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Wireless 5G Ultra Reliable Low Latency Communications

European and Austrian Research Initiatives.

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Abstract 5G standardization and research progresses at full speed on a world-wide scale. In this article we describe the architecture of future 5G systems, their use cases and key physical layer technologies. The time-plan and current state of 5G research in Europe in Horizon 2020 is presented. An overview about the research activities in Austria is given. Finally, the 5G research focus at AIT Austrian Insitute of Technology with its projects in the domain of ultra reliable low latency communications (URLLC) is introduced.

Keywords 5G · European research · Austrian research · ultra reliable low latency communications

1 Introduction

5G standardization and first system trials have created a wide interest in the new system capabilities and use cases of 5G. 5G aims to increase the peak data rate to 10Gbit/s, and focuses strongly on machine-to-machine (M2M) communication links where a latency (transmission delay from transmitter (TX) to receiver (RX)) of 1 ms and a battery lifetime of up to 10 years are key performance parameters, see Fig. 1.

2 Three Systems in One

Clearly, a 5G system will not provide all the performance targets, shown in Fig. 1, simultaneously for a single communication link. This is simply not possible from the underlying physics. In fact, 5G provides a combination of

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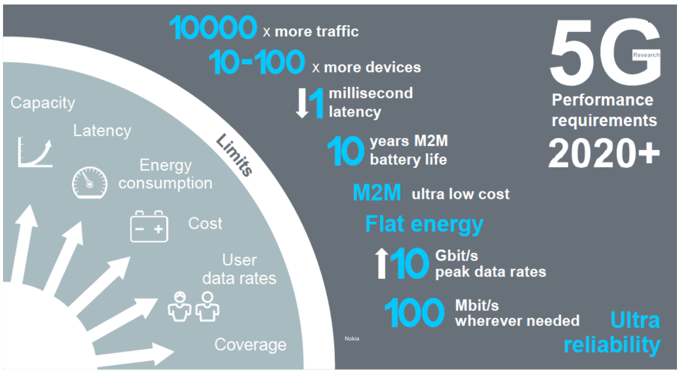

Fig. 1 5G targets, ©Nokia.

three different, so called network slices, within one system [1]. These three slices can be visualized as independent dimensions, see Fig. 2. Each dimension (network slice) targets a very different use case categorie [2]. These are:

- *Enhanced mobile broad band (eMBB)* for data rates up to 10 Gbit/s;
- *massive machine type communication (mMTC)* with low energy consumption for a battery life of 10 years, optimized for low data rates of 10 b/s; and
- *ultra reliable low latency communication (URLLC)* providing 1 ms latency at low frame error rates.

The eMBB network slice is a straight forward extension of current LTE systems to higher bandwidth of up to 10Gbit/s cell throughout. This data rate allows for ultra high definition video streaming, virtual or augmented reality applications, as well as hot spot support with high user densities. Clearly, for eMBB the focus is on high data rates. Latency and power consumption are only secondary parameters.

mMTC focuses on the internet of things (IoT) where long battery life is essential for practical operations, although data delivery does not require tight deadlines or high data rates. mMTC allow the communication with a large number of sensors, providing data such as temperature, position, etc.

URLLC is a key new wireless communication mode enabling wireless automation and control applications. These are, e.g., networked autonomous vehicles, that need a wireless communication link for data exchange especially in rural environments like city centers, to achieve the safety level of current road traffic with human drivers. Another key application domain are Industry 4.0 automation and control scenarios, to replace cables with wireless links for robot-to-robot communication links or for collaborative human-robot production scenarios.

