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Euro-5g – Supporting the European 5G Initiative

The European 5G Annual Journal

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1 Introduction

Future European society and economy will strongly rely on 5G infrastructure. The impact will go far beyond existing wireless access networks with the aim for communication services, reachable everywhere, all the time, and faster. 5G is an opportunity for the European ICT sector which is already well positioned in the global R&D race. 5G technologies will be adopted and deployed globally in alignment with developed and emerging markets' needs.

The aim of this first edition of the European 5G Annual Journal is to highlight and disseminate the European achievements in the context of global progress in the 5G PPP domain. It presents an analysis of the 5G ecosystem evolution over the past year.

1.1 Editorial

Werner Mohr, Chair of the Board, 5G PPP

The 5G Public-Private Partnership (5G PPP) within the Horizon 2020 programme of the European Union is the biggest research program in the world on 5G, which will be the future global communication network. 5G will provide a common communication infrastructure, which will be used for as many use cases in society and economy and in particular vertical industry sectors as possible in order to support interoperability, economy of scale and end-to end security for mission critical applications. 5G research in Europe is building on research projects, which started already in the previous Framework Programme of the EU (Framework Programme 7); they already paved the way towards the vision and basic concepts of 5G. Research in the 5G PPP has a very wide scope far beyond classical telecommunication. The contractual PPP instrument allows the close cooperation of 5G PPP projects on areas of common interest and interfaces between different network entities. This is facilitated by a Collaboration Agreement across all ongoing 5G PPP projects. The current 5G PPP vision and technical requirements are described in a 5G vision document, which was first published at the Mobile World Congress 2015 in Barcelona in March 2015[2].

5G PPP has established links to vertical sectors like Factories of the Future, Healthcare, Energy, Media and Automotive. Details on such use cases and technical requirements were published in a white paper at Mobile World Congress 2016[3]. This is an important precondition to understand the needs and technical requirements of vertical sectors and to take this into account in system design and standardisation.

In December 2013, the 5G PPP Contractual Arrangement was signed by the EU Commission, which is representing the public side, and the 5G Infrastructure Association, which is representing the private side in the PPP. The 5G PPP Contractual Arrangement defines key performance indicators (KPIs), which also measure the impact of 5G PPP on the global 5G development. The 5G Infrastructure Association is supporting these activities by means of dedicated working groups and activities.

Public Private Partnerships in Horizon 2020 are intended to be industry driven, to strengthen the European economy and the impact on future global standards based on research in Europe. The Association is bringing together many different stakeholders from the manufacturing industry, network operators, SMEs, R&D centers and universities. In the current governance model the Association is built on elected members by the Networld2020 European Technology Platform in order to support criteria on openness, transparency and representativeness by the huge membership of more

[2] Available for download at https://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Brochure-v1.pdf

[3] Available for download at https://5g-ppp.eu/wp-content/uploads/2016/02/BROCHURE_5PPP_BAT2_PL.pdf

than 1170 member organisations in Networld2020 of the sector[4].

Networld2020 is developing on a regular basis the Strategic Research and Innovation Agenda (SRIA) for the communication networks sector and – in cooperation with the Association – also the respective SRIA for 5G. This takes the interests of the wider community in the communication networks sector and market driven requirements into account.

From that perspective, the Association is representing and addressing the interests of its members and associate members as well as Networld2020's members towards the European Commission, other public authorities and stakeholders. The Association is cooperating with the EU Commission to develop the 5G work program in Horizon 2020, through a dedicated "Partnership Board" which discusses the work program and other activities of common interests to promote 5G PPP and its results globally.

The overall objective of the 5G Infrastructure Association is to promote R&D in the networks industry in order to strengthen the networks industry in the European Union, to foster technology skills in Europe by attracting students, and to increase the competitiveness of the European industry by providing new tools and capabilities for manufacturing in Europe. In addition, the Association is working to mobilise the community and in particular SMEs in European collaborative research projects. It is the facilitator of the 5G PPP research program on the private side.

In addition, the 5G Infrastructure Association is helping to address policy-oriented topics, which are not directly related to technical issues. The development of future networks also requires contributing to topics like standardisation, frequency spectrum, other regulatory issues, how to address vertical sectors and international cooperation to support the development of globally accepted standards. The association has already established Memoranda of Understanding (MoUs) with counterparts in China, Korea, Japan and North America and signed a multilateral MoU with these counterparts for a series of *Global 5G Events* for information exchange and consensus building in preparation of future standards.

The 19 first call projects started on July 1, 2015 and are generating significant research results. Projects are present at international conferences and activities and impact the global development. In addition, the projects have established technology-oriented working groups and cooperation means across projects and are developing joint white papers.

The 5G Infrastructure Association is looking forward for a further successful cooperation with 5G PPP projects, the EU Commission, Networld2020 and other stakeholders globally.

[4] Information on the NetWorld2020 European Technology Platform is available at http://www.networld2020.org/.

1.2 Executive summary

Future European society and economy will strongly rely on 5G infrastructure. The impact will go far beyond existing wireless access networks with the aim for communication services, reachable everywhere, all the time, and faster. 5G is an opportunity for the European ICT sector which is already well positioned in the global R&D race. 5G technologies will be adopted and deployed globally in alignment with developed and emerging markets' needs.

The aim of this first edition of the European 5G Annual Journal is to highlight and disseminate the European achievements in the context of global progress in the 5G PPP domain. It presents an analysis of the 5G ecosystem evolution over the past year.

5G PPP: an innovative initiative to foster R&D

The 5G Infrastructure PPP is a unique opportunity for the European ICT industry to compete on the global market for 5G infrastructure deployment, operation and services.

The 5G Infrastructure PPP, in short 5G PPP, is a joint initiative between the European Commission and the European ICT industry. The Commission is investing 700 million € and the industry will leverage this investment by a factor of 5, bringing the total investment into the 5G PPP to more than 4 billion €, to rethink the infrastructure and to create the next generation of communication networks and services. The 5G PPP is aiming at securing Europe's leadership in the areas where Europe is strong or where there is potential for creating new markets such as smart cities, e-health, intelligent transport, education or entertainment & media. The 5G PPP initiative will reinforce the European industry to successfully compete on global markets and open new innovation opportunities. The 5G PPP will deliver solutions, architectures, technologies and standards for the ubiquitous next generation communication infrastructures of the coming decade.

5G PPP goal is to maintain and enhance the competitiveness of the European ICT industry and to ensure that European society can enjoy the economic and societal benefits these future networks will bring.

H2020 projects phase 1

The 5G PPP is planned to be organised in three or four phases, encompassing research (current stage), optimisation (2016-2017) and large scale trials (2019-2020). It aims to deploy 5G as from 2020, which will require before 2020 to develop a series of ground-breaking technologies, global standards and to agree on relevant spectrum bands. On the 1st of July 2015, the projects from the 1st phase of the 5G PPP started with a joint meeting in Paris, France. This was a major milestone to get research investment focused in a very coherent way on the challenges associated with having a communications infrastructure capable of coping with all future demands by 2020. The first call for projects has resulted in 19 projects being selected addressing a rich cross section of the research challenges leading to a 5G infrastructure by 2020. The shared belief is that the vast majority of future communications will use wireless access technologies. This puts tremendous requirements on these projects to find ways to maximize the efficiency of the wireless interface, optimize the use of scarce resources – such as spectrum and energy – and dramatically increase the throughput capability of the infrastructure. The 5G Infrastructure will have to cope with everything from billions of small devices in the Internet of Things domain to billions of heavy data consumers enhancing their lives and activities with real-time multimedia content. The new approach must be fully convergent as well as there will be no arbitrary distinction between fixed and mobile – there will be simply a seamless infrastructure satisfying everyone's communications needs in and invisible, but totally dependable, way.

Verticals

While many technical activities around 5G are scaling up globally, requirements analysis of key vertical sectors is rapidly progressing. The emergence and deployment of 5G technology is likely to trigger innovation in this industry, thus leveraging sustainable societal change. There is a vision for 5G to become a stakeholder driven, holistic ecosystem for technical and business innovation integrating networking, computing and storage resources into one programmable and unified infrastructure. In addition, thanks to real time and larger traffic volume capabilities, 5G is expected to enable the transport of software to the data1 rather than the other way round, i.e. executing software on the device where the data is produced instead of sending all data to a centralised data centre; therefore paving the way for new opportunities in the cloud computing market, where European companies may gain significant market share2. In the long run, it will not be sufficient to explore the requirements of the vertical industries but also conduct a proper analysis of market trends in order to sense new, upcoming technology especially through companies outside the industrial mainstream. Potentially disruptive technologies typically grow widely undetected by the established industry but certainly have a large potential to become drivers for significant technical change and innovation3. Unanticipated 5G features are likely to emerge from future technological, legal, societal and socio-economic considerations.

Standardisation

The 5G standardisation framework will be defined in 2016. Use-cases originating from verticals should be considered as drivers of 5G requirements from the onset with high priority and covered in the early phases of the standardisation process. 5G will also integrate different enabling technologies (e.g. mobile, fixed, satellite and optical), spectrum- regulatory frameworks (e.g. licensed and unlicensed) and enabling capabilities (e.g. Internet of Things – IoT). The corresponding standardisation bodies need to work closely together, including with key vertical sectors, with an aligned roadmap. In the context of radio standards development, vertical use cases should be duly considered when identifying spectrum priorities.

Timeline

Phase 1 of the 5GPPP started on July 1st, 2015 and most projects will end by mid-2017. Contributions to 3GPP standardization will be important inputs during the three phases of the 5G Infrastructure PPP as shown in the figure below:

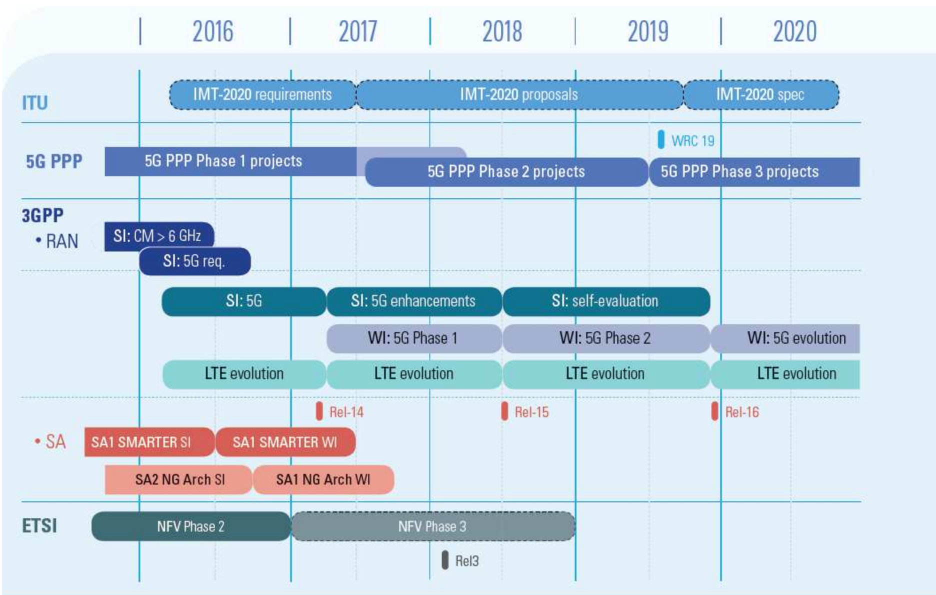


Figure 1: 5G PPP projects timeline

2 Context

2.1 Challenges of the industry

In order to fulfil the promises the 5G infrastructure can bring, there are many challenges which need to be overcome and that are thus being tackled by the 5GPPP initiative.

The most important of these challenges is of course the rollout of the infrastructure itself, the target already set for the year 2020. The real challenge here will be to deploy a 5G communications infrastructure which meets industry expectations, and thus it must be capable of coping with all future demands which are expected to be in place as we approach 2020. To deal with such high demands, it is imperative that that all technical targets are met through expected technical innovations, described in more detail at the end of this chapter. It is not only technical challenges which wait, however; another key challenge it to maintain price points of chipsets and handsets at a reasonable level. Economies of scale can be expected to drive prices down in the long run, but initial prices are required to be set at realistic levels for initial implementation of the 5G infrastructure. Another important challenge is to fulfil all of the unique requirements set out by the various verticals, such as automotive, energy, factories and e-health; such verticals contain their own specific challenges, the details of which are laid out in more details in the following chapters.

2.2 Ten key results and topics covered in the past year

We identified ten key topics concerning 5G development in Europe during the past year, as outlined below. We believe it is important to recognize these topics, and to build on them going into the future.

1) Launch of phase 1 5GPPP projects

Phase 1 of the 5GPPP projects was launched in July 2015, with a meeting in Paris.

2) Cooperation agreements / MoU (Memorandum of Understanding)

Partnerships in Asia, Russia and North America, including MoU with associations such as 5G Mobile Communications Promotion Forum Japan (5GMF), the 5G Forum (South Korea), IMT-2020 (5G) Promotion Group (China) and 5G Americas

3) First Global 5G event

The inaugural Global 5G event, took place in June 2016 in China. The second event will take place in November 2016 in Rome. A third Global 5G event is scheduled for Spring 2017 in Japan. South Korea is expected to host the 4th Global G event fall 2017.

4) 5G vertical workshops

Two 5G workshops focusing verticals were organised in the second half 2015. The first one was held on June 18th 2015 in Brussels. A second one took place in November 2015. A Media and Analyst Briefing was held in February at the MWC 2016 to launch the 5G PPP whitepaper entitled “5G empowering Vertical Industries”.

5) World Radiocommunication Conference 2015 (WRC15)

First discussions on frequencies to be used for 5G infrastructure took place at WRC15 in November 2015 in Geneva. Final decisions following technical studies will be made during the next conference in 2019.

6) Mobile World Congress 2016 (MWC16)

A media and industry analyst briefing on the launch of the 5G PPP White Paper "5G Empowering Verticals" was held at MWC16 in February 2016, and special sessions were also held.

7) Standardisation

With the standardisation framework to be defined in 2016, workshops are being organised e.g. by ETSI in Sophia Antipolis in May 2016.

8) Cooperation between 5GPPP projects: workshops

Various workshops took place involving the cooperation of 5GPPP projects, such as the "5G, From Myth to Reality" workshop in April 2016, RAN design workshop in December 2015.

9) Trials

Early trials of 5G communications commencing from 2016

10) Launch of phase 2 5GPPP projects

Phase 2 of the 5G PPP projects, the pre-structuring model, was released in March 2016, presented and discussed at EC Info Days in Bologna (March 2016), Warsaw (May 2016) and Athens (July 2016).

2.3 Significant past milestones – timeline

As already mentioned previously, the final target is to roll out commercially available 5G communication infrastructure by 2020. To achieve this goal, various milestones have been set, as pictured in the table below:

Date	Milestones
2014-2015	Exploratory phase to understand detailed requirements on 5G future systems and identify most promising functional architectures and technology options which will meet the requirements. These activities will build on previous research work in industry and research framework programmes as well as global activities in other regions and standard bodies.
2015-2017	Detailed system research and development for all access means, backbone and core networks (including SDN, NFV, cloud systems, undedicated programmable hardware…) by taking into account economic conditions for future deployment.
2016-2018	Detailed system optimisation by taking into account all identified requirements and constraints. Identification and analysis of frequency bands envisaged for all 5G communications and final system definition and optimisation by means of simulations, validation of concepts and early trials. Contributions to initial global standardisation activities e.g. in 3GPP. Preparation of WRC 19. Support of regulatory bodies for the allocation of newly identified frequency bands for the deployment of new systems. New frequency bands should be available around 2020.
2017-2018	Investigation, prototypes, technology demos and pilots of network management and operation, cloud-based distributed computing and big data for network operation. Extension of pilots and trial to non ICT stakeholders to evaluate the technical solutions and the impact in the real economy. Detailed standardisation process based on validated system concepts by means of simulations and close to real world trials.

2018-2020	Demonstrations, trials and scalability testing of different complexity depending on standard readiness and component availability
2020	New frequency bands available for trial network deployment and initial commercial deployment of new systems. Commercial systems deployment under real world conditions with selected customers to prepare economic exploitation on global basis.

