the first LTE release. Subsequent releases include new features that ideally should provide some substantial gains, e.g. Carrier Aggregation in Release 10. Release 10 of LTE is the first version approved by ITU-R as an IMT-Advanced technology and is therefore also the first release named LTE-Advanced. Later releases include work on Wi-Fi integration and small cells. As will be elaborated later, 5G work is expected to start in 3GPP in Release 14.

Massive MTC builds on area coverage and deep indoor penetration. LTE systems are well deployed, and are likely to be used to realize the Massive MTC service (LTE-M). Hence we believe that 3GPP will be the main standardization body for Massive MTC.

In some cases (e.g., short-range communication) already existing technologies (e.g., IEEE 802.11ah and Bluetooth LE) may sufficiently well meet the requirements and can be considered as such 5G components standardized outside 3GPP. Most terminals have 3GPP technology as well as Wi-Fi and Bluetooth. Integration in the device does not bring the benefits that can be achieved by network integration. Integration in the device may also result in in-device coexistence issues that need to be resolved.

Ultra-reliable MTC concerns different aspects, predominantly reliability and low latency. Low latency is achieved by radio interfaces and supporting architecture within the communication system. This is likely to require changes in the radio interface but this can be handled within 3GPP.

Reliability is an emerging property that relies on a consistent system design. In some applications, e.g. Cooperative Intelligent Transport Systems (C-ITS) the reliability hinges on dual-connectivity operations. For traffic safety applications, a network-assisted D2D communication is crucial. The network-assisted communication part naturally falls in the realm of 3GPP, whereas the D2D radio interface for ad-hoc V2X communication may be standardized by some other standardization body. In particular, for C-ITS, ETSI, CEN and ISO are together developing specifications. In this area we see an example of joint work between ISO TC204 WG18 and CEN TC278 WG16 [14]. There is also global cooperation with IEEE and SAE standardization. In addition to radio interfaces, information models and some architecture for C-ITS need to be standardized.

The concept of Connected Cars include more than the traffic safety application in the immediate vicinity of the vehicles and vulnerable road users. Providing information beyond the immediate horizon of the vehicle (which is addressed in the previous paragraph) and in-vehicle entertainment can be done by xMBB traffic. Similarly for industrial control, robot manufacturers have branch-specific standardization bodies.

V. Timeline towards 5G

It is important to ensure correct timing of 5G standardization activities in 3GPP. Premature introduction of research results into the standardization process does not benefit 5G standardization. As mentioned in the previous section, METIS and applicable H2020 projects should further develop the results before entering the 3GPP and other standardization bodies.

Following the process used for LTE we anticipate the timeline outlined below.

The first standardization task should be to develop the 3GPP design targets and requirements based on the ITU-R vision document as guidance. The appropriate timing for this is expected to be shortly after WRC15, which would correspond to roughly 3GPP Release 14. High level aspects, e.g. determining the mix of evolution and revolution in 5G systems, of 3GPP submission can be agreed also during this time.

Once the 3GPP design targets and requirements are developed, the work can progress to settling the fundamentals of the technical solution. The outcome of the 3GPP study should preferably be at a suitable level for an initial submission to ITU as a 3GPP 5G concept.

The results of the study form a basis for the follow-up WI(s) in 2018-19, which would match the expected complete ITU specification deadline in the end of 2020.

Since METIS ends in April 2015, it is expected that additional research work will be carried out in subsequent H2020 projects, especially inside 5G PPP where several follow-up project proposals are being prepared that will continue to develop key technologies researched by METIS.

The tentative timeline for the ITU, 3GPP, METIS and H2020 work is illustrated in Fig. 4.

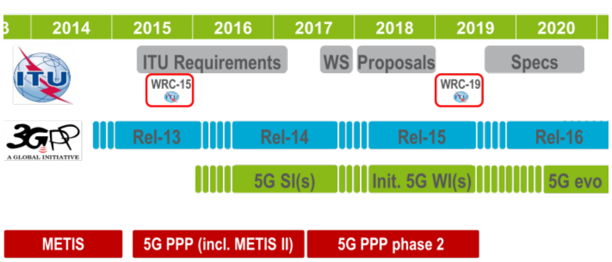

Fig. 4. Tentative timeline for ITU 5G requirements process, 3GPP standardization and EU research projects (METIS and subsequent 5G-PPP [15] projects within H2020).

VI. Conclusions

EU research projects fill an important role in aligning the requirements of 5G systems and identifying and investigating promising technology components before the standardization work starts.

METIS has identified a set of main fundamental services; xMBB, Massive MTC, Ultra-reliable MTC, and enablers; Dynamic RAN, Spectrum toolbox, new lean signaling/control and localized traffic flows. METIS is investigating technology components enabling these services and enablers.

3GPP is foreseen as the main 5G standardization body, but METIS research is applicable also to other standardization bodies, e.g., ISO, CEN, and ETSI. The 5G standardization will start in 3GPP with Release 14, for commercial deployment in 2020.

Acknowledgment

Part of this work has been performed in the framework of the FP7 project ICT-317669 METIS, which is partly funded by the European Union.

The authors would like to acknowledge the contributions of their colleagues in METIS, although the views expressed are those of the authors and do not necessarily represent the project.

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