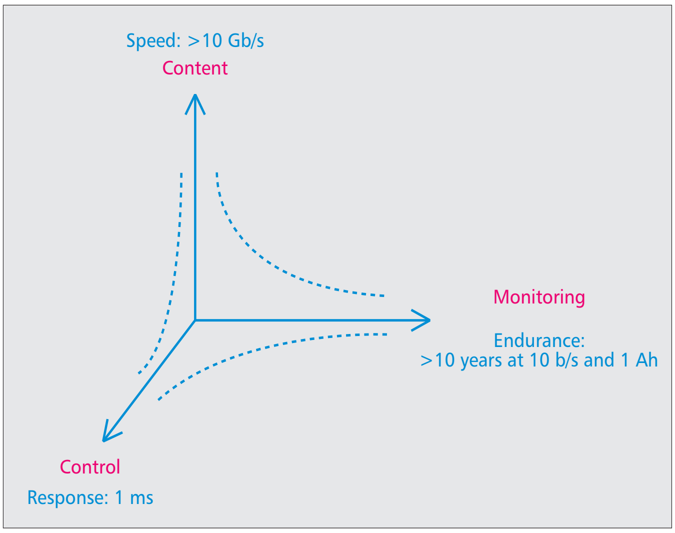

Fig. 2 5G dimensions [1].

3 New Technologies

All of the above described new 5G features cannot be achieved by simply downloading a new app on your current generation smart phone. Fundamental changes are needed to the physical wireless transmission layer technologies to achieve the target parameters of Fig. 1. Three key new technologies have emerged as primary candidates. These are [3]:

1. Massive multiple-input multiple output (MIMO) systems [4,5] using a large number of antennas ($\sim$ 100) at the base station to allow for spectrally efficient transmission;
2. the millimeter-wave frequency band from 30-90GHz is utilized to increase the available bandwidth for high data rate wireless links [6]; and
3. network densification reduces the cell size and allows increased cell cooperation [7,8].

All three technologies together shall increase the overall capacity of 5G systems by a factor of 1000 compared to current 4G LTE systems.

4 5G Timeline - Research, Trials, Standards

An ambitious time-line is in place to progress from research over trials to a standard specification, see Fig. 3. The European commission is funding research projects in three phases via Horizon 2020 (H2020) in the 5G public private partnership (PPP). Phase two projects are currently ongoing and phase three projects are about to start. In parallel, the 3GPP provides regular standard releases, implementing first 5G features, enabling trials to be conducted

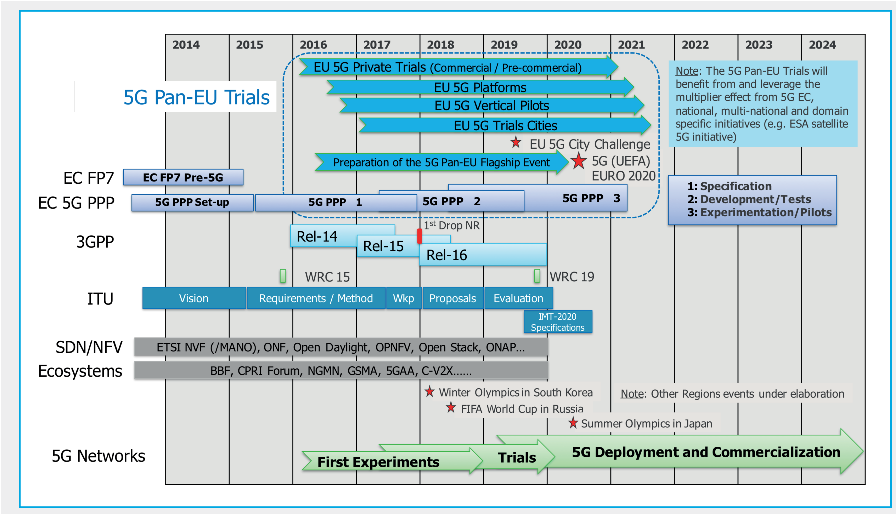

Fig. 3 5G European timeplan, ©EC.

with standard like equipment. Release 15 will be published mid 2018 containing the 5G new radio (NR) physical layer specification. Release 16 is expected end of 2019. The world radio conference (WRC) will define the frequency bands for the 5G deployment in 2019.