Table 1: From 5G exploration to 5G deployment

In addition to the overall milestones leading up to 2020, another important aspect to consider is standardisation. It is clearly expected that the core of the 5G standardization related to mobile technologies will happen in the context of 3GPP, e.g. 3GPP RAN, CT and SA groups. However the 5G Infrastructure PPP members will also contribute to a wide range of other standardization bodies (IETF, ETSI, ONF, Open Daylight, OPNFV, Open Stack…). A high-level overview of the 5G roadmap, as seen from 5G Infrastructure PPP, is depicted below:

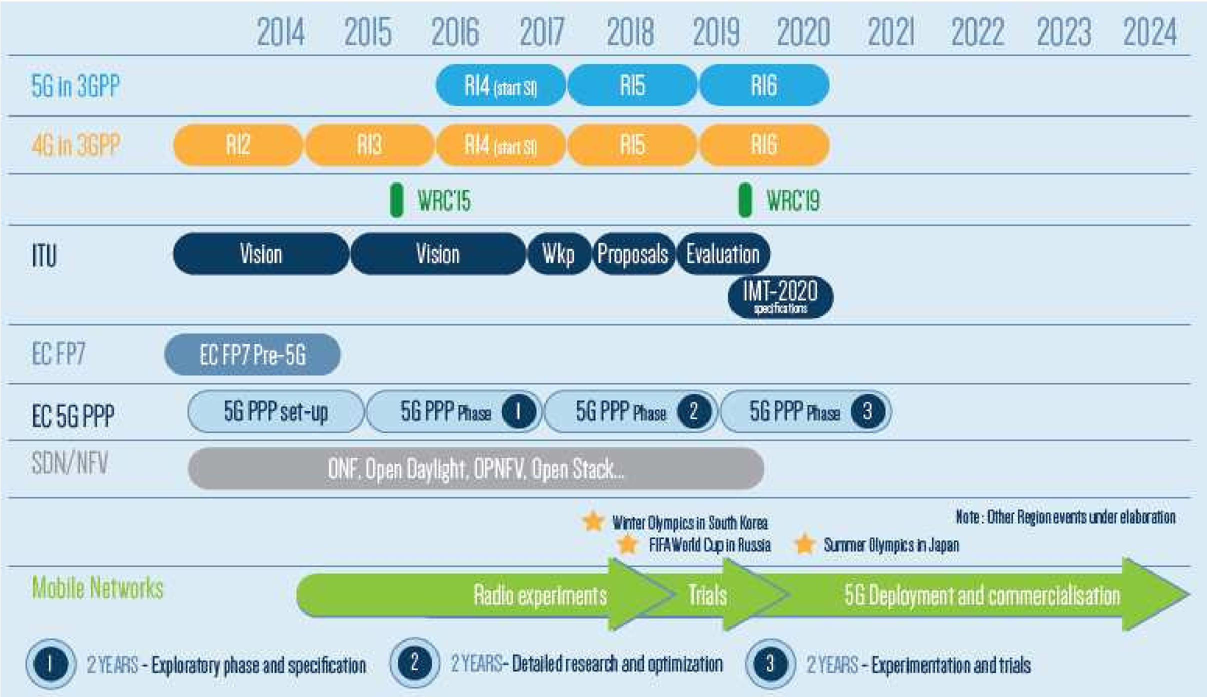


Figure 2: 5G roadmap

Combining the two timelines above, standardised 5G commercial launches are expected from 2020 onwards, but some players have proclaimed commercial 5G launch dates prior to this. For example, Ericsson and TeliaSonera announced they expect their 5G collaboration to begin providing services to customers as soon as 2018, while South Korea are looking to become the world's first such provider especially with the PyeongChang 2018 Winter Olympic Games in mind, and have stated that they expect a test network running by 2017. Verizon in the US have even stated that "some level of commercial deployment" is expected to begin by 2017, with field tests to start in 2016. Elsewhere, Japan have committed to 5G rollout in time for the 2020 Olympic games, while other countries such as Australia, China and Qatar are also eyeing 2020 as launch dates.

2.4 Major expected innovations

In order to achieve 5G expectations much innovation is necessary, not only in technology but also in terms business models within vertical integration.

Concerning the technological innovations, these must allow for the use of contiguous and wide spectrum bandwidth; flexible resource allocation and sharing schemes; flexible air interfaces; new waveforms; agile access techniques; advanced multi-antenna beam-forming and beam-tracking and MIMO techniques; new radio resource management algorithms, to name just a few. Further, SDN (Software Defined Network) and NFV (Network Function Virtualization) will be at the core of this 5G architecture and the main enabler for this required flexibility and tighter integration with infrastructure layers. Both fronthaul and backhaul is also expected to be integrated into a common transport network under an SDN-based and NFV-enabled common control.

Such 5G capabilities, backed by technological innovation, will then lead to innovation in business models. The requirements from 5G differs greatly from vertical to vertical, yet higher throughput, lower energy and lower latency are traffic profiles which can help the digitalisation and beyond of any vertical. Examples of such innovations in verticals are laid out later in this document.

3 H2020 5G projects

3.1 5G Norma

5G NORMA: A NOvel Radio Multiservice adaptive network Architecture for the 5G era based on Network Slicing

5G NORMA is an EU-funded project within the 5G PPP initiative with focus on adaptive and future-proof 5G mobile network architecture. In the following, some initial considerations on 5G NORMA's architecture framework are presented.

Mobile networks are becoming an important enabler for the ongoing digitization of business and daily life enabling the transition towards a connected society. The increasing adoption of smartphones and tablets is driving the use of high volume consumer services such as video streaming, resulting in a fast growth of mobile broadband traffic. In parallel, services in high priority areas for our society such as education, health, and government, as well as vertical business areas such as smart grids, transportation, and automation increasingly rely on a mobile communication infrastructure. In these areas, autonomously communicating devices will increasingly create mobile traffic, but with significantly different characteristics from today's dominant human-to-human traffic. Hence, future 5G networks have to combine high performance with the support for business-specific functionality.

A new 5G radio interface will be only one element of a solution. 5G NORMA is going to propose an end-to-end architecture based on network slicing. Network slices are mutually isolated, dedicated networks designed along business-specific functionality demands. Executing multiple such slices on a common infra-structure yields a multi-service and multi-tenancy architecture that will allow for optimising resource utilisation and exploiting economies of scale.

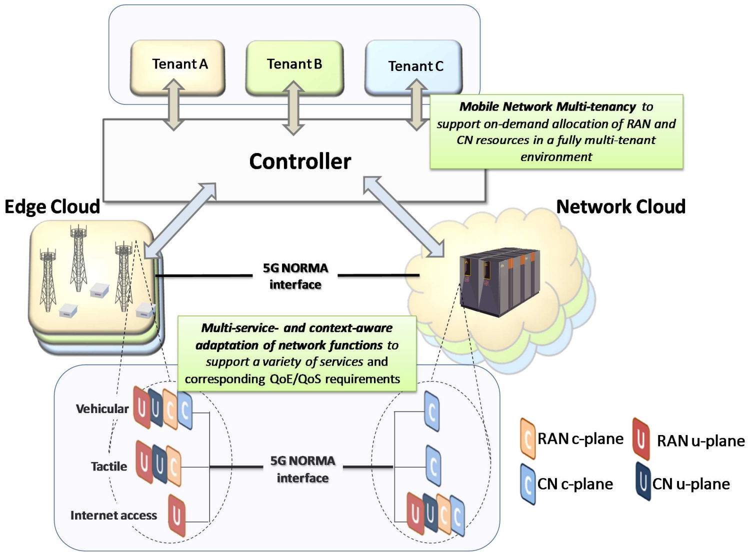


Figure 3: Multi-service and multi-tenancy architecture

The key ideas behind 5G NORMA's architecture for achieving high degree of flexibility are (i) to decompose the mobile network functions (including access and core functions) and adaptively allocating them to the access network or a central cloud, and (ii) to control this allocation by a Software-Defined Network Controller based on service demands and resource availability. This leads to an architectural concept where the functionality executed in the cloud is designed following a software-defined approach: It relies on well-defined 'programmable' interfaces towards radio access node that allow for flexibly adapting the mobile network behaviour.

The design of the 5G NORMA architecture is accompanied by a socio-economic analysis of the benefits of 5G NORMA innovations to determine the value both to the telecommunication industry and to the society. The result of this work will enable 5G NORMA to identify the relative value of each planned 5G NORMA innovation, and to direct the technical work to focus on the innovations with the highest potential for creating additional value.

3.2 METIS-II

METIS-II develops the overall 5G radio access network design and provides the technical enablers needed for an efficient integration and use of the various 5G technologies and components currently developed. The innovation pillars that allows METIS-II to achieve this goal are: a holistic spectrum management architecture addressing the spectrum crunch, an air interface harmonization framework enabling an efficient integration of new and legacy air interfaces, an agile Resource Management (RM) framework providing the dynamics required to efficiently adapt and utilize the integrated 5G air interfaces and radio concepts according to the varying traffic demand and service requirements, a cross-layer and cross-air-interface system access and mobility framework ensuring an ubiquitous access continuum, and a common control and user plane framework providing the means for an efficient support of the broad versatility of services expected for 5G as well as a future-proof and cost-efficient implementation of the 5G integration.

In the first phase of its activity, METIS-II has already reached some consensus and achieved some important milestones. It has described the key requirements on the 5G RAN architecture that have been identified and derived from the diverse service and use case needs, and explicitly elaborated on the requirements posed by the notion of Network Slicing in 5G. On spectrum topics, METIS-II considers that the 5G system will build upon a set of spectrum usage forms such as the use of dedicated licensed spectrum, horizontal sharing of bands with differentiation according to limited spectrum pools, mutual renting and unlicensed use, as well as vertical sharing of bands. Due to this wide range of spectrum usage forms, and also a wide range of bands from 0–100 GHz and the required service diversity, METIS-II envisions the overall 5G air interface (AI) to comprise multiple so-called air interface variants (AIVs), including the evolution of existing radio such as Long Term Evolution Advanced (LTE-A) and novel AIVs introduced in 5G, which may be tailored towards specific bands, cell types or services.

A key question regarding the overall RAN design is to which extent different AIVs can be harmonized towards a single AI protocol stack specification in order to reduce implementation and standards complexity and improve cost-efficiency for devices having to implement multiple AIVs. Finally, METIS-II is considering various changes in 5G compared to legacy systems that will impact the design of system access and mobility management procedures. For instance, the introduction of a novel RRC “Connected Inactive” state is being discussed.

In the first phase of its activity, METIS-II has already described the key requirements posed by the diverse service and use case needs on the 5G RAN architecture, and explicitly elaborated on the requirements posed by the notion of Network Slicing in 5G. The requirements have been identified and derived from the diverse service and use case needs. The project has also published a white paper stating the early consensus reached among the partners on key 5G RAN design aspects outlining the important design questions for the RAN and initial answers to these questions.

A further distinctive feature of the project is the realization of a visualization platform where the innovations studied in the different Work Packages (and also in other 5G PPP projects) are represented in an interactive way. A first version of the platform was shown in the EU booth at MWC16. An example of such visualization capabilities is given in the figure below.

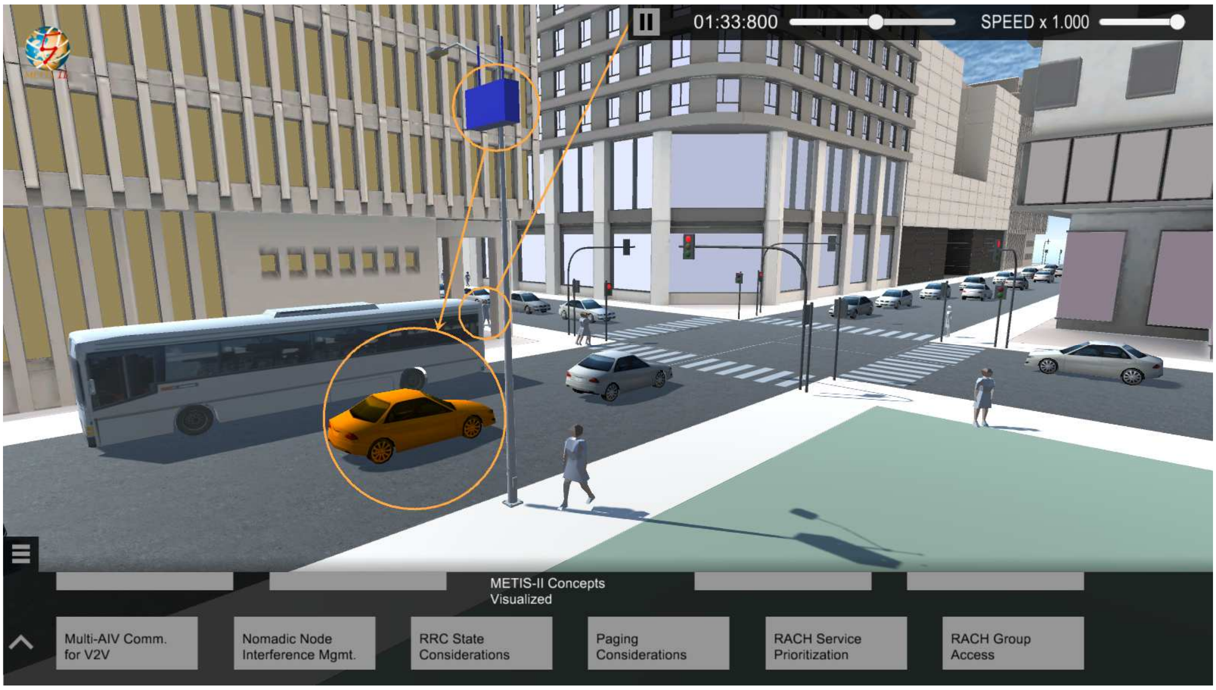


Figure 4: METIS-II Visualisation Platform

3.3 5G-Crosshaul

The goal of the 5G-Crosshaul project is to design a 5G transport network solution that can address the anticipated challenges of cost, efficiency and scalability. Such solution envisions a seamless integration of existing and emerging fronthaul and backhaul technologies into a converged SDN/NFV-based framework capable of supporting 5G system architectures and performance requirements.

The architecture framework targeted by the 5G-Crosshaul project (cf. Figure 5) aligns with the architecture in ETSI NFV ISG and embraces the SDN concept with 1) decoupled data and control planes, 2) logically centralized control and 3) exposure of abstract resources and state to applications. The SDN framework considered aligns with open-source projects ONOS and OpenDayLight. Data switching for fronthaul and backhaul traffic is primarily packet-based through the Crosshaul packet forwarding elements (XPFE), but for some particular fronthaul traffic requiring extremely low latency circuit-switching is provided through Crosshaul Circuit Switching Elements (XCSE). The 5G-Crosshaul project also advances in the definition and integration of link layer technologies, capable of accommodating the bandwidth requirements of 5G.

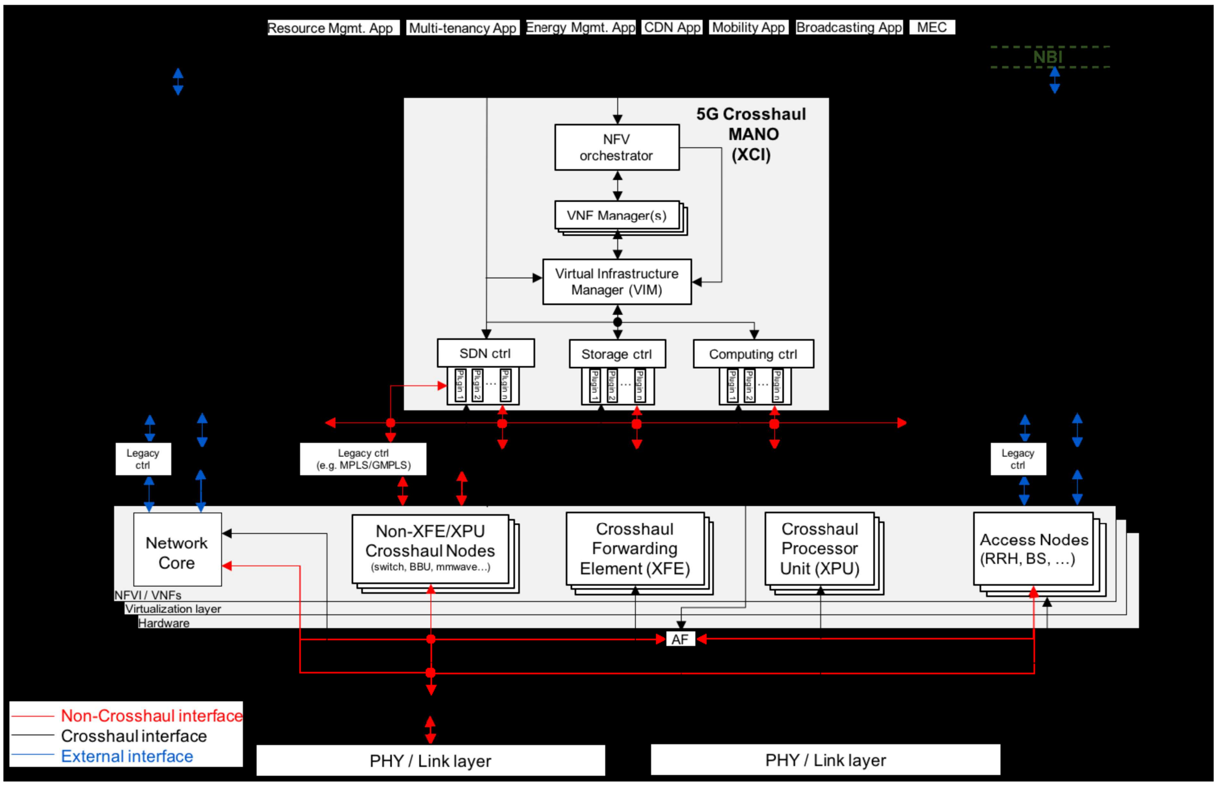


Figure 5: Architecture of 5G-Crosshaul

Applications running on top of the Crosshaul Control Infrastructure (XCI) are also being developed, with focus on aspects related to network re-configuration, energy efficiency, media distribution, and mobility management. Examples of these applications include: 1) Resource Manager Application (RMA) for dynamic network reconfiguration, 2) Energy Management and Monitoring Application (EMMA) for optimisation of energy consumption by activating and deactivating network elements depending on the context, 3) CDN Management Application (CDNMA) and the TV Broadcasting Application (TVBA) for media distribution, and 4) Mobility Management Application (MMA) for mobility management optimization even in the most challenging scenarios (e.g. high-speed trains).

The validation of the project design will be through proof of concept components integrated together and demonstrated in four testbeds in Berlin, Barcelona, 5TONIC/Madrid, and Taiwan, respectively. Together, all trials will be carried out to verify the accomplishment of the required Key Performance Indicators (KPIs), as well as the challenging objectives described in the proposal.

3.4 5G-XHaul

To meet the requirements of next generation mobile networks, several radio access technologies (RATs), such as millimetre wave communications, massive MIMO, etc., are being proposed. For supporting these RATs with different degrees of centralisation, as well as novel use cases at a reasonable cost, a more flexible, dynamically configurable transport network is required. Centralized radio access network (RAN) architectures, such as C-RAN, are considered instrumental to fully exploit the capabilities of future 5G RANs. However, RAN centralisation imposes stringent requirements on the transport network. To relax these requirements, the approach of evaluating the so-called functional split (c.f. 6) is currently playing a key role. The design of 5G faces the challenge of finding the optimal balance between the RAN gains obtained through centralized architectures, and the associated costs of the transport network. As a result, a single transport network must be able to simultaneously service multiple RAN implementations. In 5G-XHaul, we have investigated 5G transport network capacity provisioning based on real-world 4G traffic traces and their projected values for 5G urban scenarios (Figure 7a). Our analysis, for three 5G representative RATs (more details in 0[2]), shows that the combination of utilisation-dependent functional splits and statistical multiplexing, can reduce aggregated transport traffic by up to two orders of magnitude when compared to today's CPRI-based networks (c.f. Figure 7b). From this study, and in order to enable the required degree of flexibility while keeping the network manageable, we propose in Table 2 an initial set of four transport classes. Building on these principles, 5G-XHaul proposes a converged, packet-based, and SDN-enabled transport network that is a key enabler for future 5G services.

