Why 5G?*

New services – Larger ecosystem – Better performance – Innovative Architecture

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Abstract The global society and the worldwide economy are becoming increasingly dependent on information and communication technologies (ICT), especially on wireless connectivity. The recently defined 5G infrastructure, on the verge of being broadly deployed, promises to finally deliver on the long sought-for ubiquitous and always-on connectivity. 5G will allow for new applications and unique service capabilities, not only for consumers but also for new industrial stakeholders, creating new business opportunities and allowing for novel Business to Business to Customers (B2B2C) business models. The society will benefit from the availability of such new services in many tangible different ways. Nonetheless, to make such transformation happen, a larger ecosystem, which merges existing and new ICT stakeholders, as well as different verticals and industries, is needed. Based on an innovative architecture, which can scale and adapt to future needs, and a new radio interface, 5G will

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provide significantly better performance and new capabilities, mandatory for that transformation to take place.

1. 5G, the enabler of new services

4G was designed to improve capacity, user data-rates, spectrum usage and latency with respect to 3G. 5G aims at being much more than a simple evolution of 4G, as it will be a key enabler of the future digital world, the next generation of ubiquitous, ultra-high broadband infrastructure that will support the transformation of processes in all economic sectors and the growing consumer market demand. This is reflected in ITU-R's defined objective for IMT-2020:

> "Enabling a seamlessly connected society in the 2020 timeframe and beyond that brings together people along with things, data, applications, transport systems and cities in a smart networked communications environment"

In fact, 5G is designed to create the conditions to launch new applications and provide new unique service capabilities not only to consumers, but also to new stakeholders (e.g. vertical industries, novel forms of service providers, infrastructure owners and providers).

Firstly, 5G will ensure unprecedented user experience continuity also in challenging situations. For example, HD video will be commonplace and available anywhere, teleworking will be possible also for those living in small villages or travelling in high speed trains and airplanes. 5G systems will provide user access anywhere and will select transparently for the user the best performing access among the several available ones, based on heterogeneous technologies like WLAN, satellite, 4G and the new radio (NR) provided by 5G. The choice of the best performing access will not only be based on throughput but on the most relevant metrics depending on the nature of the service; for instance, the right balance between latency and throughput is very important for an Augmented Reality (AR) consumer moving around.

5G will also be a key enabler for the Internet of Things (IoT), by providing the platform and services to connect and properly operate a massive number of objects. To make best use of the newly provided services of 5G, the environment in which we move will have sensors and actuators spread everywhere. Since they require very low energy consumption to save battery lifetime, the future network will have to find effective ways to handle a huge number of objects requiring a highly dynamically changing amount of small energy. Objects, users and their personal networks, whether body-worn or in a household, will be producers and consumers of data. Future smart phones, drones, robots, wearable devices and other smart objects will create local networks, using a multitude of different access methods. 5G will allow all these objects to connect seamlessly and independently of a specific access network technology.

Furthermore, several mission-critical services will be natively supported by the 5G infrastructure, thanks to the unprecedented reliability and achievable-on-demand low latency. 5G will cover services which were handled by specific networks for reliability reasons such as public safety. It will also cover new services requiring real-time reactivity, such as *vehicle-to-everything* (V2x) communication services and industry applications (e.g. process automation), paving the way towards enhanced self-driving cars, a much more advanced factory automation or remote health services.

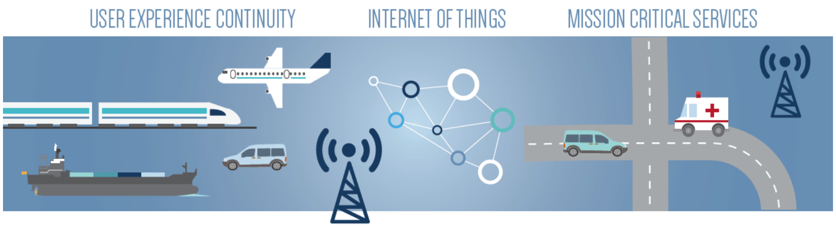

Figure 1: 5G new service capabilities

As a conclusion, 5G will efficiently support the three mentioned different types of traffic profiles, namely, high throughput (e.g. for video services), low energy (e.g. for long–lived sensors) and ultra-reliable and low latency (e.g. for mission-critical services). In addition, the 5G infrastructure will cover the network needs and contribute to the digitalization of vertical markets such as automotive, banking, education, city management, energy, utilities, finance, food and agriculture, media, government, healthcare, insurance, manufacturing, real estate, transportation and retail.