5 European 5G-PPP Phase 2 Projects

The currently ongoing 5G-PPP phase research project in H2020 are focusing on 5 key aspects:

1. *Wireless radio access network*: The project ONE5G[1] investigates end-to-end 5G new radio improvements, while SAT5G[2] deals with the integration of satellites into 5G. The URLLC connection in different scenarios might vary quite significantly (vertical sectors). Hence, URLLC communication links for vehicles is the focus of the project 5G CAR[3] and URLLC for factories-of-the-future (FoF) is taken care of in the project Clear5G.
2. *Optical and wireless access network*: Due to high bandwidth requirements of 5G, an efficient optical access network is required. At the same time mmWave frequencies require new design methods for antenna arrays. Both topics together are tackled in the project BLUESPACE[4] to obtain an optical beamforming interface for mmWave transmission. Visible light communication within buildings is the topic of the project IoRL[5], and an optical

[1] one5g.eu
[2] sat5g-project.eu
[3] 5gcar.eu
[4] bluespace-5gppp.squarespace.com
[5] iorl.5g-ppp.eu

fronthaul architectures is investigates in 5G-PHOS[6]. Computing resources at the network edge, e.g. directly at the base station, are needed for low-latency operations. The combination of such edge computing with optical networks is the topic of the project 5G-Pitcture[7]. Finally, the project METRO-HAUL[8] investigates optical software defined networks (SDN) and network function virtualization (NFV) within optical transport networks.
3. *Networking and vertical industrial use cases*: Broadcast and multicast for 5G is taken care of in 5G-Xcast[9], the project 5G-Transformer[10] provides a mobile transport and computing platform for vertical industry sectors, while a communication infrastructure for the energy grid is designed in the project NRG-5[11].
4. *Network slicing and edge computing*: A general slicing network shall be the outcome of SLICENET[12], solutions for 5G edge cloud computing and communication are provided by the project 5GCity[13], and finally network management for 5G edge computing is investigated in 5G ESSENCE[14].
5. *SDN, NFV and services*: Virtual network functions for 5G networks are the topic of 5G-MEDIA[15], 5G-MonNArch[16] deals with mobile network slicing using SDN and NFV, verification and validation of NFV is the scope of the project 5G-Tango[17]. A 5G service framework is being developed in MATILDA[18] and the goal of the project NGPaaS[19] is a telco grade platform as a service.

6 Austrian 5G Research Landscape

With the project databases available at the Austrian Research Promotion Agency (FFG)[20] and of the Christian Doppler Research Association[21] the following 5G related activities can be identified in Austria:

– TU Wien: Christian Doppler (CD) Lab for "Dependable Wireless Connectivity for the Society in Motion"

[6] www.5g-phos.eu
[7] www.5g-picture-project.eu
[8] metro-haul.eu
[9] 5g-xcast.eu
[10] 5g-transformer.eu
[11] www.nrg5.eu
[12] slicenet.eu
[13] www.5gcity.eu
[14] www.5g-essence-h2020.eu
[15] www.5gmedia.eu
[16] 5g-monarch.eu
[17] 5gtango.eu
[18] www.matilda-5g.eu
[19] ngpaas.eu
[20] projekte.ffg.at
[21] cdg.ac.at

- Salzburg Research: Network layer research for cyber physical systems (5G-Mlab, TriCePS)
- Johannes Kepler University Linz: CD-Lab Digitally Assisted RF Transceivers for Future Mobile Communications
- Graz University of Technology: Dependable, secure and time-aware sensor networks (DeSSnet)
- Uni Klagenfurt: 5G playground Carinthia

6.1 5G Research at the AIT Austrian Institute of Technology

At the AIT Austrian Institute of Technology a comprehensive 5G research focus has been established in recent years for URLLC applications as well as optical wireless interfaces.