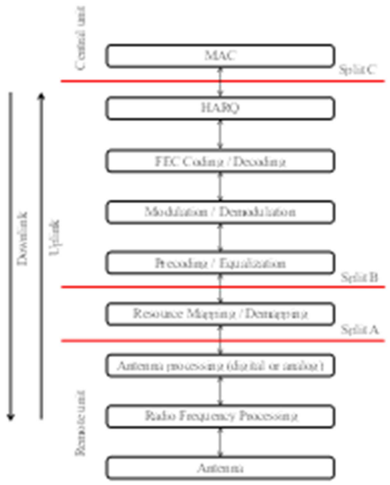


Figure 6: Functional Split Options

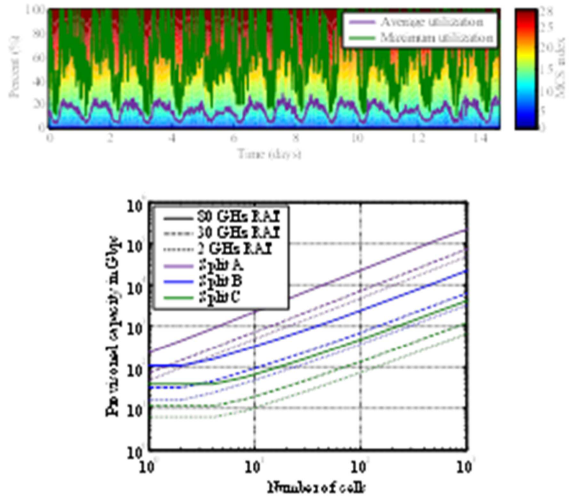


Figure 7: a) Measured MCS distribution and maximum and average resource utilisation b)Provisioned transport capacity versus number of cells

	Use case	Transport latency (round trip)	Synchronization	Typical data rate per access point
TC 0	Synchronization	Very low variance	Enabler	10 Mbps
TC 1	Split A FH traffic Split B FH traffic without relaxed HARQ Tactile user traffic Failover signaling SDN in-band control signaling	≤ 200 µs	Synchronous, time aligned	100 Gbps
TC 2	Split B traffic with relaxed HARQ Split C traffic with coordinated beamforming Relaxed tactile user traffic	≤ 2 ms	Synchronous, time aligned	50 Gbps
TC 3	Split C traffic without coordinated beamforming Conventional BH/ fixed access traffic Control signaling	≤ 20 ms	Asynchronous, not time aligned	10 Gbps

Table 2: Basic transport classes for a packet-based and SDN-enabled transport network.

[1] J. Bartelt et al., ”The Impact of 5G Radio Access Technologies on a Converged Fronthaul and Backhaul Network,” submitted to IEEE Comm. Magazine, Feb. 2016.

[2] 5G-XHaul Project, Deliverable D2.1 ”Requirements Specification and KPIs Document”, submitted on March 1st, 2016.

3.5 5G-ENSURE

5G Enablers for Network & System Security & Resilience

The 5G-ENSURE project (http://www.5gensure.eu/) brings to the 5G PPP a consortium of telecom and network operators, IT providers and cyber security experts addressing priorities for security and resilience. The overall goal of the 5G-ENSURE project is to deliver strategic impact across technology, business enablement and standardisation by realising a vision for a secure, resilient and viable 5G network. To achieve this overall ambition a number of specific objectives are targeted:

- 5G Security Architecture to expand the mobile ecosystem & enable entirely new business opportunities.
- An initial set of non-intrusive security enablers for the core of the 5G Reference Architecture.
- 5G Security test bed to demonstrate the security enablers.
- Contributions to standards bodies with a focus on 3GPP and ETSI.

The general framework defining 5G-ENSURE and its goals is shown in Figure 8.

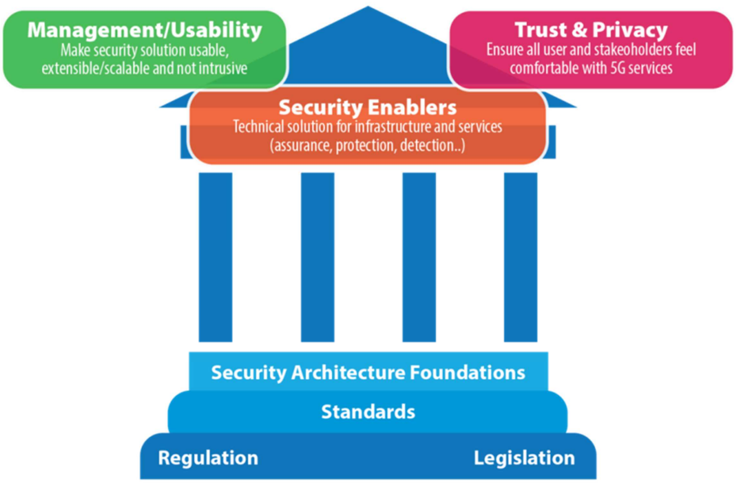


Figure 8: The pillars of 5G-ENSURE

In order to pave the way for security architecture definition and implementable enablers, the first technical studies have focused on use cases and security enablers’ road map.

As the basis for all other research activities in 5G-ENSURE, 31 use cases have been defined [1] (with others expected from the 5G PPP Working groups and standards bodies) to improve security and privacy & implement new 5G functionalities across a wide variety of deployments: IoT, SDN & virtualisation, ultra-reliable and standalone operations. The use cases can be clustered into: 1) Identities, Authentication, Authorisation and Privacy; 2) Software Defined Networks, Virtualisation and Monitoring; 3) Availability, Reliability and Integrity and 4) Lawful Interception.

The security enablers represent the major security building blocks for the 5G system. The initial enablers’ road map identifies the following classes of enablers: AAA (Support for IoT and satellite systems; Trust and liability levels), Privacy (Increased assurance and confidence), Security Monitoring (Security by operation), Trust (Trustworthy dynamic 5G multi-stakeholder system with new trust models) and Network Management & Virtualisation Isolation (Mitigating security threats in SDN). For each 5G-ENSURE security enabler, an open specification will be published and for most of the enablers also a software release will be provided. The first set of implemented enablers will be validated in the test bed already by the end 2016.

Standardisation is a common theme running through 5G-ENSURE, with many of the partners already contributing to relevant standards and security certification schemes to generate confidence and trust in future networks. Specifically, the 3GPP study item on Next generation/5G security will be one of the main goals for standardisation activities during 2016.

[1] 5G-ENSURE, "D2.1 Use cases," 2016. [Online]. Available: http://www.5gensure.eu/sites/default/files/Deliverables/5G-ENSURE_D2.1-UseCases.pdf.

[2] 5G-ENSURE, "D3.1 5G-PPP Security enablers road map (early vision)," 2016. [Online]. Available: http://www.5gensure.eu/sites/default/files/Deliverables/5G-ENSURE_D3.1-5G-PPPSecurityEnablersTechnicalRoadmap_early_vision.pdf.

3.6 CHARISMA-5G

CHARISMA: Hierarchical architecture for 5G open access networks

CHARISMA's objective is the development of an open access, converged 5G network architecture, based on virtualised slicing of network resources disposed to different service providers (SPs), supporting network intelligence distributed out towards end-users. Such an approach offers a means to achieve important 5G key performance indicators (KPIs) related to low latency, high and scalable bandwidths, energy efficiency and virtualised security (v-security). CHARISMA integrates such diverse technologies into a single architecture with attendant software-defined networking (SDN) and network functions virtualisation (NFV) amongst other important technology trends. This architecture presents key technology challenges, while making issues such as security, energy efficiency, and scalability ever more critical.

A key architectural innovation of CHARISMA is the adoption of a hierarchical approach, with intermediate active nodes between the central office (CO) and end-users (Figure 10). Each node corresponds to a CHARISMA Aggregation Level (CAL) in a hierarchy of levels. The CHARISMA architecture includes 4 levels of aggregation (CALs), from the Customer Premises Equipment (CPE) at CAL0 (degenerating if necessary to User Equipment (UE)) to the Optical Line Termination (OLT) at CAL3. Intermediate CALs host the (micro-, macro-, etc.) Base Stations (BS). Each active node has its own scalable intelligent management unit (IMU) performing data storage/caching, data processing and routing functionalities. The IMU models computing and storage resources that are either spare within the access network nodes (e.g., BSs), or introduced with commercial off-the-shelf (COTS) servers. Overall, the CHARISMA architecture is much more distributed in nature, as compared to more centralized 5G architectures, and following current trends for more distributed C-RAN.

The CHARISMA control and management is based on advanced virtualization techniques and software-defined network (SDN) programmability to maximize efficient utilization of network resources, achieve quicker operational/functional modifications, and manage the network over a faster service provisioning time cycle. The designed architectural framework is aligned with the reference points proposed by the ETSI NFV MANO WG for the management and orchestration of the VNFs and provides control, management and services orchestration on top of the open access network (Figure 2). The main functionalities to be implemented will be multi-tenancy, network slicing, end-to-end virtualised security, VNF orchestration, service lifecycle management, content caching, hierarchical routing and data-path offloading in smart NIC.

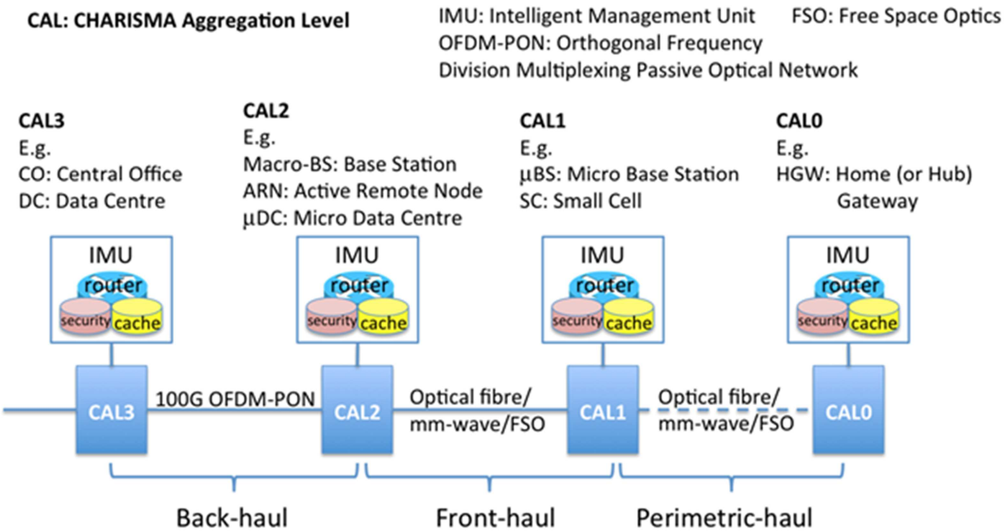


Figure 9: CHARISMA hierarchical architecture

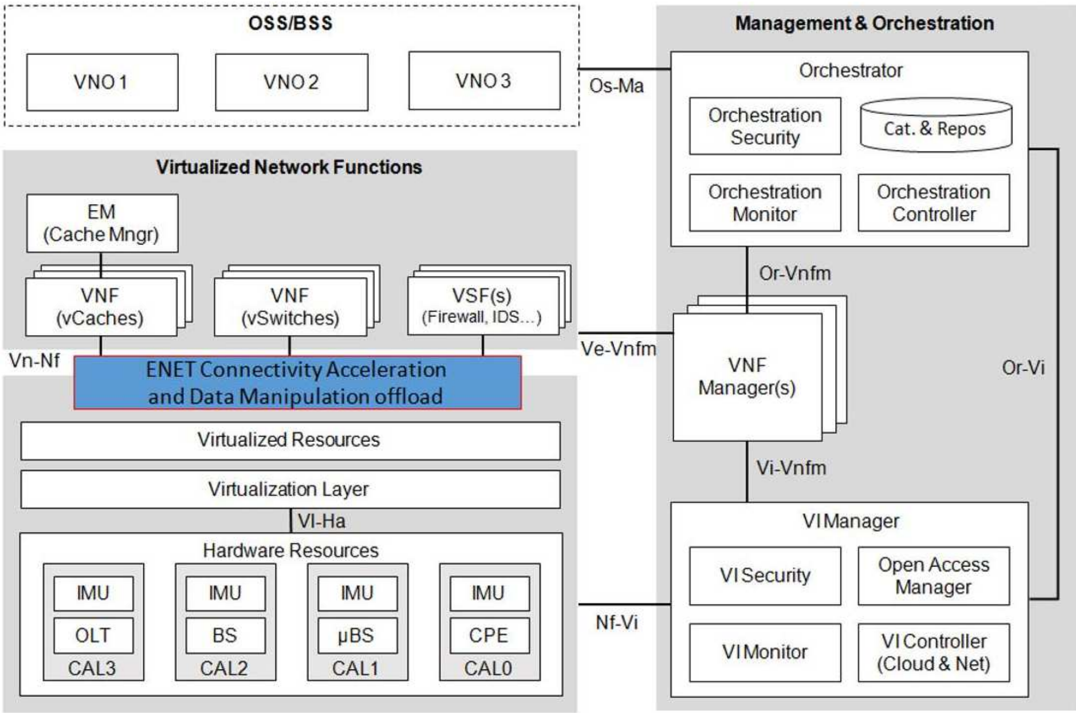


Figure 10: CHARISMA control and management plane

3.7 mmMAGIC

The mmMAGIC project first public deliverable (D1.1) on **use cases, KPIs and suitable frequency bands** was released in November 2015, stressing some key new 5G use cases and services with the potential of changing societal life and opening new business perspectives. Some use cases leverage on entertainment, organisation of data and connectivity to provide immersive 5G experience, cloud service, media on demand or moving hotspots.

Chanel Measurement and Modelling: In support of accelerated 5G standardisation activities, mmMAGIC has unleashed its highly ambitious measurement campaigns across 5 European countries aiming at developing a unified channel model for the frequencies in the 6-100 GHz range. Along those campaigns, mmMAGIC's initial channel model was released in March 2016 with deliverable (D2.1) in line with the 3GPP-3D channel model methodology, where the QuaDRiGa channel generator was used as the reference implementation.

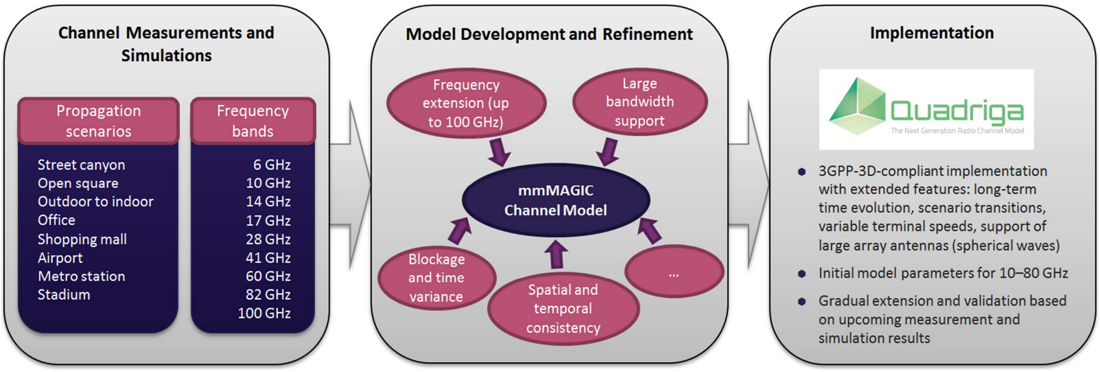


Figure 11: Propagation scenarios, frequency bands and channel model development

RAN Functions and Architecture Integration: Initial concepts on mm-wave 5G architecture and system integration were published in deliverable (D3.1) in March 2016, to enable an enhanced future 5G RAN. Here the focus was on the upcoming challenges and related solutions, mainly from the RAN architecture perspective. In particular, to provide highly efficient mobility management and to limit the core network signalling, solutions for mm-wave cell clustering and also utilising lower-bands support were proposed.

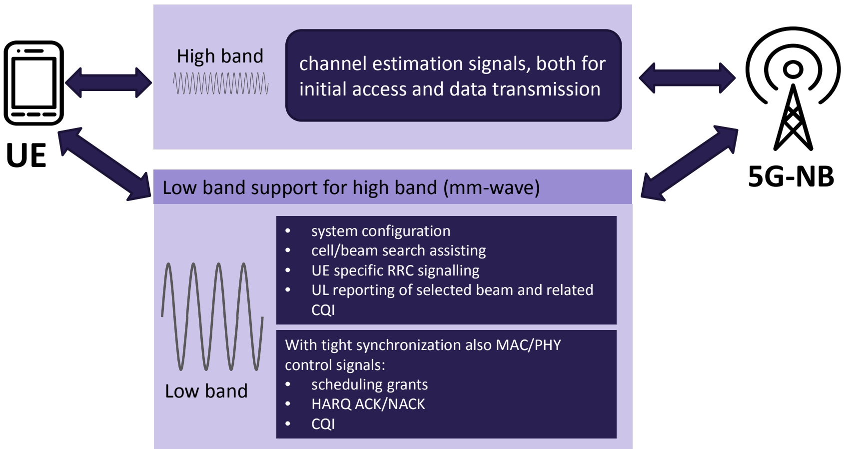


Figure 12: mmwave system with low band support carrying specific control or system information

Radio Interface and Multi-Antenna Multi-Node Design: mmMAGIC proposed a number of waveform candidates that were initially evaluated according to the KPIs identified as relevant by the project. A high-level comparison between such candidates was made. The general principles of numerology/frame structure design were identified, followed by several concrete preliminary design examples taking into account the mm-wave specific requirements. Furthermore, the initial concepts and proposed solutions on multi-antenna and multi-node transceiver schemes in mm-wave spectrum were also provided as part of deliverable (D5.1) in March 2016. Another important contribution is the modelling of the hardware impairments in mm-wave transceivers and the analysis of their impact on system performance.