Commercial first deployments of 5G-like systems have already started in 2018, as specifications have recently completed, defining the 5G System and a first set of 5G services, under 3GPP Release 15, the so called 5G Phase 1. Though a broad deployment of 5G services is expected to take place in 2020, meanwhile the experimentation phase and the first trials are going into the field with more and more real users, so to mature a newly defined technology and to identify the most promising technical enhancements needed to make the 5G proposition a reality.

2. 5G as a promoter of a new ecosystem

5G can be thought of as being more like a Business-to-Business (B2B) rather than a Business-to-Customer (B2C) technology. By leveraging technological advances like SDN, NFV and network slicing, 5G provides advanced management capabilities and increased flexibility. This will enable a shift from the traditional model of providing bundles of similar services. By slicing the network and assigning each part a specific behaviour and capabilities, in terms of mobility, latency, data rate, etc., 5G allows operators to offer differentiated services using a single physical infrastructure. This in turn makes it possible to target particular economic or industrial sectors and multiple markets. It is thus expected that 5G will be capable of better meeting the unique needs of different players, opening up new opportunities for both the so-called verticals and Mobile Virtual Network Operators (MVNO).

In this new era, the traditional model of MNOs, negotiating contracts in bilateral basis, will become obsolete as new players and roles (especially intermediaries) will enter the value chain, thus creating new relationships between the stakeholders, finally leading to new partnerships and innovative ecosystems. Some of those new ecosystems have already been operating since a while, e.g. the 5GAA (*5G Automotive Association*) and the 5G-ACIA (*5G Alliance for Connected Industries and Automation*), gathering under the same umbrella entities spanning very different types of activity (e.g. operators, car manufacturers, industries, telecom equipment vendors, software houses, research institutes and consumers). Moreover, the need of network densification will create new opportunities for "upstream" players like independent operators that will acquire sites, deploy their infrastructure and offer wholesale to operators. This model, usually known as neutral host, will be mainly applicable in dense urban areas and indoor public spaces, and will allow partnerships and co-investment schemes between operators, vendors and verticals.

The ongoing discussions in standards on the next features to be added to the initial 5G deployment hint at the concrete possibility to finally deploy local private networks, thus allowing for unprecedented use cases and services, of which several different verticals will benefit, like media and entertainment or factory automation, among others. Additionally, compared to previous generation systems, 5G standards are including significant enhanced capabilities allowing 3rd parties (e.g. verticals) to customise network architecture and policies.

Last but not least, owners of sites suitable for 5G antenna installations, such as landlords or stadium owners, will gain significant negotiating power as the supply of available sites will be lagging behind the demand for such sites. Infrastructure resources, connectivity and all network functions will be delivered as a service. The ensuing environment will foster partnership-based business models. Operators will tap into the opportunity to enhance the value of third-party services. Partnerships will be established on multiple layers ranging from sharing the infrastructure, to exposing network capabilities as a service end-to-end, and integrating partners' services into the 5G system, through a rich and software-oriented capability set.

With 5G, network services will rely massively on software, with the cloud computing model extending to the telecom industry and cloud-native applications evolving to 5G-ready applications, with a stronger awareness of networking capabilities. Larger IT providers have already penetrated this market recently, relying on their expertise in cloud computing and virtualization to provide the same value proposition towards the telecom sector. It may cause a disruptive impact to network manufacturers which will reposition themselves, with a rollout of software solutions from their in-house development labs, or strategic partnerships with new IT providers.

Edge clouds will emerge at locations only to be made accessible by operators, as mandatory for 5G to guarantee the promised low latency. Besides services and applications running over-the-top (OTT) and other interacting directly with 5G core, a new generation of providers will take benefit of this new location, building a new ecosystem right at the edge. We will see some specific network platforms for each vertical sector with dedicated features and performance requirements (e.g. high reliability for health or automobile verticals or high density of terminals for smart cities).

Vertical industries will benefit from this environment, by being enabled to build their applications on top of a flexible network, capable of providing networking services through network slices tailored to a specific vertical and to adapt their configuration accordingly to the vertical application's evolution. These capabilities will create further opportunities for business interactions among multiple network service providers, vertical industries and application developers, fostering a dynamic market evolution, which will be instrumental to create new working opportunities, thus finally impacting the whole society in a positive way.