- *Massive MIMO for Reliable 5G Vehicular Communications (MARCONI)*: Connected autonomous vehicles are able to exchange sensor information (radar, optical, etc.), kinematic information and maneuver information to achieve cooperative joint decisions in difficult traffic situations. This cooperation helps to improve traffic safety and approach the goal of zero accidents. Highly-reliable and low-latency 5G wireless vehicle-to-infrastructure (V2I) communication links shall enable the cooperation in a controlled manner, connecting vehicles to a mobile-edge cloud computing center at the base-station location. The project MARCONI uses a massive multiple-input multiple-output (MIMO) systems where the base station is equipped with 30...100 antenna elements while the mobile station uses a single antenna. With this setup, it is possible to focus the transmit energy of the base station by coherent superposition at the location of the mobile station. New algorithms are explored to enable massive MIMO links for highly time-variant and non-stationary V2I scenarios. To avoid shadowing, algorithms for distributed massive MIMO antennas are devised and transceiver algorithms are implemented on a real-time software-defined radio (SDR) testbed.
- *Fast Production Line Reconfiguration - Replacing Cables with Radio Communication Links (UNWIRE)*: The dynamic reconfigurability of current production systems is severely hampered by the fixed wiring of automation and control systems. The exchange of cable connections with ultra-reliable wireless communication links, will improve the reconfigurability of future production lines. Thus, the communication between sensors, actuators and processing units within a control cycle, needs to be supplemented by low-latency wireless communications. For fast control processes in production systems, a control cycle time of approx. 100μs is needed, which is not achievable with current wireless communication systems (state-of-the-art is 16 ms). Therefore, new low-latency wireless transmission methods are required for dynamically reconfigurable production systems that exploit all diversity sources in industrial scenarios to achieve high transmission reliability. Based on a future production scenario analysis, the research within

UNWIRE aims for an industrial communication link with a cycle time of 125μs. The frame error rate is minimized for industrial scenarios, through optimized wireless signal processing algorithms (in the transmitter and receiver) and the dynamic selection of wireless relays with multiple antennas (network diversity). The key innovation of UNWIRE is to allow the dynamic reconfiguration of production systems by the replacement of fixed wiring with radio links.
- *Secure Connected Trustable Things (SCOTT)*: The project SCOTT focuses on wireless sensor and actuator networks and communication in the areas of mobility, building and smart infrastructure. This addresses numerous European societal challenges such as smart, green and integrated transport, secure and inclusive societies as well as health and wellbeing. SCOTT will enable efficient, trustworthy connectivity and facilitate ubiquity of intelligent embedded systems and systems of systems, thus essentially contributing to burning issues in Automated Vehicles or Industry 4.0. AIT is contributing to the measurement, modeling and real-time system level simulation of multi-node communication networks between vehicles on the street and on rails. On rails the communication link is used to realize a virtual coupling of high speed trains.
- *Heterogeneous Integration of Millimeter-Wave Technology (TRITON)*: Millimeter-wave technology exploits unused frequency band starting from 30 GHz opening new vistas for 5G communication scenarios. In the project TRITON solutions for mm-wave technology along the entire functional chain are developed: originating from high-frequency gallium-nitride-on-silicon-carbide (GaN-on-SiC) and silicon-germanium (SiGe) electronics capable to operate energy efficiently at frequencies like the 30-GHz Ka-band towards silicon-on-insulator (SOI) photonics featuring low-drive modulators and photo detection for seamless translation of signals to and from the optical domain. TRITON aims to fabricate and characterize test-chips, incorporating the functionalities of millimeter-wave amplification in the 27-32 GHz range and translation to and from the optical domain in view of emerging applications in 5G and the industrial internet.

7 Conclusions

Research, standardization and deployment of 5G is currently under way at full pace using the targeted effort within Horizon 2020 in Europe. Current European research projects investigate radio access, optical networks, network slicing and edge computing, software defined networks, network function virtualization as well as service creation. Research activities in Austria are strongly focused on the Austrian industry needs, which are chip design, network operation, and 5G for vertical ultra-reliable low-latency communication use cases. It is clear that the planned early 5G deployment will not stop research and development. New 5G features will be added with a regular release rhythm throughout the next years to come.

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