3.8 VirtuWind

Virtual and programmable industrial network prototype deployed in operational **Wind**park

3.8.1 Abstract

Green, renewable Energy is fundamental to European growth. A large portion of this will come from wind energy. Reducing the production costs of Wind Energy will accelerate this technology and its adoption. VirtuWind proposes innovative application of Software-Defined Networking (SDN) and Network Functions Virtualization (NFV) in wind parks. This will reduceing capital invest (CAPEX) in turbine control components and will reduceing operational & Maintenance (OPEX) costs over the lifetime of the turbines.

The EU-H2020 project VirtuWind will demonstrate the technical and economic benefits of introducing SDN and NFV technologies which are core to future 5G networks for the wind energy industry. VirtuWind solution aims at network programmability, re-configurability and multi-tenant capability with an open, modular and secure control infrastructure to be deployed in an operational windpark.

3.8.2 Project objectives:

Following are the 5 key objectives of VirtuWind as depicted in Figure 1:

1. Realize industrial-grade Quality of Service (QoS) for intra-domain SDN solution: VirtuWind aims to extend SDN and NFV with industrial-grade QoS capabilities and to validate the intra-domain solution through prototyping and lab testing.

2. Guarantee inter-domain QoS for SDN based multi-operator ecosystem: VirtuWind will develop mechanisms that allow access to SDN-enabled network infrastructure in different operator environments to enforce a QoS path through multi operator domains.

3. Reduce time and cost for service provisioning and network maintenance: VirtuWind will specify and develop a suitable SDN northbound interface allowing applications to easily request communication services. Centralized control systems via SDN will take much less time to install, commission and maintain. This will bring programmability to the industrial network, thus increasing the velocity of service provisioning and reconfiguration.

4. Assure security-by-design for the SDN and NFV ecosystem: Introducing concepts like SDN and NFV for critical infrastructures requires careful investigation of the new security risks, as new threats may arise which never before existed in legacy systems. VirtuWind will establish a comprehensive threat and risk framework for industry-grade SDN networks.

5. Field trial of intra- and inter-domain SDN and NFV prototype: The developed SDN and NFV solution will be set up and demonstrated at a field trial in the "Floe" windpark located in Brande, Denmark.

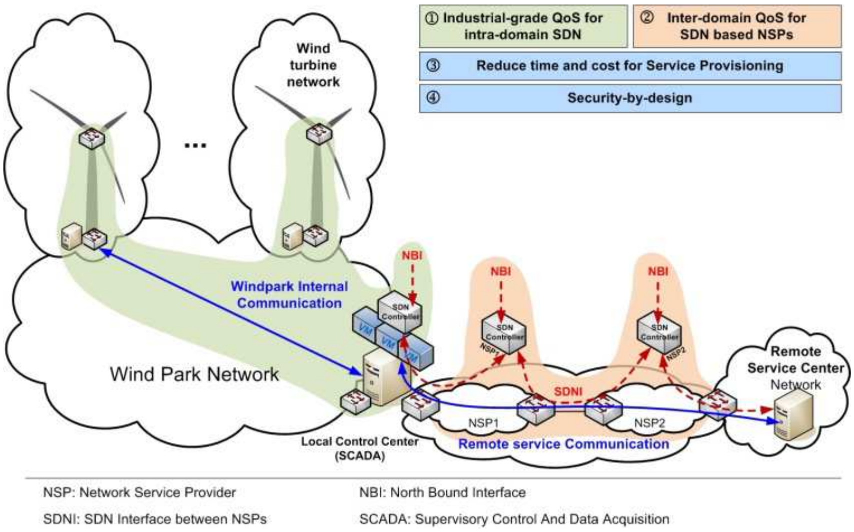


Figure 13: Windpark network as representative industrial network

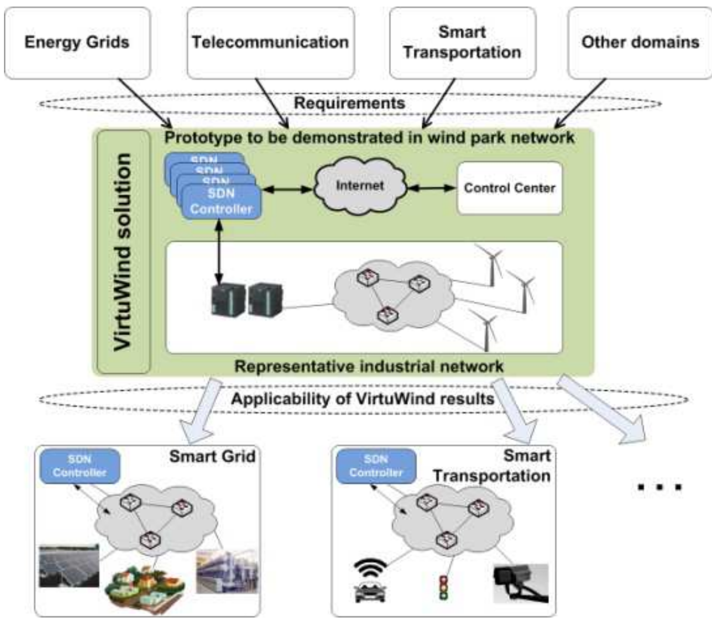


Figure 14: VirtuWind proposed solution

The wind power industry has been selected as a representative example of industrial networks with strict performance, security, and reliability requirements (Figure 13). As such, the corresponding solutions for VirtuWind will be applicable to other industries such as automotive, smart grid, as well as to the mission critical applications of the next generation mobile networks, i.e., 5G networks.

3.8.3 Project timeline and results so far

VirtuWind started in July 2015 and will run for 36 months. Focus in year one is on the requirements analysis and the architecture design. In year two, implementation of required functionalities and modules will start, and lab testing of the prototypes will ensure to meet the project objectives. In year three, the project will work on setting up and conducting the field trials of three scenarios in a real wind park in Denmark. Evaluation of the field trials and project results will be available in late June 2018.

In the first ten project months, VirtuWind achieved results in terms of requirements collection as well as architecture design.

Requirements collection was not only based on applications in wind power industry and the envisaged trial scenarios. VirtuWind consortium partners investigated twelve use cases from different industrial domains, such as energy, smart grids, telecommunications, security, critical infrastructures, transport and emergencies, and wide area communication networks, and collected requirements for using SDN and NFV based networks in these domains. Collected requirements were consolidated and mapped to the VirtuWind use case. The results of the use case analysis and the requirements were documented in the first technical project deliverable in project month three and form the basis for future VirtuWind work.

Before creating the high level architecture a detailed analysis of the requirements from previous deliverable was done and validation against the VirtuWind demonstration scenarios ensured completeness of collected requirements.

VirtuWind's work on the architecture design is not only based on the project internal requirements analysis, but takes also into account inputs from the architecture definitions of ONF and ETSI NFV in order to be compliant with existing design paradigms.

Currently VirtuWind is starting the detailed definitions of functionalities and interfaces and will soon start implementation. In autumn 2016 the final VirtuWind architecture will be released.

3.9 SONATA

SONATA: Agile Service Development and Orchestration in 5G Virtualised Networks

Software Defined Networking (SDN) and Network Function Virtualization (NFV) are emerging as major transformational technologies towards Software Networks, evolving the telecom sector with new network capabilities and business opportunities. SONATA addresses the significant challenges associated with both the development and deployment of the complex services envisioned for 5G networks and empowered by these technologies.

SONATA is developing a NFV framework that provides a programming model and development toolchain for virtualized services, fully integrated with a DevOps-enabled NFV service management and orchestration platform (NFV MANO). The developing results include:

- Programming model and SDK to facilitate network service development for third-party developers.
- Service platform with modular NFV orchestration framework (NFVO) for network operators.
- DevOps model for software networks that integrates these stakeholders together for an agile service lifecycle.

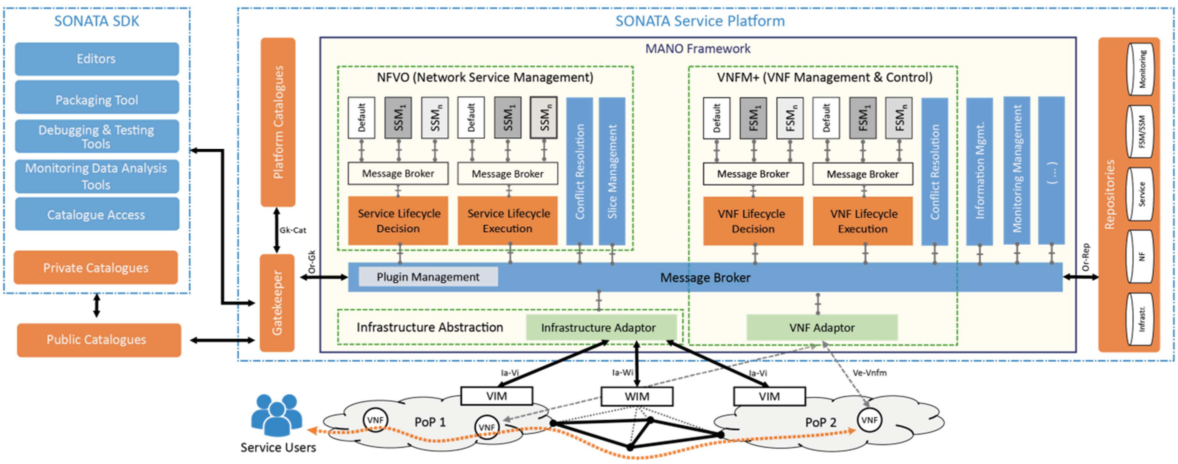


Figure 15: SONATA NFV Service Platform and SDK Architecture

The NFV MANO landscape is growing greatly, with newly announced commercial and open source solutions developing in late 2015 and early 2016. The full transformation to Software Networks by operators is a grand undertaking, and far from immediate. Operator SDN/NFV roadmaps are long-term, working now in proof of concept trials with vendors as they look to integrate with OSS, and first incremental NFV adoption on their networks. NFV MANO solutions and facilitated network service development are recognized as a foreseen need when NFV becomes state of the art and deployed heavily in production.

SONATA is including the following features and innovation beyond the ETSI-specified NFV resource and service orchestration (NFVO) and Virtual Network Function Management (VNFM) of the MANO layer:

Modular and Customisable MANO Plug-in Architecture:

- Providing NFV MANO flexibility to network operators with customisable platform functionality and ability to add new features via plug-ins
- Empowering operators and third-party service developers with control over specific orchestration and management functionalities pertaining to their own service, through function- and service-specific managers ("FSM/SSM" in architecture)
- Advanced conflict resolution for resource allocation introduces auction-based mechanism to establish priorities among services

Interoperable and Vendor Agnostic Framework:

- Multi-VIM, multi-vendor, multi-site support
- Underlying ETSI-based architecture and compliance
- SDN/NFV integration and for better interoperability between NFV MANO layer and SDN controller

Efficient Network Service Development and DevOps:

- Providing service developers with a SDK for efficient creation, deployment and management of VNF-based network services on the platform
- Unique NFV DevOps workflow and platform/SDK support bridges collaboration between operators and service developers

5G Slicing and Recursion Support:

- Slicing support delivers performance isolation and bespoke network configuration for industry verticals foreseen in 5G networks
- Recursion support allows stacked tenant and wholesale deployments in new software networks business models

SONATA is a highly collaborative effort, with 15 partners representing telecom operators, manufacturers, system integrators, service providers, SME developers, research institutes and universities. The project is preparing its first open source release for this summer 2016.

In the meantime, please visit www.sonata-nfv.eu and Twitter @sonataNFV for more information, our uses cases and architecture deliverables.

3.10 Fantastic 5G

Flexible air interface for scalable service delivery within wireless communication networks of the 5th generation (FANTASTIC-5G)

Frank Schaich (Nokia-Bell Labs), Salah El Ayoubi (Orange), Berna Sayrac (Orange), Martin Shubert (Huawei ERC), Hao Lin (Orange), Klaus Pedersen (Nokia Bell Labs), Musbah Shaat (CTTC), Gerhard Wunder (HHI)

3.10.1 Our ambition: A flexible 5G air interface for efficient service coexistence

While 5G networks are expected to offer extremely high user throughputs and to extend the mobile network coverage to almost everywhere on Earth, they are especially awaited on another challenging front; that of Machine Type Communications. From this perspective, 5G is expected to mark a disruptive change with respect to previous generations, covering the needs of the Internet of Things and of vertical industries. In addition to **Mobile BroadBand (MBB) and Broadcast/Multicast Services (BMS)**, 5G has thus to meet the requirements of the following "new" core services:

- **Massive Machine Communications (MMC),** where a massive amount of sensors/meters/actuators are deployed anywhere in the landscape and need to access the wireless network, sending in most of the cases relatively small packets per connection,
- **Mission Critical Communications (MCC),** where messages need to be transmitted between machines with very low delays, very high reliability and/or very high availability.
- **Vehicle-to-vehicle and vehicle-to-infrastructure communications (V2X),** with typical examples from road safety combining V2X with MCC, and infotainment which is the combination of V2X with BMS and/or MBB.

FANTASTIC-5G's ambition is to develop a single air interface for 5G on spectrum bands below 6 GHZ. Our air interface is intended to be flexible, versatile, scalable and efficient in order to address the requirements of all these above-mentioned services.

3.10.2 The road towards the 5G flexible air interface

FANTASTIC-5G evaluates the technical components and then integrates them within a single air interface. The design starts by the so-called Service Integrated Drivers (SIDs), each of them tailored towards one of the 5 core services. SIDs constitute a structure connecting the different tasks of the Project, and their design is optimized on **both link and system levels**. Once individual SIDs are optimized, they will be harmonized in the "Overall SID" which will adapt the optimal link and system level components to service co-existence, without having an overly complicated system.

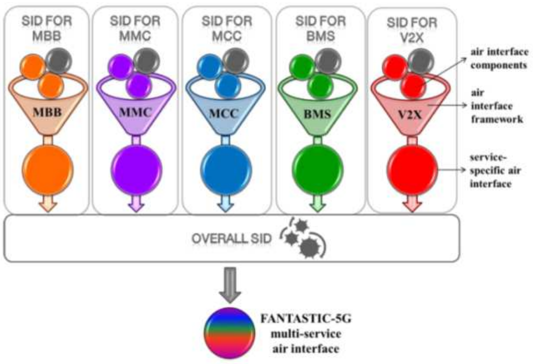


Figure 16: Fantastic 5G Service Integrated Drivers

3.10.3 First project results

Nine months after the project launch, the overall air interface picture is getting clearer. On the link level, the landscape of waveform proposals and of channel coding techniques has been thoroughly analyzed, and the pros and cons of the different solutions with respect to the different services are identified. On the system level, enhanced MIMO techniques, efficient Radio Resource Management (RRM) and scalable channel access protocols have been developed and optimized for the different services.

FANTASTIC-5G started working on the selection and integration of these technical components within the overall air interface and on their evaluation by the means of system level simulations and hardware demonstrators. “Fantastic” challenges are lying ahead…

3.11 Flex5Gware

It is expected that 5G devices will have to cope with a heterogeneous environment, which includes the support of multiple RATs and operational modes ranging from device-to-device (D2D) communications to mmWave technologies, and even new body area networks (wearable devices). In addition, a very important aspect related to 5G devices is that they are expected to integrate and interact with a multiplicity of sensors (e.g., those related to location and positioning, environmental conditions, image processing etc.). In this context, Flex5Gware researchers participated in the Microsoft indoor localization competition at IEEE/ACM IPSN 2016 in the category of positioning solutions based on commercial devices. An average error of 3.17 m was achieved in a very challenging environment for radio propagation with metal structures and two floors. This kind of indoor positioning solutions in 5G platforms will provide additional context awareness to the communication and the deployed RAT, allowing improvements in the efficiency of existing services and in the allocation of network resources, and help provide better user-centric and personalized services.

A similar heterogeneous situation to that of 5G devices is also valid for 5G network elements. Since cost and flexibility of deployment will be key factors, a shift toward SW-based implementations and virtualization technologies will be required. In this SW domain, Flex5Gware researchers have proposed a context-aware, cognitive and dynamic HW/SW partitioning algorithm for 5G network elements. This algorithm exploits knowledge (e.g. prediction of a hotspot) derived by network and sensor measurements and decides upon the HW or SW execution of functions in order to fulfil and maintain the application goals. The algorithm leads to high flexibility, performance and energy efficiency.

In the HW domain of network elements, Flex5Gware research focuses on incorporating solutions for increased operating bandwidth, multiband functionalities and key component implementation for mmWave transceivers, which will enable the efficient utilization of spectral resources at frequencies below 6 GHz and also at mmWave ranges. In particular, Flex5Gware researchers have proposed an architecture design for the transceiver of medium range base stations that supports three radio bands together with a design of a multiband (6x20 MHz carrier configuration) high-power amplifier with an output power of 53 dBm. The presented three-band transceiver solution considers radio bands defined for mobile communication (E-UTRA band 7 and 38 at 2.6 GHz and band 22 and 42 at 3.5 GHz) and one band between 2.7 and 2.9 GHz, which is in discussion to become available during the next years.

Another important aspect related to the HW domain in network elements for mmWave ranges is the on-chip frequency generation via a local oscillator (LO), which is a key part of all high performance transceivers. The quality of the LO signal provides fundamental limitations to the achievable data rates and receiver selectivity. In the Flex5Gware project, 60 GHz voltage-controlled oscillators (VCO) have been designed in 28 nm SOI CMOS, fabricated and measured to evaluate their performance. In particular, the fabricated VCO shows superior performance with respect to the state of the art in terms of power consumption (3.15 mW), phase noise (-116.5 dBc/Hz) and device footprint (0.016 mm2).