3. 5G enhanced performance

5G is mandated to significantly increase the available communication system performance, according to several system parameters and Key Performance Indicators (KPI). As recommended by ITU-R, 5G is therefore not only expected to be disruptive but also to act as an economy booster by fostering the creation of (i) new services that will positively impact important societal aspects, (ii) new ways to seize business opportunities, especially for the new service providers, as well as (iii) new business models supported by advanced ICT technology enablers.

The 5G architecture and its underpinning technologies will allow the usage of network functions and resources that are tailored to optimize specific services. Furthermore, allowing for even more advanced sharing infrastructure and spectrum capabilities, 5G will help reducing deployment costs and foster the entrance in the market of new players, thus enriching and enlarging the ecosystem of service providers.

Those disruptive capabilities will provide ubiquitous access to a wide range of applications and services, and will allow for increased resilience, continuity, much higher resource efficiency, and an overall significant decrease of system energy consumption. At the same time, 5G will increase the level of security and privacy of future communications. In addition, 5G will provide enormous improvements in capacity and boost user data rates. For instance, peak data rates up to 20 Gb/s will be available. A capacity of 10 Gb/s/km will be required to cover, e.g., a stadium with 30,000 devices relaying the event in social networks at 50 Mb/s. Moreover, reduced end-to-end latencies of the order of a millisecond are needed to support immersive interactive applications and ensure ultra-responsive mobile cloud-services.

Besides the human-centric applications, some of which have been outlined above, it is expected that a wide variety of Internet of Things (IoT), massive Machine-Type Communication (mMTC) and especially Ultra-reliable Low-Latency Communications (URLCC) applications will be mainstream by 2025. The capability of the telecommunication system to fulfil the numerous and diverse new requirements coming from the above-mentioned applications and the 5G system verticals will require important changes to the currently defined and implemented architecture components of mobile systems.

Figure 2, taken from the ITU-R [1], document "enhancement of key capabilities", compares existing and forthcoming system parameters and KPIs and highlights the main benefits expected from 5G.

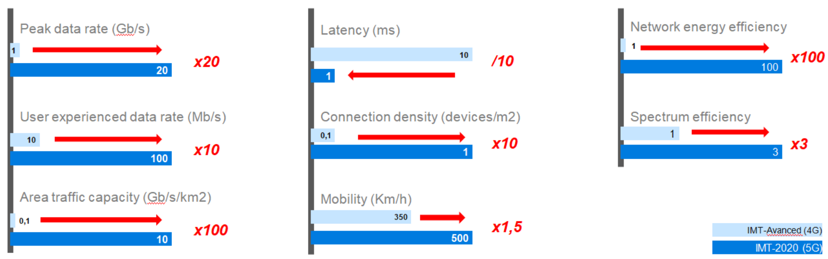

Figure 2: IMT-2020, enhancement of key capabilities [1]

It is important to highlight that not all of the enhanced capabilities described above will be required by each 5G service, everywhere and all the time. Each connected device will typically have its mix of latency, bandwidth and traffic intensity requirements. Also, each connected area will have its specific characteristics: the network will not provide the same coverage for a business district, a stadium, a residential area, or on board a vehicle. This is why the infrastructure has to be enhanced so to be flexible and able to dynamically adapt itself to the characteristics of the specific service demand expected in that particular area. 5G is therefore expected to provide, for instance, extended coverage for mMTC services and high bandwidth for eMBB services.

Radio based services rely on regulated access to electromagnetic spectrum, only at specific frequencies. In order to provide very high overall system capacity, so to fulfil the new 5G service requirements, especially the eMBB ones, it is required to make use of very wide contiguous carrier bandwidths, from hundreds of MHz up to several GHz. That will be possible, if contiguous frequencies are to be used, only thanks to higher carrier frequencies, i.e. well above 6 GHz, in the lower millimetre wave spectrum.

4. Innovation, at the heart of 5G

To achieve the expected enhancements in capacity, coverage, reliability, latency, energy consumption, flexibility, availability and fast services deployment, a new system architecture and a new radio interface are at the core of the 5G proposition. However, besides the intrinsic innovations introduced by the technology, the 5G system architecture and its deployment will leverage on other emerging, innovative, technologies, its success being the result of all those combined together.