Other relevant hardware improvements for network elements that are being researched in Flex5Gware are active envelope tracking and PA pre-distortion for wideband power amplifiers, and the addition of new features and capabilities that are not yet in operational use, such as full duplex operation or implementations of massive MIMO technologies.

4 5G initiatives

The European Commission strongly supports International cooperation and seeks for a global consensus on 5G for the development of globally accepted standards and spectrum requirements. Agreements have already been signed with all regions in the world. In 2015, the 5G Infrastructure Public Private Partnership, 5G PPP, established partnerships with similar 5G programs outside Europe.

- Early March 2015, a MoU was signed between 5G PPP and 4G Americas (www.4gamericas.org/en/). Both organisations will share information on 5G concepts and on spectrum.
- Also in March 2015, the 5G PPP and the 5GMF (http://5gmf.jp/en/) signed a Memorandum of Understanding (MoU) for 5G in which both organisations stated they will collaborate in road mapping and developing 5G.
- At the end of September 2015, the 5G PPP and IMT-2020 (5G) Promotion Group (http://www.imt-2020.cn/en/) in China signed a MoU.
- In October 2015, 5G Americas, (Americas), The Fifth Generation Mobile Communications Promotion Forum (5GMF) (Japan), 5G Forum (Republic of Korea), IMT-2020 (5G) Promotion Group (non-profit organization, China) and The 5G Infrastructure Association – Public Private Partnership (5G PPP) (Europe), entered into a MoU for the organization of "*Global 5G Events*" twice a year.
- In February 2016, the EU and Brazil signed a joint declaration at the Mobile World Congress in Barcelona. They committed to developing global definition of 5G and to identifying the services which should be the first delivered by 5G networks. The two partners will also work to define common standards in order to have a stronger position on the global stage. They will cooperate in identifying the most promising radio frequencies to meet the additional spectrum requirements for 5G, especially in the framework of the International Telecommunication Union (ITU). In addition, they will promote the deployment of 5G in fields like smart cities, agro-food, education, health, transport or energy as well as possibilities for joint research projects in this area.

Earlier in June 2014, the European Commission and the South Korean Ministry of Science signed an agreement to "deepen discussions in the area of Net Futures". They agreed to work together towards a global definition for 5G. They also decided to cooperate on R&D for 5G. A cooperation framework was settled by a Memorandum of Understanding signed in June 2014 by the 5G Infrastructure Association. The MoU for the 5G vision defines requirements, concept, frequency and global standards preparation.

Alongside with major regional/national 5G initiatives, a number of European universities have launched research programs on 5G in the last couple of years. They all tightened up strong partnerships with industrial partners. Two UK universities are well positioned and the Technische Universität Dresden (TUD) is very active.

- The Center for Telecommunications Research (CTR) at the King's College (UK)
- Established in the early 1990s, the CTR was deeply involved in 3G and 4G systems and started to consider 5G early 2014. CTR is contributing to 5G NORMA (the 5G Novel Radio Multiservice adaptive network Architecture) representing academia alongside with the University of Carlos III of Madrid and the University Kaiserslautern in Germany. Previously, the CTR worked within the EU funded ICT-SELFNET project which aimed to design a self-autonomous network in context of future Internet.

- The 5GIC (5G Innovation Center) at the University of Surrey (UK)
  Officially launched in September 2015, the 5G Innovation Centre at the University of Surrey in Guildford is 5G equipped with a live outdoor and indoor test bed to test technologies in real situations. On top of that, the 5GIC is participating to the Euro-5G project in charge of dissemination actions.
- The 5G Lab at Technische Universität Dresden (TUD, Germany)
  The 5G Lab of TUD was created in September 2014 as a partnership between Vodafone and TU Dresden. The 5G Lab participates in the 5G PPP research project 5G-XHaul. TU Dresden's Vodafone Chair Mobile Communications Systems contributes in 5G-XHaul by providing its expertise on 5G access technologies and how these impact the design of the future transport network.

4.1 A conclusion on future actions and some first info/advertisement for the European "global 5G " event in Q3/Q4

The European Commission's goal for a global consensus on 5G is progressing well. The 5GPPP plays an essential role on federating the European input. The European Commission has established joint declarations on 5G with major countries in the world so far. Work continues and cooperation agreements are also being discussed with India and the USA. Parties in the USA (5G Americas), Japan (The Fifth Generation Mobile Communications Promotion Forum, 5GMF), Korea (5G Forum), and China (IMT-2020 (5G) Promotion Group) and the 5G PPP for Europe, decided to organize "*Global 5G Events*" twice a year to globally promote 5G. The "*Global 5G Events*" intend to support multilateral collaboration on 5G systems across continents and countries. Basic areas of interest for the "*Global 5G Events*" include, but are not limited to:

- Vision and requirements of 5G systems and networks
- Basic system concepts
- Spectrum bands to support the global regulatory process
- Future 5G global standards
- Promotion of 5G ecosystem growth

The first two "*Global 5G Events*" are scheduled for May 31-June 1 in Beijing (China) under the responsibility of IMT-2020 (5G) Promotion Group and for November 9-10 in Rome (Italy) under the responsibility of the 5G Infrastructure Association.

5 5G Thematic chapter

5.1 5G and the Factories of the Future

The European manufacturing sector has suffered from increased competition of BRIC (Brazil, Rusisa, India and China) countries and the effects of financial crisis, which in 2012 triggered the European Commission to call for immediate action to implement a Factories-of-the-Future (FoF) PPP (Public Private Partnership) to increase Industry's share of GDP (Gross Domestic Product) to 20% by 2020. While the introduction of steam power, the assembly line and early automation characterized the first three industrial revolutions, a fourth revolution is ongoing and fuelled by Cyber-Physical-Systems (CPS) as the basis of intelligently connected production information systems that operate well beyond the physical boundaries of the factory premises.

5.1.1 Socio-economic drivers for Horizon 2020

Two main trends in manufacturing are driving the transformation and will influence the future competitiveness: (1) the increasing role of services in manufacturing and (2) the growing importance of global value chains. It is estimated that by 2025 manufacturers will get more revenue from services than from products. This is a consequence of a trend called "servicization of manufacturing", indicating a shift from solely selling produced goods to providing added value services together with either connected (smart) or non-connected goods. The growing importance of global value chains is a second trend that drives the demand for truly connected manufacturing eco-systems.

5.1.2 How 5G can be a catalyst

5G promises to be a key enabler for Factories of the Future. It will not only deliver an evolution of mobile broadband networks, it will provide the unified communication platform needed to disrupt with new business models and to overcome the shortcomings of current communication technologies. As such, 5G technologies have the potential to amplify and accelerate the ongoing transformation, and to unlock a next level of efficiency gains in manufacturing even for the vast community of European manufacturing SME. Five use case families have been identified: time-critical, reliable process optimization inside digital factory; non time-critical communication inside the digital factory; remotely controlling digital factories; Seamless intra-/inter-enterprise eco-system communication; and connected goods – incorporating product lifetime.

5.1.3 Business and policy aspects

The huge amount of data collected before, during and after the production of finished goods have enormous potential for usage to support decisions, facilitate collaborative manufacturing or to drive next-generation innovations.

5.1.3.1 New business models leveraging data collection within the manufacturing context

The connection with the suppliers, supply chain, engineering and manufacturing services and other manufacturers promotes the growth of new data-driven business models either by service providers or by manufacturers. While the manufacturer can have an important role on the product improvement and product oriented models, other service providers can be more efficient in the data oriented business models due to their expertise in ICT solutions rather than in manufacturing products.

5.1.3.2 New business models leveraging data collection outside the manufacturing context

In general, the manufacturer loses connection with the product as soon as the product leaves the factory; thus the knowledge of the behavior of the product along the whole lifecycle has the potential to lead to significant improvement of the product design, and to introduce new data-driven business services. The need to improve the product design will drive the need to collect more product-related data. The services focused on product performance are a new business topic as well. In this case, the product is at the customer with performance data the key aspect, and the goal is to improve the product behavior on site reducing its maintenance, consumption, stops, and more.

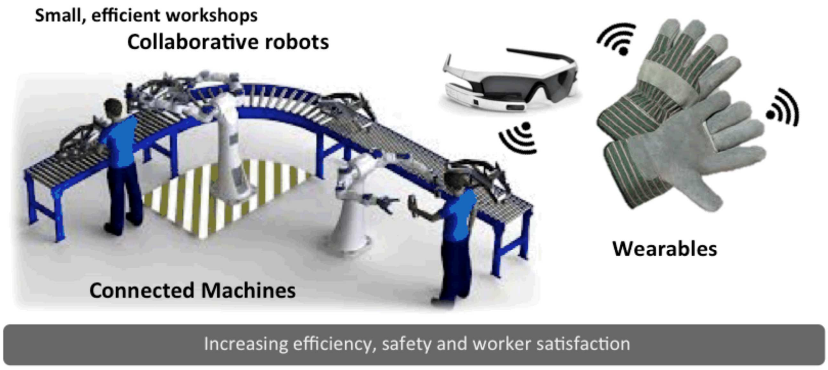


Figure 17: Use case family 1 – Time-critical process optimization inside factory

5.2 5G and the Automotive Vision

The automotive industry is currently undergoing key technological transformations, as more and more vehicles are connected to the Internet and to each other, and advance toward higher automation levels. In order to deal with increasingly complex road situations, automated vehicles will have to rely not only on their own sensors, but also on those of other vehicles, and will need to cooperate with each other, rather than make decisions on their own.

5.2.1 Socio-economic drivers for Horizon 2020

Vehicles can exchange information with other vehicles (V2V), with the roadside infrastructure (V2I), with a backend server (e.g., from a vehicle manufacturer or other mobility service providers) or with the Internet (V2N), with a pedestrian (V2P), etc. To refer to all these types of vehicular communication, the term Vehicle-to-Everything (V2X) has been proposed.

In the global context of road transport, connectivity will be a critical enabler to support the take-off of new business opportunities relating to vehicles and the EU and Member states' policies in the context of transport. The Internet of Things (IoT) will contribute to collect additional data, complementing the data already collected by vehicles and traffic management centers. This data, exchanged along the roads and on the Internet, will be useful to develop new services for vehicle users. The automobile industry sees two main trends with relevance for the 5G automotive vision: (1) automated driving and (2) road safety and traffic efficiency services. Activities from various stakeholders, including governments, in Europe and the USA, are supporting or even advocating vehicle communication.

5.2.2 How 5G can be a catalyst

Connected driving already started with 2G more than 10 years ago and has been improving over the years together with the deployment of 3G and 4G mobile communication networks. However, the current IEEE 802.11-based V2X communication technology is a short-range ad hoc broadcast system developed for the exchange of object information and not for the exchange of sensor data; as vehicles advance toward higher automation levels and need to deal with increasingly complex road situations, there will be limitations and therefore a need for a complementary communication technology for the exchange of cooperative information with higher bandwidth and improved reliability. Another fundamental reason is the cost; setting up a new IEEE 802.11-based infrastructure and cover all the necessary areas could cost in the order of 4000 €/km2. But utilizing the current cellular infrastructure – with appropriate software upgrades – the goal can be achieved in a fraction of that cost.

5.2.3 Business and policy aspects

New connected cars business models have already emerged and these will be spurred by the availability of eCall in Europe and with the rapid growth and penetration of 4G, enabling a host of telematics and security applications. This will transform the relationships between car manufacturers, network and technology providers and services, such as insurance, driver assistance, security or content delivery. 5G will benefit from this trend and see a multiplication of new partnerships, also enabled by concomitant enhanced safety, mobility and environmental stewardship of 5G networks.

Regarding the automotive sector, in order to capture the value of new opportunity areas like the creation of a service platform for Business-to-Business (B2B) or Business-to-Government (B2G), with an estimated potential of 30 USD/vehicle/year, equipment manufacturers need to connect in a secure and trusted way, vertically and horizontally, their value chain with wireless service providers, potential clients, fleet management companies, car rental and car-sharing services, infotainment content providers and developers of location-based services. Opportunities generated by 5G ecosystems for the automotive industry range from savings in public safety through a reduction in the number and severity of accidents (with both costs in terms of lives and property damage), savings in infrastructure planning and maintenance, to reduction in CO2 emissions. Assuming complete penetration of V2X applications, annual economic damage from accidents might be reduced by up to EUR 6.5 billion in Europe alone. Furthermore, up to EUR 4.9 billion of economic losses might be avoided due to improved traffic efficiency and reduction of environmental damage (simTD Project, June 2013).

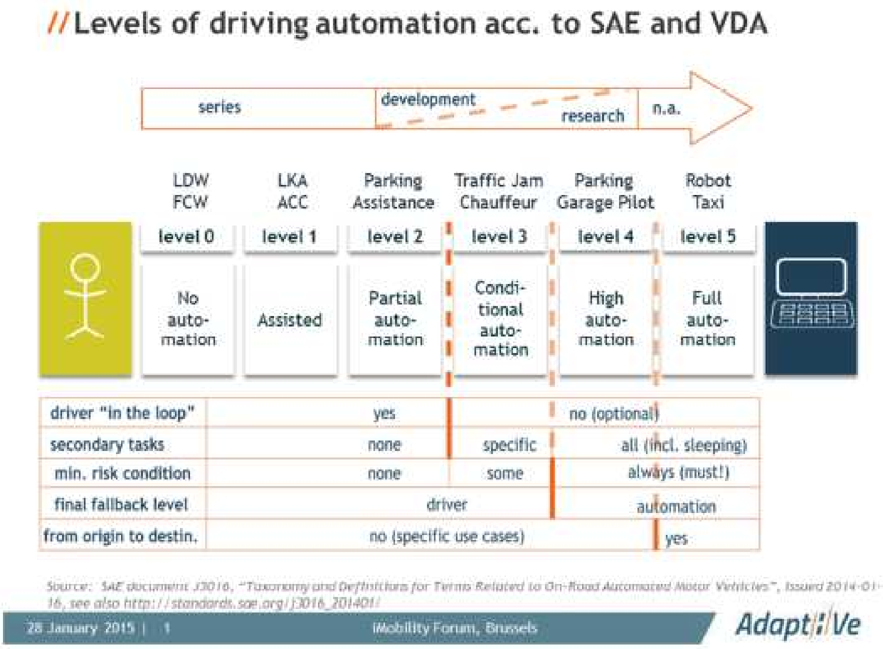


Figure 18: SAE (US Society of Automotive Engineers)/VDA (German Association of the Automotive Industry) automation levels

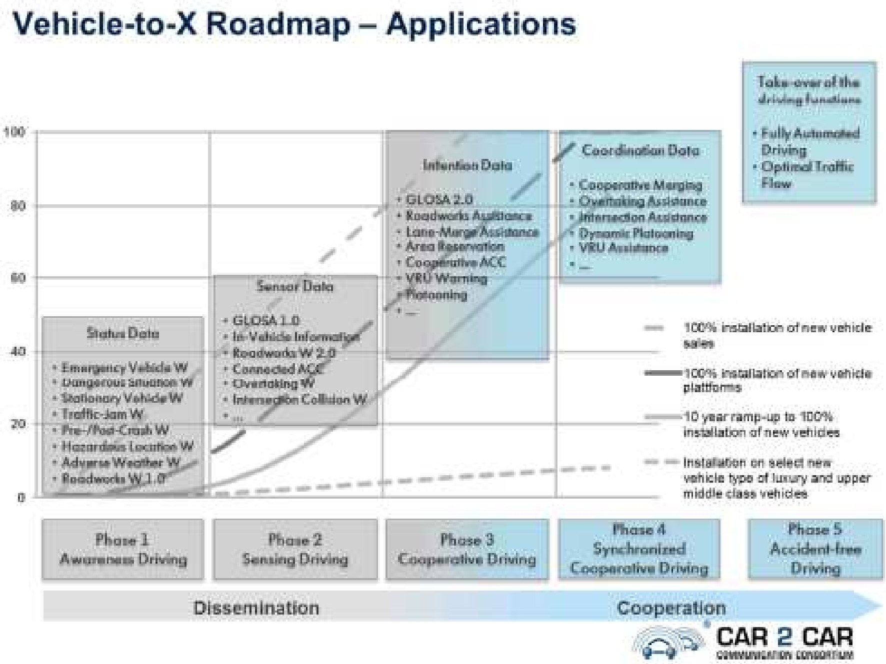


Figure 19: The Car-2-Car Communication Consortium applications roadmap

5.3 5G and Energy

The energy vertical has some very specific requirements on the supporting communication solutions going beyond what can be provided by current generic telecoms' solutions. In this industry longevity of 20 years is normal, plug and play, deploy once and operate "forever" is assumed to be given. On the performance side concerning latencies the requirement is not about the best case, not even average case, but concerns the worst case, since the failure to deliver a single message within its guaranteed delivery time can have a severe impact on the process that is controlled.

5.3.1 Socio-economic drivers for Horizon 2020

Where historically predictable end user profiles would allow scheduling of appropriate levels of generation to meet demand via large central thermal and hydro generation stations, we are now faced with unpredictable small generation stations (solar, wind, etc. in their thousands) combining with changing end-user energy use patterns (such as mobile large demand/storage units such as Electric Vehicles). Further, the concept of "prosumers" (producers + consumers) for the future energy grid means that the users themselves can become energy producers as well as consumers. Due to changes in the social, commercial, technical and market landscape, the European energy industry needs to adapt to the changing nature of both supply side and demand side requirements. Individual users, local communities and regions will be able to take their own decisions regarding power generation and usage independently from the incumbent strategies.

5.3.2 How 5G can be a catalyst

The demand for efficient and reliable communication solutions is expected to grow due to the emergence of smart grids, and a lion share of the growth will take place in the medium-voltage and low-voltage domain towards secondary substations and distributed energy resources as well as between secondary substations and primary substation. Storage e.g. with EV batteries will also be part of this economic system. 5G then has the potential to provide economically viable wireless solutions, decentralising the energy networks with increased resilience compared to LTE. This way, future smart grids can be provided with an increased usage of protection, control and monitoring leading to improved power quality, fewer power outages, smaller power outage areas, and easier grid deployments with less environmental impact in urban areas.

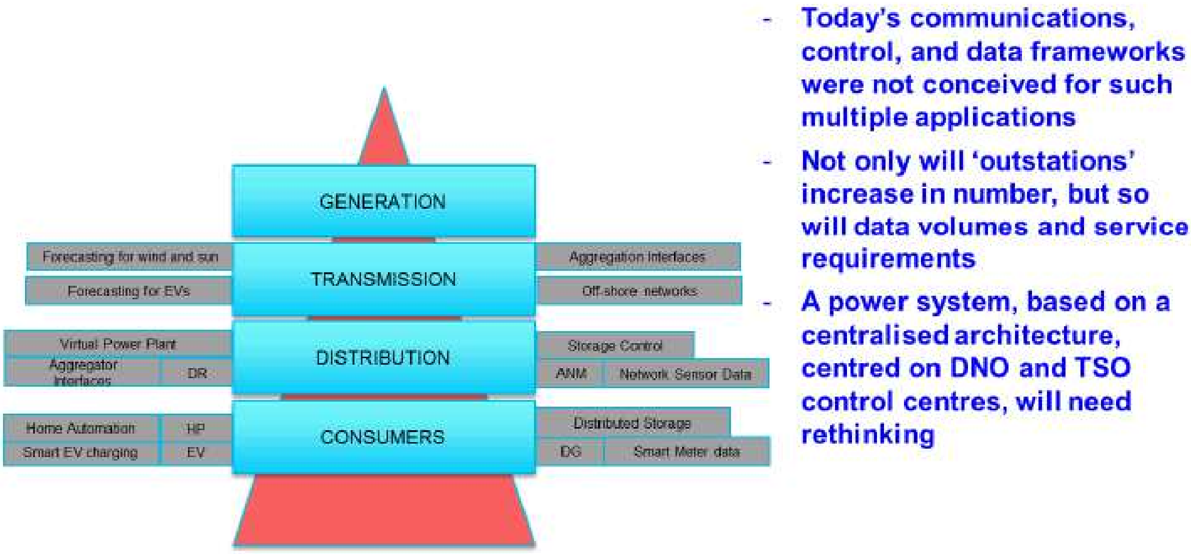
5.3.3 Business and policy aspects

The traditional electricity business model in Europe providing stable income for utilities and stable supply for customers at predictable and affordable prices is undergoing a paradigm shift. In particular there are three main key aspects, as follows.

Firstly, 5G Technology is to enable new Smart Grid business models. The smart grid becomes more flexible and efficient but critically depends on the availability of high-quality data collection, transmission and analysis for operations and marketing. This results in a customer-centered industry, possibly a shared economy for electric power. 5G features are expected to contribute to the smart grid new business models enablement.

Secondly, there will be various quality levels for electricity supply (traditional supply, low-cost, back-up only, environmentally-friendly supply, etc.), and also various levels of associated services and data management (bundling pricing schemes; data monetization). This then leads to more flexible pricing schemes, integrating the value of customer produced electricity, such as pay-as-you-go, bartering, real-time peak pricing etc. New business models will also emerge in the value chain linking the traditional utilities and the myriad of services providers in the ecosystem: market places, innovative revenue split schemes, incentive schemes, etc. All these will be explored by the proponent actors.

Finally, demand response will affect the business models. Electricity supply and prices may vary considerably over time and space, with customers choosing the quality level they require or can afford depending on available supply. Also, additional services will be offered, based on the data accumulated through smart metering and customer smart home applications: optimization of consumption, predictive maintenance, home surveillance, etc.



DR=Distributed Resources, ANM=Active Network Management, HP=Heat Pumps, DG=Distributed Generation

Figure 20: New requirements for the power grid

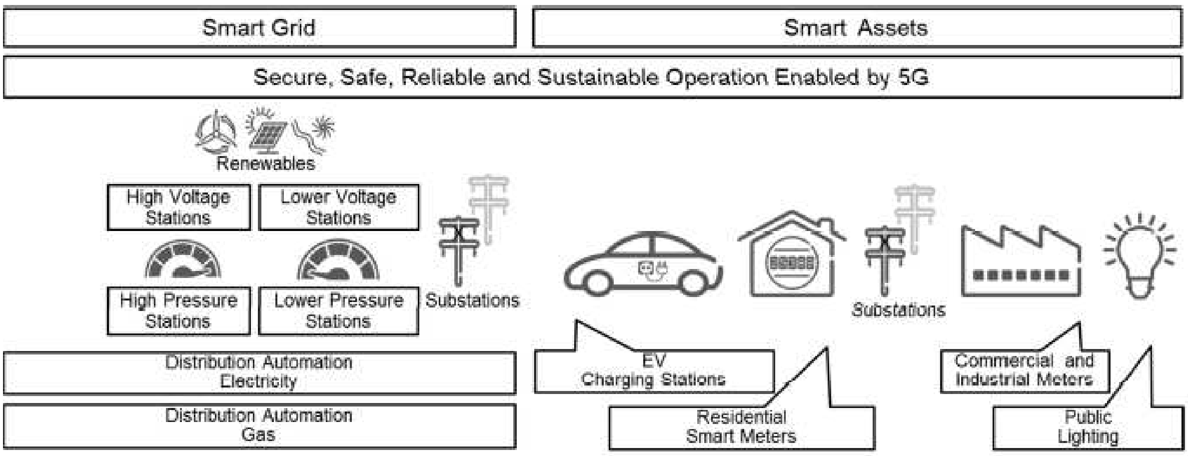


Figure 21: The energy uses cases highlighting the smart assets use cases and the energy distribution use case from smart grids

5.4 5G and e-health

The e-Health sector is identified as a priority in the European Digital Agenda and subsequently in many national digital agendas for the following main reasons: the rise in healthcare costs as percentage of GDP continues to outperform the average economic growth (GDP); and digitalization and virtualization of care have been considered a major driver towards the transition of healthcare from a hospital based, specialist driven system towards a distributed, patient centered care model with the point of care shifting to the periphery.

5.4.1 Socio-economic drivers for Horizon 2020

In most European countries direct healthcare costs stand for more than 10% of the GDP with a strong annual increase. According to OECD data the annual average growth rate in health expenditure per capita in the period 2000-2009 was around 4%, while at the same time the corresponding average increase of the GDP was only 1.6%. These indicators suggest that the cost of healthcare delivery is not sustainable and that measures have to be taken to mitigate this risk.

5.4.2 How 5G can be a catalyst

Four main groups of possible scenarios have been identified in which the rollout of 5G would act as a catalyst: Assets and interventions management in Hospitals (Assets tracking and management, Intervention planning and follow up); Robotics (Remote surgery, Cloud Service Robotics for Assisted Living); Remote monitoring of health or wellness data (Ageing well, Life style and prevention, Follow up after acute events and assisted living in chronic scenarios); And smarter medication (applying medication to the patient on a remote basis, Smart Pharmaceuticals, Algorithm supported theory-based health behavior change).

5.4.3 Business and policy aspects

Future business models and value chains should be flexible and adaptable to allow each stakeholder group to focus on its core competencies, such as delivery of care, sector application development, platform, infrastructure or network service provisioning. Specifics to the health vertical are regulatory and liability concerns, as detailed below.

5.4.3.1 Regulation

Regulation is a particularly important challenge for the full deployment of m-Health solutions in Europe. Currently, new m-Health devices are often covered by two regulatory frameworks; the Radio Equipment and Telecommunications Terminal Equipment (RTTE) and EU Medical Devices Directives (MDD). This raises questions regarding application and coordination between these different regulations.

Software is considered an integral part of a product/device in the context of the EU MDD. In the context of “softwaretized” networks with concepts like SDN and NFV, any 5G network applying these concepts and used for e-Health may also be considered integral part of the product/service. A legal framework for data protection must also be considered, including practices and processes for conditions and agreements to share private information, and obtaining consent from user/patient.

5.4.3.2 Liability

Traditionally product liability is limited to “products” in the form of tangible personal property, but since the network is an inherent part of the service/product, liability issues are introduced. It should be noted that smart (connected) devices will have a far reaching impact on manufacturers, service companies, insurers and consumers, and that a product or service may become defective due to either network and/or service failure (even temporal), or due to security vulnerabilities (in the device software, the “softwaretized” network, or the service in the cloud infrastructure).

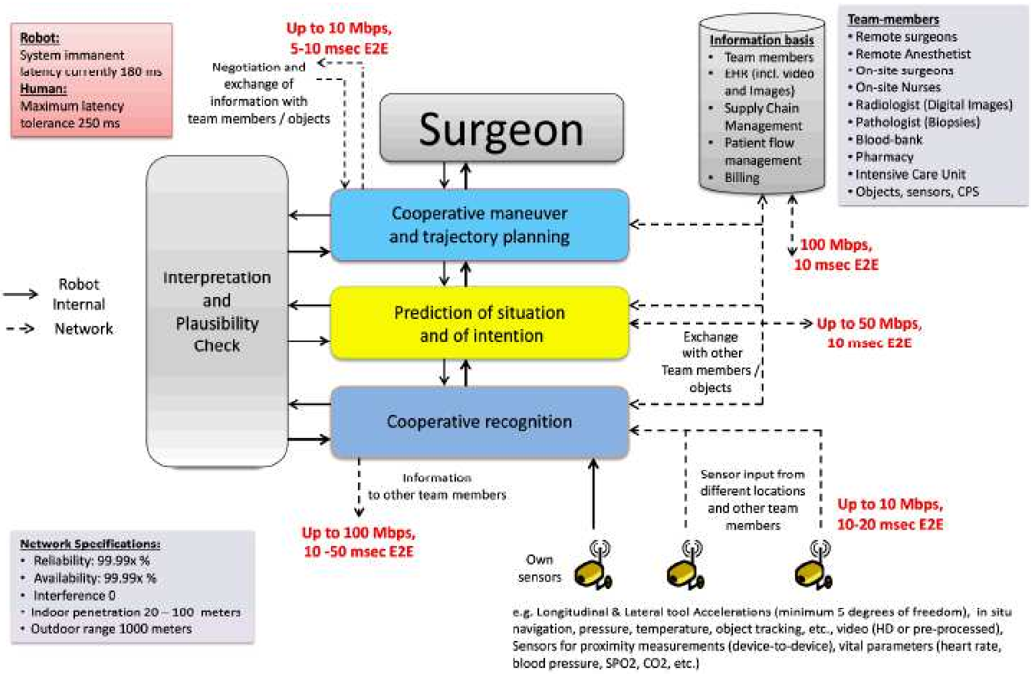


Figure 22: a robotics assisted tele-surgery scenario

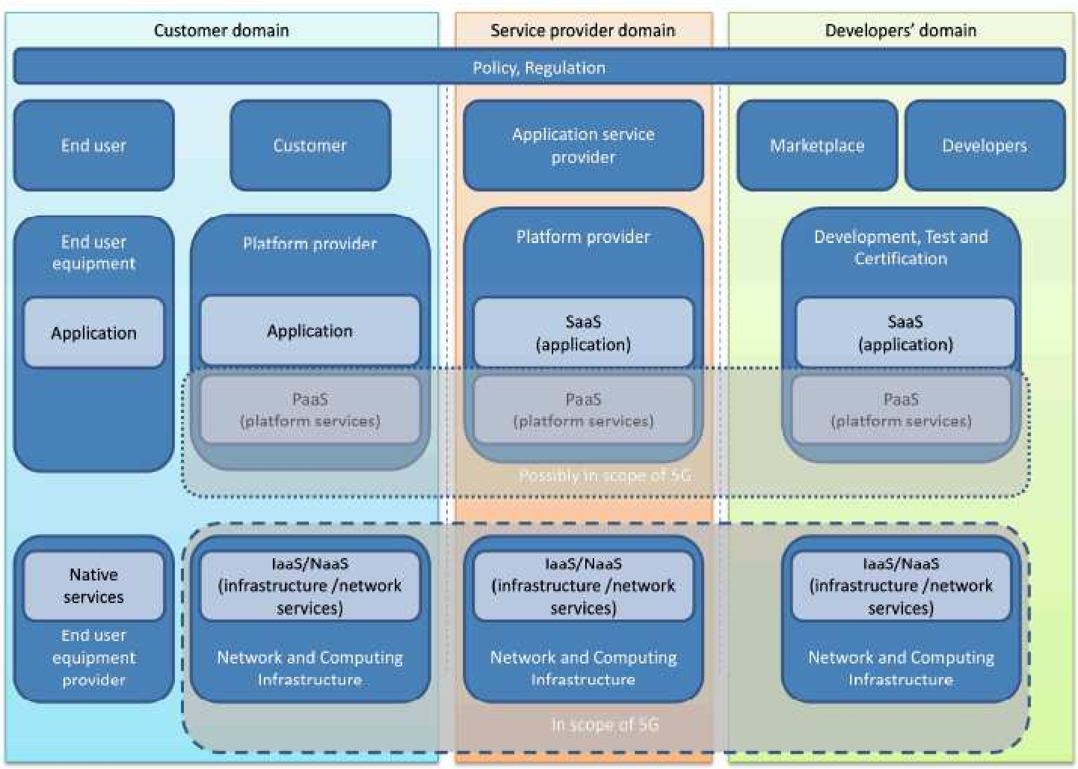


Figure 23: The potential for supporting ecosystem development with flexible business models and value chains

5.5 Energy efficiency brought about by 5G PPP

To meet the 5G PPP objective of 10 times lower energy consumption, the system must be energy efficient both when transmitting data and when not transmitting data. The latter may seem trivial, but the network nodes in today's networks are idle most of the time and the cost of overhead in the form of transmission of control signals even when no data traffic is transmitted is totally dominating the network energy consumption. Improvements in energy efficiency can be achieved by e.g. new, lean signalling procedures, novel air interface designs, and network node activation/deactivation. Lean signalling only transmits the minimum necessary signals continuously in idle mode, such as paging and random access since users/devices must be able to detect the network, and the network must be able to locate the users/devices. Energy efficiency also has impact on operational expenditure (OPEX) and capital expenditure (CAPEX). The energy consumption is a significant part of the network OPEX, and hence the OPEX is reduced by improving the energy efficiency. CAPEX is also reduced by improved energy efficiency, since reduced power dissipation allows more cost-efficient solutions in, e.g. battery backup and cooling systems.

5.5.1 Lean System Control Plane (LSCP)

In terms of energy consumption, traditionally the energy consumption and battery life of the terminals did not raise problems. In the mMTC (Massive Machine-Type Communication) service case however, terminals will be deployed on the long term without the possibility of periodical charging. Therefore power consumption is vital to the mMTC devices in order to fulfil the 5G PPP goal of x10 longer battery life. In general, reduced energy consumption for the terminals is achieved by shorter transmission times and lower output power for a given payload. mMTC requires optimized sleep mode solutions for battery operated devices, and mobility procedures with a minimum of signalling and measurements. The increasing number of network nodes requires lean signalling for energy performance boost, which LSCP can provide.

5.5.2 Dynamic RAN: activation/deactivation mechanisms will enable significant energy saving

Dynamic Radio Access Network (Dynamic RAN) is a new paradigm of wireless networking which integrates Ultra-Dense Networks (UDNs), nomadic nodes, moving relays, beamforming, D2D (Device-to-Device) communication and device duality in a dynamic manner for multi-RAT (Radio Access Technology) environments. Network densification offers a fast way to increase the network capacity. Networks have been densified from traditional macro-cellular networks to small cells, and the densification will continue to UDNs for both outdoors and indoors deployments. In some deployments the inter-site distance will be as small as tens of meters. The large number of UDN nodes prohibits cell planning in the traditional sense. Furthermore, to avoid unnecessary interference and power consumption, UDN nodes not serving any users will be turned off. Hence, although stationary in a physical sense, a UDN network will hence exhibit a dynamic behaviour in a communication sense. With the rise of connected cars in the current decade, the cars will not be only communicating with each other and the network, they can also serve as flexible means of wireless access points for both in-car and out-car users, e.g. nomadic nodes and moving relays. Such access points on the move can be utilized to enable temporal network densification to tackle the varying traffic demand over time and space on-demand. Within the framework of Dynamic RAN, the network deployment becomes flexible to cover the inhomogeneous distribution of traffic demand over time and space in an agile way. The network needs to react quickly and dynamically to fulfil the service requirements, which may unpredictably change in a certain region during a relatively short time period. An example of a Dynamic RAN is given in the figure below. To minimize the total energy consumption of the network and controlling the interference environment, the Dynamic RAN uses activation/deactivation mechanisms to select which nodes/beams should be activated at which times and locations. UDN nodes are densely deployed at fixed locations, whereas the availability of the nomadic nodes depends on battery constraints and parking behaviour of the drivers, which in turn depends on, e.g. day time and region.