A new 5G Core to interconnect everything

The architectural changes to the telecommunication systems, needed to fulfil the expected 5G business and performance requirements, are significant compared to the existing deployed networks. In order to realize such radical changes, the various 5G subsystems and interfaces, as well as their integration into the overall 5G substrate and the interwork with the legacy systems, need to be inspired by modern operating system architectures.
The design principles of 5G Core service based network architecture (defined in the latest standard specifications [2]) can be synthesized in the following points:

1. Modularized network architecture, defining a plurality of elementary network functions enabling flexible and efficient network slicing
2. Service Based Architecture (SBA), allowing direct interaction among network functions, via the exposed services
3. Minimization of dependencies between the Access Network (AN) and the Core Network (CN)
4. Support of "stateless" Network Functions, where the "compute" resource is decoupled from the "storage" resource
5. Support of concurrent access to local and centralized services, to support low latency services and access to local data networks
6. Introduction of data analytics capabilities, to enable enhanced network automation
7. User Plane (UP) and Control Plane (CP) separation, as already introduced in previous generation networks.

These characteristics allow 5G deployments to adapt to a wide range of scenarios and appropriately exploit the adoption of technologies like SDN, NFV and MEC for 5G deployment, operation and services implementation. End to end slicing will be a central feature and selling argument of 5G, with explicit, native support, which exploits virtualization and much of the characteristics presented above.

A new radio interface to connect everything

One of the key enhancements of 5G is its new radio interface, called 5G New Radio (NR). Designing a wireless access network that simultaneously satisfies future demands for both human-centric and machine-centric services calls for technologies that present some characteristics:

1. Operation from low to very high bands: 0.4 – 100Ghz, including standalone operation in unlicensed bands
2. Up to 400 MHz component-carrier bandwidth (up to 100MHz in <6GHz; up to 400MHz in >6GHz) and up to 16 component carriers
3. Set of different numerologies for optimal operation in different frequency ranges
4. New channel coding (LDPC for data channel, Polar coding for control channel)
5. Native support for Low Latency (shortened Transmission Time Interval (TTI))
6. Native support for ultra reliability (Multiple diversity mechanisms)
7. Flexible and modular RAN architecture: split fronthaul, split control- and user-plane
8. Support for devices connecting directly, with no network (D2D, V2x)
9. Native support for Network Slicing

5G network deployments are expected both in the “low” bands (i.e. in frequencies below 6GHz) and in the “high” bands (i.e. in frequencies above 6GHz), using macro and small cells, coexisting with cellular legacy technologies (2G, 3G, 4G/LTE) and other wireless technologies like WiFi. In certain areas (especially urban and indoor) and to guarantee the required coverage and performance, 5G deployment will be based on Ultra-Dense Networks (UDN), with the deployment of a significant number of small cells, coexisting with macro cells. This will put pressure on costs and the transport network, as presented below.

A wireless network made of optics

With the advent of the 5G era, requirements like CapEx reduction, performance and energy efficiency (OpEx) improvements, capacity sharing and optimization, together with the need to deploy dense radio networks, are emphasized. As a consequence, the need to have the Radio Access Network (RAN) evolving from monolithic deployments to a generalized Cloud RAN (C-RAN), where Radio Units (RU) units are connected to Distributed and

Centralized Units (DU/CU), in a balanced splitting of functions, emerges as being fundamental. Thus, appropriate RAN functions split, interconnected by appropriate front/mid-haul optical fiber, packet based solutions, will be key in the 5G RAN architecture, answering the strict requirements of the 5G enablers, such as massive MIMO, mmWave and ultra-dense cells.

5G as well as data centres will be key technological and business growth drivers for the optical communication industry. The Optical Transport Network (OTN/WDM) is a robust solution which can provide a reliable broadband fronthaul delivery, using high capacity DWDM and Ethernet (like IP/Eth-eCPRI), being a promising option to support functional splits. Passive Optical Networks (PON) can reduce the cost of fiber deployment and reuse the current optical distribution network, subject to bandwidth upgrade (e.g. via NG-PON2), low latency and protection-multi-wavelength allocation requirements. *Radio over Fiber* (RoF) can be considered in the long term, as Digital RoF (CPRI like) cannot cope with mm-wave technology.

Furthermore, breakthrough technologies in optical interfaces and components will be needed. Especially advanced technologies like Silicon Photonics can be the cost-efficiency enabler for C-RAN, based on optical fronthaul and Wavelength-Division Multiplexing (WDM).

Software based architecture

5G will be driven by software. Network functions are expected in a number of points of presence, from the core to the edge of the network, to meet performance targets. As a result, 5G will heavily rely on emerging technologies such as SDN, NFV and Multi-access Edge Computing (MEC) to achieve the required performance, scalability and agility.

The search for solutions to make resource allocation in telecommunication networks more dynamic, performance-optimized and cost-effective, has brought forth the characterizing three features of flexibility, programmability and energy-efficiency. The first two are addressed by Software Defined Networking (SDN) and Network Functions Virtualisation (NFV). In particular, in the vision of ETSI [3], the third one leverages "…standard IT virtualisation technology to consolidate many network equipment types onto industry standard high volume servers, switches and storage", which could be located in Datacentres, Network

Nodes and in the end user premises. The 5G architectural framework is expected to instantiate on these, achieving unprecedented flexibility, performance and efficiency, integrating mobile wireless and fixed network components in a unified heterogeneous networking framework.

Complementarily, NFV and SDN allow more flexibility and tighter integration with infrastructure layers. However, none of the two is essentially a networking technology, as both assume an underlying network on top of which to operate. Hence, 5G will provide a unified control for multi-tenant networks and services through functional architectures deployment across many operators' frameworks, giving service providers, and ultimately prosumers, the perception of a convergence across many underlying wireless, optical, network and media technologies. 5G will make possible the fundamental shift in paradigm from the current "service provisioning through controlled ownership of infrastructures" to a "unified control framework through virtualization and programmability of multi-tenant networks and services", natively supporting and exploiting slicing.

Artificial Intelligence powering 5G

While the diversity of services and the complexity of the infrastructure will increase with the introduction of 5G, 5G is also expected to radically cut infrastructure Total Cost of Ownership (TCO), as well as the service creation and deployment times. Hence, service and network management, which classically rely on the Operation Administration and Management (OA&M) tools and the Business and Operations Support Systems (BSS and OSS), will evolve accordingly with advanced automation, including cognitive operations for handling trillions of actuators, sensors, and exploiting Big Data for better QoS and QoE, whatever the prosumer will be (human, machine or thing).

Considering the expected significant dependency industry and society will have on 5G, the development of cognitive features, as well as the advanced automation of operation through proper algorithms, will be paramount to achieve the required availability and reliability levels, and to optimize complex business objectives, such as end-to-end energy consumption. In addition, the exploitation of Data Analytics and Big Data techniques, via the incorporation of

Artificial Intelligence, will pave the way to monitor the users' Quality of Experience through new metrics combining network and behavioural data, while guaranteeing privacy.

5. 5G Standardization and launch of first commercial services

Several standards bodies are involved in the definition of the forthcoming 5G system. The most important one is the 3rd Generation Partnership Project (3GPP), even though others, like e.g., ETSI and IEEE, are also working on defining some aspect of the 5G system.

In September 2018, 3GPP has completed the definition of the first set of 5G features, called *5G Phase 1*, under the stream of activities of the so-called 3GPP Release 15. This first set defines the new telecommunication architecture components and protocols and messages needed to make interwork the 5G new access technology, called 5G New Radio (NR), with the legacy systems. From the usage scenarios point of view, 5G Phase 1 has focused on mainly defining the eMBB services, whereas the other two main usage scenarios, i.e. URLLC and mMTC will be the focus of the ongoing 5G Phase 2, under the activities of the 3GPP Release 16, planned to be completed by the end of 2019. The content of what will come afterwards, most probably called 5G Long Term Evolution (5G LTE), under the work of 3GPP Release 17, is still a matter of speculation.

ETSI and IEEE are also working on some aspects of 5G system. For example, the IEEE 1932-1 group on *licensed/unlicensed spectrum interoperability* and ETIS RRS groups on *eLSA*, an extension of the LSA (*Licensed Shared Access*) concept, needed to fulfill the requirements of 5G verticals, like Media and entertainment.

2018 is also the year of the first commercial launch of 5G services. For instance, since October, Verizon in US leverages the capability of 5G connections to provide a better user experience in households. More launches are planned at the beginning of 2019, but it is in 2020 that a real broad deployment of 5G services is expected to take place. Meanwhile, the experimentation phase and the first trials are going into the field with more and more real users, so to make mature the newly defined 5G technology. Such trials and first commercial launches are key to identify the most promising technical enhancement needed to make the 5G system proposition not only a reality, but also a commercial success.

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