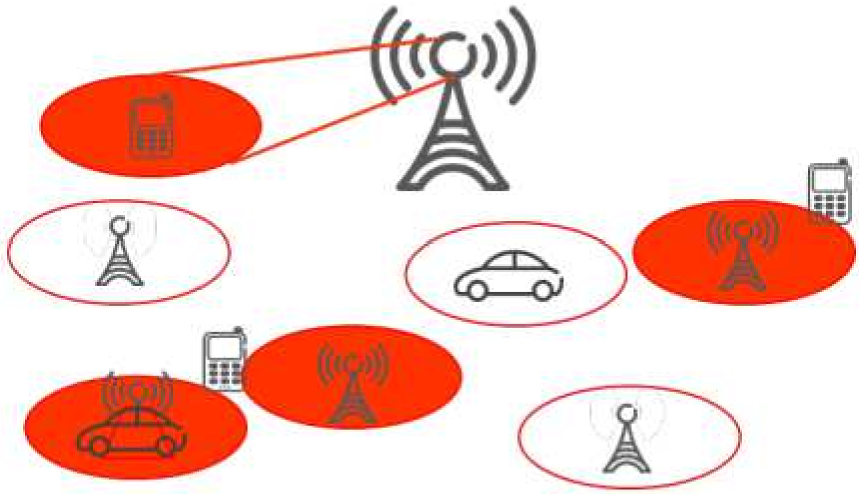


Figure 24: Illustration of a Dynamic RAN including UDN nodes, nomadic nodes, and beamforming lobes. Solid red indicates activated, empty indicates deactivated

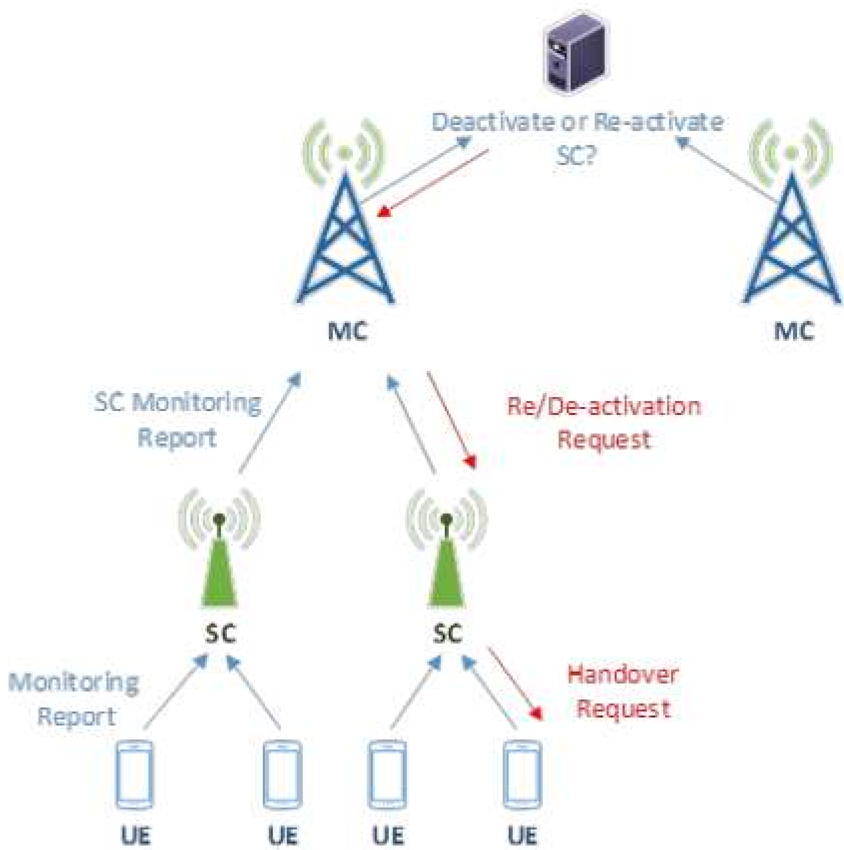


Figure 25: Activation and deactivation of small cells in UD

5.6 5G and security

5.6.1 Why is security so important

With 2G, 3G and 4G, security was mainly introduced to protect the system and be able to earn trust from customers and possible new users as well as to protect the ecosystem balance with fraud prevention and correct charging. These two important objectives were reached by incremental measures taken when developing new radio technology. 2G thus leveraged on 1G analogical failure to build a system capable of preventing eavesdropping through encrypted radio interface. Fraud prevention was secured thanks to strong authentication system based on a SIM card. Overall, although not perfect, security measures helped protect what was at the core of the system, basic voice and data connectivity.

With more and more people, objects, machines and wearable devices connected in the future, some of which with a critical role, security is more than ever a key requirement for 5G. Not only will people be connected but also machines and industries. Above all, the new architecture and flexibility brought by 5G will cause a host of new players to work, collaborate and compete using the same infrastructures. With virtualization present everywhere in the 5G system, new players will thus interact on the same network. In addition to traditional MNOs and MVNOs, Private Virtual Network Operators will use the same resources instantiated in network slices. Business customers will also be able to deploy their own application servers and will constitute an additional layer on top of the network. In addition, part of the network may also be operated by different players. Some small cell specialists could operate Small Cell as a Service, some equipment manufacturers may operate some network functions and devices themselves and may actively collaborate with the network. This makes more than ever security a key requirement in the building and developing of 5G.

5.6.2 How to implement security procedures within 5G?

But in order to be effective, security has to be built in such a way that it is mostly transparent to the user and easy to implement at all the different layers of the network. Rather than completely redesigning security within 5G, it is thus necessary to identify all the shortcomings of the system and all the players that are going to interact with the system and at which point. This is all the more important as security comes at a price tag so security measures should be studied carefully to prevent any unnecessary measures.

Below are the new security challenges raised by 5G:

- Decoupling of software and hardware: previously, dedicated hardware with dedicated (internal) security process was used but with virtualization, telecom software do not benefit anymore from this dedicated security. With operators possibly hosting 3rd party application in their cloud, the software will have to be correctly isolated.
- More devices, more people, more business models and more value associated to connectivity will make it even more appealing and impactful to attack the network with more possible points of attacks.
- With the advent of big data and the emergence of an economy based on crowd-sourced data analytics, user privacy will have to be more than ever protected, requiring anonymization process built within the system.
- Some industries have specific security requirements. Does it mean that 5G has to be certified against one of those standards in addition to other requirements? As security comes with a price tag, how should it be implemented in the system?

- How can the battery life of specific devices be preserved while not building easy-to-attack security holes in the network?

In order to solve these challenges, flexibility will be required and network slicing will be critical in managing these different security requirements. Network slicing will have to provide high-insurance isolation mechanism to each slice. This will enable to contain security costs on the infrastructure virtualization/isolation layer. A limited number of standardized and interoperable security measures could be implemented in every slice while additional and use case specific security measures would be deployed only in slices that require it.

Figure 26: Identifying the security threats and requirement at each layer – Source: Nokia

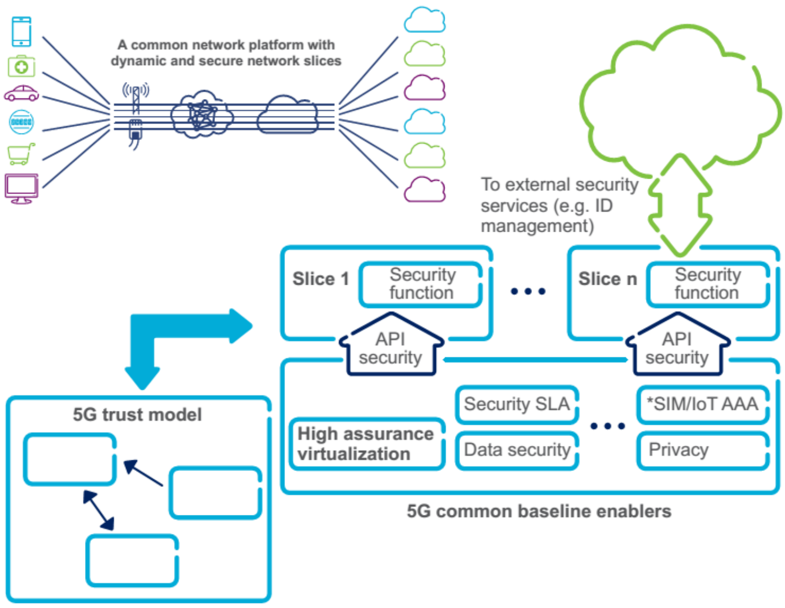


Figure 27: High level 5G security principles – Source: Ericsson

5.7 Technical aspects: RAN design & network slicing

5.7.1 5G RAN architecture

With the objective of providing 1000 times higher capacity per area, 10-100 times higher data rate per user, serve 10-100 times more devices per area at 10x longer battery lifetime, and provide 5 times lower end-to-end latency than today's 4^{th} generation cellular technology, 5G will have to adopt a completely new architecture. This architecture will have to be flexible enough to maintain some level of compatibility with other Radio Access Technology and still enable completely new concepts and technology to be supported and notably but not only new air interfaces. This will be all the more important as 5G will be developed in multiple phases where the first phase will focus on operation on frequency bands below 6 GHz. Because the second phase will necessarily bring new air interface to support mmWave operations, 5G architecture will therefore have to support the addition of new technologies from the outset.

5.7.2 SDN and NFV at the core of 5G

This required flexibility of 5G will be supported by multiple concepts and technologies. Software Defined Network (split of user and control plane) and the Network Function Virtualization will be at the core of this architecture and the main enabler for this flexibility. Instead of relying on dedicated hardware for each network functions, virtual machines will run them on normal IT servers, which will notably enable to pool resources and distribute those more effectively in different parts of the network from the core network to the edge of the network going through the aggregation point.

The infrastructure layer, which will encompass all the physical resources such as RF units, storage resources and transport networks, will be supplemented with two other layers. It will be completed by a business enablement layer where network functions will be deployed and the business application layer with Application Programming Interfaces (APIs) to enable the easy development and deployment of new business services. Possibly, those services will be deployed by third party players outside of the network of the operator.

5.7.3 Network slicing, an enabler for new business opportunities

- The three layers will be orchestrated by an end-to-end management and orchestration entity whose responsibility will be to create slices. They will be aimed at fulfilling specific use cases with own requirements in terms of latency, throughput, and energy consumption and so on. A slice could be created for instance to provide massive machine type communication when another one will provide enhanced mobile broadband services. A slice could use network functions deployed in the core network while applications requiring the shortest latency possible would see (some) network functions deployed at the edge to reduce latency and possibly offload the backhaul network. Those slices will be run in parallel on the same infrastructure. The E2E management and orchestration entity will thus allocate resources from the three layers to the different slices, notably hardware and software parts including transport networks, computing and storage resources, RF (Radio Frequency) units, including antennas and cables.
- From a user perspective, this slice will be seen as an independent network but will really run on the same network infrastructure to the other slices. One slice will possibly have multiple instances also meaning that the concept of virtual operator will change slightly in the future since third party players will be capable of developing their own services.
- The concept of network slicing will be completed by other mechanisms as a support for the

expected flexibility. Since multiple air interfaces will be developed to support multiple and diverging needs, a mechanism will have to be developed to enable those multiple air interfaces to coexist on the field. This is what the adaptive air interface is for. It will also leverage on adaptive frame structure to provide much more flexibility in the development of air interface.

5.8 Standardisation

5.8.1 5G standardisation and specifications

Many different players are involved in the research, development and proposal of technologies aimed at fulfilling the key criteria that have been defined for 5G. These players are involved in various initiatives around the world that bring together mobile network operators, mobile device and infrastructure equipment vendors, regulation authorities, universities and so on. Such initiatives are meant to foster innovation and make consensus emerge on how each piece of technology should be standardized. This standardization process will begin, within 3GPP at first, keeping in mind the final objective of being selected as an IMT-2020 technology by the International Telecommunication Union. The final deadline for standard submission is October 2020.

Within 3GPP, 5G standardization efforts really begins with the Release 14 of LTE in the first half of 2016 but also leverages on study items started in previous releases. It will probably last until LTE release 17 due to start around the end of 2019. There will be two phases of development. The first phase, which would last between the end of 2017 and the end of 2018, will focus on developing 5G for frequency bands below 6 GHz, which should not necessarily require a new air interface. The second phase would address the whole frequency range envisioned, i.e. from 1 GHz to 100 GHz as well as new air interfaces that are mandatory to operate in the mmWave frequency bands where path attenuation is much more important and therefore requires specific air interface. This second phase would start at the beginning of 2018 and would end at the end of 2019.

This streamlined approach is aimed at securing a quick development and making the technology available for early deployment, namely by South Korean players, which have already stated that they wanted to showcase the technology with pre-commercial deployment at the winter Olympic games of Seoul in 2018. The ability to use higher frequency bands will further improve capacity and throughputs but will also require, from a regulation standpoint, that new frequency bands for mobile broadband are adopted globally, something that is due to happen with World Radio Conference (WRC) 2019. By 2020 deployment in the mmWave bands should be very limited.

5.8.2 Contribution of Europe to 5G development

Ultimately, the goal of research and development initiatives such as the 5G PPP projects is to come up with technologies/concepts propositions that will shape 5G standardization. Being part of this process is strategic to secure leadership in areas where Europe is strong and enable to build a technology that will answer the need of the European society while leaving space for innovation. In the end, patents and the positive economic impact resulting from the enabling of new markets such as smart cities, e-health, intelligent transport, education or entertainment & media is also strategic.

In total, 19 projects have been funded as part of the 5G PPP, of which 12 were launched in July 2015. Contributions of these projects are various and deal with various concepts and technology proposals. The aim of 5G is to provide 1000 times higher capacity per area, 10-100 times higher data rate per user, serve 10-100 times more devices per area at 10x longer battery lifetime, and provide 5 times lower end-to-end latency than today’s 4th generation cellular technology, while having the same cost and energy dissipation per area as today.

To fulfill this vision, 5G will need to be flexible enough to support multiple use cases while enabling significant cost and energy saving. Most of 5G PPP contributions will bring flexibility to mobile network operators, device manufacturers and the various users (consumers, vertical industries, smart cities and transportation…) in various areas. The architecture itself of 5G will need to be flexible with concepts such as network slicing, adaptive air interface, the possibility to select the most adequate path to reach a user and deliver content. Some innovation will enable to bring mobility to the provision of content for example by dynamically selecting whether it should be delivered from the core network, the aggregation point or at the edge of the network. Then, it will be possible to select whether this content should be delivered directly from the macro-cell site, a small cell, closer to the user or even through another device that would turn to collaborate with the network. In order to accomplish such actions, a certain number of KPIs will have to be monitored and techniques such as machine learning and cognitive technologies will be leveraged to dynamically adapt to varying network conditions.

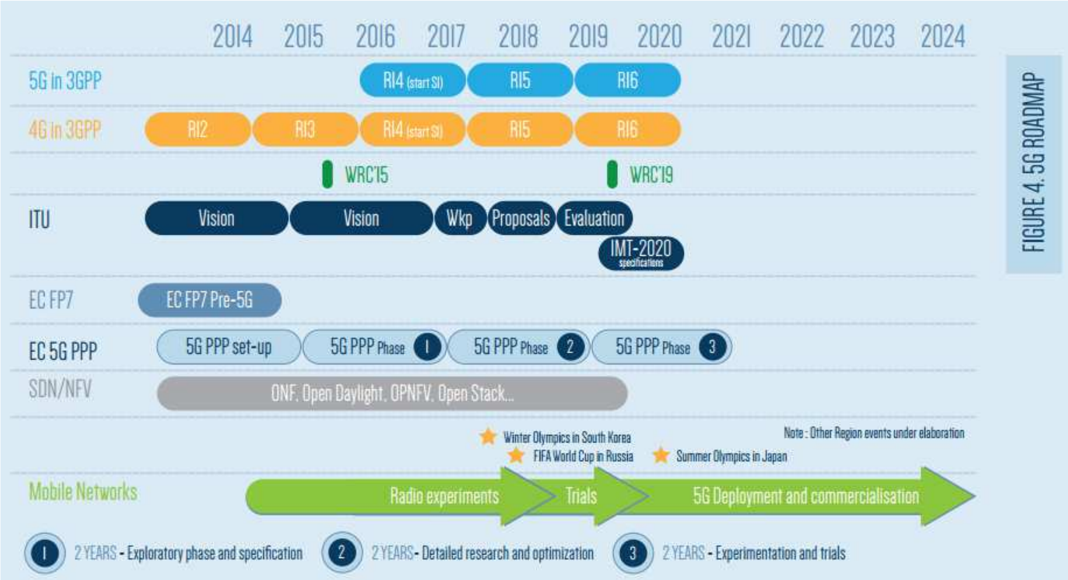


Figure 28: 5G roadmap – Source: 5G PPP

Not only the Radio Access Network will benefit from those innovations but other parts of the network, namely the fronthaul and the backhaul network. While the concept of heterogeneous network has for the moment been mainly applied to the RAN, it will also cover the multiple technologies available for the backhaul and fronthaul, which will be strategic in making possible the efficient operation of ultra-dense-networks.

Figure 29: 5G networks and service vision – Source: 5G PPP

5.9 Latency reduction with 5G

5.9.1 How to reduce latency?

While latency radically improved between 3G and 4G, it is still critical for several applications to further reduce latency in order to enable new use cases to emerge. Applications where latency reduction is critical include all the application where real-time operations are critical such as traffic safety control, transportation, autonomous driving, video games, finance, etc., With 5G, a targeted latency of 1ms is expected.

In order to bring the end-to-end latency to such a level, the whole chain has to be optimized from the device to the server, going through the base station, backhaul network and so on. Therefore, several efforts can be undertaken to reduce latency as much as possible.

To begin with, efforts can be carried on shortening the Transmission Time Interval (TTI), something that is currently a study item within LTE Release 13. TTI is basically the length of time required to transmit one block of data. It is only after a full block has been received that the receiver can estimate the Bit Error Rate (BER) and possibly request for a block of data to be resent if an error is detected through a Hybrid Automatic Retransmission Request (HARQ). In order to adapt quickly to the changing radio conditions, a shorter TTI is required. While LTE has a TTI as low as 1ms, TTI within 5G could be as low as 0.2ms.

Shortening this TTI will improve the feeling of reactiveness especially for the transfer of small files, such as typically those used for web browsing. Being able to do so, however, requires reduced processing time on both the device and the receiver in order to handle frames more quickly. Also, this TTI shortening can be completed with a new frame structure that would adapt to the changing radio conditions. In situations with a good link quality, the efforts to control the frame structure could be reduced and adapted in the case of degrading radio conditions.

This work around the frame however will only impact a small portion of the end-to-end latency. Indeed, most of the latency observed in a network comes from the time that is taken to transport information from the antenna to a server on the internet, passing through the fronthaul, backhaul, core network up to the Internet. That is why the backhaul network is so important and has such impact on the overall Round Trip Time. If latency can be improved in this part of the network, overall latency can be also reduced by deploying required network functions and content (through caching servers) at the edge of the network. This will be notably enabled by further network virtualization with network slicing resources being selectively deployed at the edge of the network.

5.9.2 How would usages evolve?

There has been much discussion on the kind of usages that could be enabled from latency reduction. Some people have argued based on neurological studies that reaching sub 1ms latency made no sense, because the time that it takes for the human to perceive sound or images is longer than this 1 ms objective. The European Broadcasting Union for instance recommend a lip synch delay between 40 ms and 60 ms, which means that humans would not see the difference in latency between video and audio reduced to 1 ms. However, for machine to machine communication, this kind of latency will easily come with an advantage. Besides, with billions of objects and devices to be connected on the network, reduced latency will benefit the most demanding applications.

Among the applications that require very short latency are all the real time applications which include autonomous driving, remote surgery, virtual and augmented reality, vehicle control systems and so on. Outside real time applications, the development of cloud usage will also benefit from a reduced latency and will enable more powerful applications to be proposed as a service.

It is to be noted that since some applications can support much longer latency, such as monitoring of some remote assets, there are also researches being carried out to leverage those inferior latency requirement and improve the battery life of those devices.

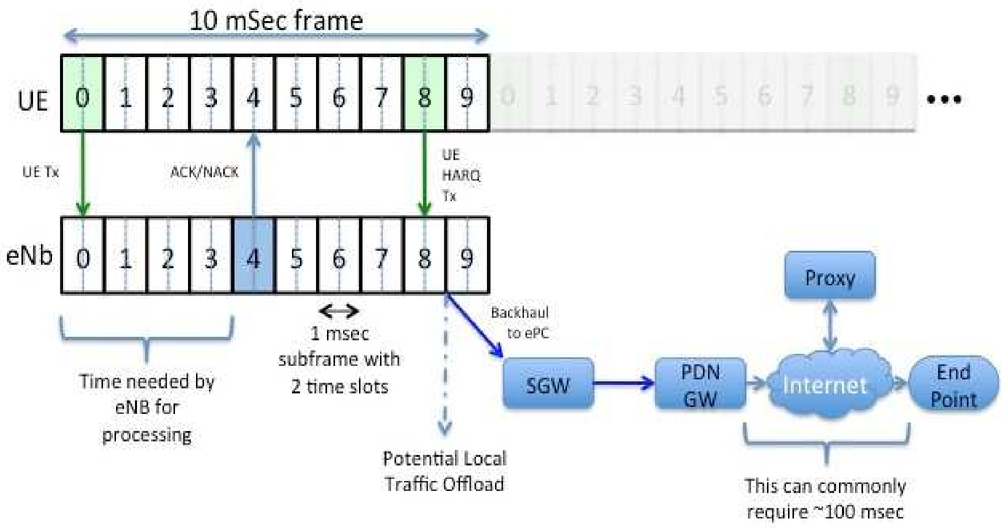


Figure 30: understanding where end to end latency comes from in the network – Source: http://5gnews.org/latency-5g-legacy-4g/

5.10 Backhaul /Fronthaul developments

5.10.1 Improvement in the RAN requires rethought backhaul and fronthaul

Backhaul is critical to support the increasing flow of data stemming from more and more users in densely populated and highly equipped areas. While today LTE commonly support maximum throughputs of hundreds of megabytes per sites, 5G will have to support far higher throughputs (in the tens of gigabyte range). While fiber was long seen as the only possible backhaul technology for 5G (and even for 4G), wireless could also have its word to say with new technologies that compress data traffic much more effectively and enable strong enough latency rates. This is all the more true that wireless technologies in the mmWave band enable even smaller latency than fiber. The possibility to use wireless technologies will bring a lot of flexibility in the further deployments of network infrastructure. This is especially true as fiber is not available everywhere and is very costly to deploy when not already available. On the contrary, wireless backhaul are much easier to deploy and sometimes less costly.

But backhaul is not only important because of the data it has to transport to the core network, it is key in enabling collaboration between the many small cells that will be deployed to densify the network and increase both capacity (through frequency reuse) and coverage. However the proximity of these cells as well as their density will create both opportunities and challenges. The challenges pertain to the mitigation of interferences between nearby (small) cells as well as with the overlying macro cell. In order to mitigate interferences, cells will have to communicate and coordinate themselves. This is why latency will be so important. Depending on the traffic in a given area and the position of each user, small cells will be able to decide which users could be served by which cell. A user will thus possibly be served, either by the (small) cell where the user is located, or by a nearby cell if the user is at the edge of the cell, or (and not least) by several cells at the same time, through coordinated multipoint. To better secure the mobility within this network of small cells, the control plane and user plane will be split with the control plane managed by the macro network and the user plane going through the small cell. Here again, backhaul will be critical to improve the performance of heterogeneous networks, all the more since smaller cells also mean more signalling traffic to handle. In the end, this will significantly improve the performance.

5.10.2 Toward an integrated back- and front-haul network

This more complex network will require heavy optimizations and Self Organizing Network features will be developed for the backhaul itself to improve significantly the time to deploy small cells. Backhaul links will be automatically configured depending on the options available. Throughout the day depending on the evolution of traffic, backhaul will be leveraged to adjust the level of emission, trigger energy savings mechanism and enable the caching of contents at the edge of the network. At some time of the day, some small cells will be sleeping, while some UE may also come to relay some part of the user or control plane, requiring for an orchestration that will be eased by the split of the antennas and the baseband units, which will be connected by the fronthaul network. Baseband units will possibly be virtualized on standard IT servers and pooled in aggregation points where processing resources will be allocated to each cell depending on the needs. This will save both costs and energy. Like for the backhaul network, wireless technologies will also possibly be used bringing more flexibility for operators to cover remote or difficult to reach areas.

In the end, 5G will both face and leverage a much more heterogeneous network, not only in the radio access network but also between the RAN and the core network. Some research is being carried out to integrate the backhaul and the fronthaul together. This is notably the case as part of the European project Cross-haul. The aim of this project is to integrate “the fronthaul and backhaul networks with all their wire and wireless technologies in a common packet based transport network under an SDN-based and NFV-enabled common control.” To this end, an abstraction layer will be created that will possibly provide back and front haul as a service.

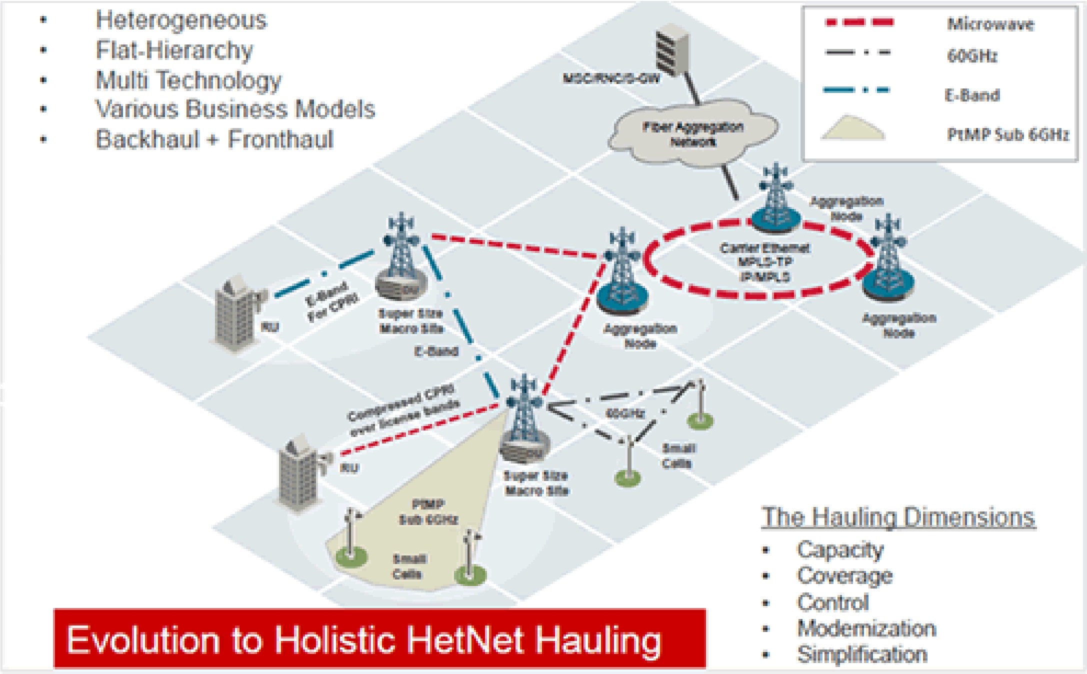


Figure 31: Illustration of a heterogeneous backhaul network – Source: Ceragon

5.11 Spectrum aspects for 5G

In the early preparation of 5G network visions [1] it is clear that access to spectrum will become key to achieve the expected results of 5G PPP. Seven projects in 5G PPP address in some way spectrum topics. These projects are listed in Table 3.

Project	Contribution to the 5G spectrum topics
5G-Crosshaul	Integrated fronthaul/backhaul wireless options in frequency bands up to 100 GHz, with particular attention to the 50-90 GHz range
5G-Xhaul	Focus on the 60 GHz band for backhaul/fronthaul
COHERENT	Management schemes for shared spectrum
FANTASTIC 5G	Access to spectrum below 6 GHz
METIS-II	Spectrum rationale and technical aspects of spectrum
mmMAGIC	Spectrum above 6 GHz, including mm-waves, for 5G mobile communications access and self-backhaul
Speed-5G	Smart management of multiple radio access technologies resources and dynamic spectrum access

Table 3: 5G PPP projects addressing spectrum topics for 5G

5.11.1 Expected spectrum demand

An overall amount of new spectrum to several hundred GHz will be necessary for 5G services. Several 5G PPP projects describe expected scenarios of 5G services to get a clearer view on requirements including needed spectrum in the future.

The projects METIS-II and mmMAGIC published their studies in May 2016 and December 2015 respectively. Both project reports address the bands above 6 GHz. The most demanding requirements are derived from providing 4k video. It will need 15 - 25 Mbit/s leading to about 60 - 70 Gbit/s per km for a typical city population density. In spectrum terms this leads to 600-700 MHz per operator.

Table 4 provides requirements to spectrum for the 4k video as Media on Demand and nine other use cases as estimated by mmMAGIC [2].

Use case	BW-DL (MHz)	BW-UL (MHz)
Media on Demand	500	10
Cloud services (pico cell environment)	300	50
Dense urban society with distributed crowds	1 175	2 350
Smart office	1 000	270
5G immersive experience	1 640	820
50+ Mbps everywhere	588	294
Moving Hotspots (Relay/cell in-vehicle)	100	50
Moving Hotspots (Not in-vehicle cell/relay)	50 000	25 000
Remote surgery/robotic control	500	10
Tactile internet	10	10

Table 4: Bandwidth requirements for the use cases studied by mmMAGIC, Table 6-2 [2] Bandwidth (BW), downlink (DL), uplink (UL)

5.12 Possible candidate bands

A number of frequency bands below 6 GHz are allocated to mobile service and identified for International Mobile Telecommunications (IMT) in Radio Regulations [3]. The last World Radio Conference in 2015 (WRC-15) identified some new bands for IMT. All these bands are below 6 GHz, and will clearly become available for 5G (as identified for IMT 2020 in the ITU-R terminology). Decisions were taken in favour of the 700 MHz band, 1427-1518 MHz, and 3.4 - 3.6 GHz, identified for IMT.

Resolution 238 (WRC-15) [4] lists the bands which have become the candidate bands for 5G, as detailed in Table 5.

Bands that have allocations to the mobile service on a primary basis	Candidate bands for additional allocations to the mobile service on a primary basis
24.25-27.5 GHz	31.8-33.4 GHz
37-40.5 GHz	40.5-42.5 GHz
42.5-43.5 GHz	47-47.2 GHz
45.5-47 GHz	
47.2-50.2 GHz	
50.4-52.6 GHz	
66-76 GHz	
81-86 GHz	

Table 5: Bands for sharing and compatibility studies

The decision is to perform sharing and compatibility studies and allocate in 2019, including identification for IMT, at the next WRC. 5G PPP projects will contribute to these studies.

5.13 Spectrum licensing and sharing

Mobile network operators need security for long-term investments in building and operating networks. Traditionally, and perhaps still the case, they prefer exclusive licence rights to spectrum. However, the most important aspect is a stable and predictable regulatory regime.

Projects are analysing spectrum sharing aspects such as licenses shared access (LSA) or authorised shared access (ASA) and aim at trials in some markets. Also studies of game theory and graph theory are investigated by COHERENT, but more for laboratory tests and simulations. This work is still in an early phase.

References

[1] ITU-R, IMT Vision - Framework and overall objectives of the future, development of IMT for 2020 and beyond, Recommendation M.2083 September 2015

[2] mMAGIC, Use case characterization, KPIs and preferred suitable frequency ranges for future 5G systems between 6 GHz and 100 GHz, Deliverable D1.1, 30 November 2015

[3] ITU, Radio Regulation, 2012, Geneva

[4] ITU, Final Acts WRC-15, World Radiocommunication Conference, International Telecommunication Union, Geneva, 2016

6 5G chronicle

A number of actions have been pursued since the launch of the 5G PPP projects (most of them started on the 1st of July, 2015). The past year has been rich in events and promotional activities. This section provides a global overview and reports in particular on major past events.

In particular, Memorandum of Understandings (MoUs) paved the way to a global harmonised 5G promotion and workshops allowing close and smooth cooperation among the various 5G PPP projects and effective dissemination actions to be orchestrated. 4G Americas (Americas), The Fifth Generation Mobile Communications Promotion Forum (5GMF) (Japan), 5G Forum (Republic of Korea), IMT-2020 Promotion Group (5G) (non-profit organisation, China) and obviously the 5G Infrastructure Association Public Private Partnership (5G PPP) (Europe) all acknowledged the need of a global and common 5G promotion as 2020 approaches.

The parties have agreed to jointly organise two "*Global 5G Events*" per year in the coming years to focus their efforts and leadership. The first two "*Global 5G Events*" are scheduled for May 31-June 1 in Beijing (China) under the responsibility of IMT-2020 (5G) Promotion Group and for November 9-10 in Rome (Italy) under the responsibility of the 5G Infrastructure Association.

6.1 Verticals workshops

Digitalisation of verticals is a key topic. Two workshops on vertical industries were co-organised by the European Commission and the 5G PPP.

- The first one took place at the EUCNC 2015 in Paris on the 1st of July 2015. The state of the art of vertical industries digitalisation was clearly explained. Requirements for 5G and potential benefits from 5G for verticals rank among the hottest issues.
- The second workshop was held on the 9th and 10th of November 2015 in Brussels. It focused on the five white papers released by the 5G PPP on verticals (eHealth, Factories of the Future, Energy, Automotive, specialised services/Network management). A large panel of companies and institutions in each vertical industry contributed to this first-of-this-kind of workshop with many valuable insights. Disruption of current ecosystems and emergence of new data-driven business models were debated. The key role of regulation and policy was also mentioned. Above all, use cases and related technical requirements in each vertical industry as well as pre-standards work attracted much attention.

6.2 5G Multilateral Workshop on Regional Initiatives on 5G Spectrum

The first 5G Multilateral Workshop between Regional Initiatives on 5G Spectrum and Standards was held on October 20th, 2015 in conjunction with ICT 2015. Some open preliminary issues for 5G standardisation were discussed. They highlighted urgent need for collaborative work and inevitable network convergence.

6.3 ICT 2015 in Lisbon (10-22 October 2015)

At the ICT 2015 in Lisbon strong cooperation between 5G PPP projects was demonstrated and intensively disseminated through many channels. Demos were shown and early outputs and innovations were highlighted. The brochure presenting the 5G PPP phase 1 projects was distributed. The 5G vision brochure and flyers have also been disseminated in Lisbon.

6.4 MWC'16 (22-25 February 2016)

During the MWC'16 in February, 5G PPP projects presented an overview of the PPP and its activities at the EC booth. In addition, the 5G PPP whitepaper entitled "5G empowering Vertical Industries" was launched in a special media and analyst event at MWC. The paper which outlines how 5G network infrastructures will enable the digitalisation of society and economy (especially in the automotive, transportation, healthcare, energy, manufacturing as well as media and entertainment sectors) was warmly welcomed.

6.5 EuCNC 2016

A number of 5G PPP projects contributed to the success of the EuCNC 2016 conference through dedicated workshops, oral sessions and/or paper presentations in the main conference.

Notably, FANTASTIC-5G, mmMAGIC and FLEX5GWare held a workshop on 5G Physical Layer Design and Hardware Aspects Below and Above 6 GHz. 5G-Crosshaul organised a Workshop on "Next Generation fronthaul/backhaul integrated transport networks. CogNet held a workshop on Network Management, QoS and Security on June 27. The projects CogNet, SelfNet, SONATA, 5G-ENSURE and 5G-NORMA all presented papers at this workshop. METIS-II also organised an international workshop on 5G Architecture.

6.6 5G PPP projects jointly organised a number of workshops

5G PPP projects jointly organised a number of joint workshops highlighting strong cooperation between projects:

- The METIS-II chaired workshop in Stockholm (Sweden) in September 2015 gathered eleven 5G PPP projects (out of 19) and focused on radio aspects for future communications. The IEEE ICC 2016 held at the end of May 2016 in Kuala Lumpur (Malaysia) gave the opportunity to METIS-II, mmMAGIC, 5G NORMA and FANTASTIC-5G to focus on 5G architecture and specifically on RAN design. The 4th CLEEN workshop at the end of May 2016 was a jointly initiative between three 5G PPP projects (FLEXWARE, 5G NORMA and SPEED-5G).
- EuCNC 2016 gathered many 5G PPP projects contributing its success.
- Other joint initiatives will follow in the second half 2016. The second 5G workshop on 5G RAN design is co-located with GLOBECOM 2016 (Washington DC, USA). It will be jointly organized by five 5G PPP projects (METIS-II, FANTASTIC 5G, mmMAGIC, 5G-Crosshaul and Flex5Gware), the highest number of projects involved so far reported.

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