

A 5G Infrastructure for “Anything-as-a-Service”

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Abstract

In this paper, we describe our vision of the advanced 5G infrastructure, a ubiquitous mobile ultra-broadband network supporting the Future Internet (FI). It is argued that 5G should not be simply seen as an evolution of current 4G networks, but, rather a revolution in the ICT field towards the “nervous system” of the Digital Society and Digital Economy. In fact, 5G will efficiently enable new ultra reliable, dependable, secure, privacy preserving, and delay critical services to everyone and everything, such as machines, vehicles, smart things, robots, etc. Adoption of new service models, such as “Full Immersive Experience”, enriched by “Context Information”, and “Anything as a Service” will create the conditions for the socio-economic sustainability of 5G infrastructures. In particular, “Anything as a Service” is a paradigm where devices, machines, smart things or robots will become “tools” to produce and consume applications, services and data, both for business and pleasure. This will dramatically contribute to the development of the Digital Economy centered on robots working alongside humans, thus freeing up people from many cognitive tasks and creating new jobs. As of today, for 5G many challenges are still to be addressed to meet the target performance indicators, especially, in terms of latency, reliability and spectrum usage. This paper gives a comprehensive analysis of said challenges, including recommendations on target network architectures and related enabling technologies. An exploitation scenario for Europe is presented and, eventually, a survey about main RT&D and innovation activities on 5G ongoing globally is provided.

Keywords: 5G; SDN; NFV; Edge Computing

Introduction

Today, we are witnessing the convergence of three paradigms, i.e., “cloud computing”, “more and more powerful terminals” and “high speed connectivity”, into a single point: the smart phone. All of this is built on the foundations of “bit pipe networks” of the Internet Service Provider (ISP), adopting the “Client-Server” model. As Google pointed out at Mobile World Congress (MWC), in 2010, “The smart phone is the extension of what we do and what we are: the mobile is the answer to pretty much everything” [1].

Two fundamental questions arise: Are current and projected technology trends truly intercepting the Digital Society and Digital Economy needs and stakeholders’ requests? In the future, is this tendency sustainable from the business point of view? There are several socio-economic indicators showing that it will be beneficial to pursue a change of paradigm (going beyond the Client-Server) and that technology will be ready to support this change. As an example, Figure 1 shows a use case where two smart-phones (Clients) are in communication using a service application running in a Server (in the Cloud) connected through the ISP bit pipe (high speed network). For instance, if LTE-Advanced was deployed, it would provide a link level speed up to 1Gb/s in the downlink (from access point to terminal) and 500 Mb/s in the reverse direction. Hence, 4G would nicely suit most of today’s service applications using smart-phones: unbearable user experience is likely due to either a static and sometime not completely effective network planning, or because the broadband network has not been properly deployed yet. However, the mobile network infrastructure has been neither conceived nor designed for flexible spectrum usage, carrying mission critical or massive machine type of traffic and/or connecting other type of devices than smart-phones, with much more stringent performance requirements, especially, in terms of throughput, latency, reliability, robustness, security and dependability [2-4]. New service scenarios, e.g., from smart grid to telemedicine, from self-driving cars to advanced robots (with real-time remote control and monitoring) in Digital Factories, from sound-/light-field for full immersive experience to tactile Internet, place new requirements on the network and devices. Machine-type communication (MTC) services must be efficiently supported in a

scalable manner. For instance, for seamless integration of smart cars, 5G networks are expected to provide measurable and provable security, as well as end-to-end delays below 5 ms, with 99.999% transmission reliability and approx. 100% availability. Moreover, for reproducing real 3D scenarios, like big events and professional transmissions, where an immersive experience is achieved through capturing and rendering signals coming from a large number of sensors and multi-directional transmitters, any future 5G infrastructure is expected to cope with 30-50 Mb/s for a single video transmission (before channel coding)

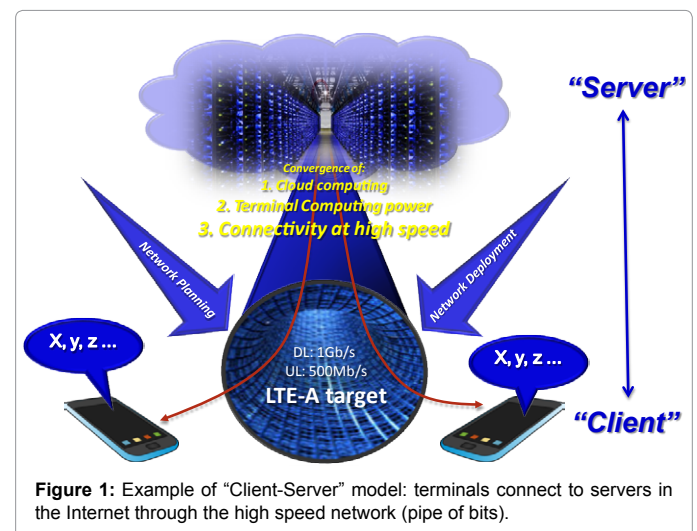


Figure 1: Example of “Client-Server” model: terminals connect to servers in the Internet through the high speed network (pipe of bits).

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and perform most of the light-field and sound-field processing in the network, as mobile devices are likely to receive only a portion of the full set of views and channels available. This will require the network to adapt the data stream with (close to) “zero latency”, according to decoder characteristics. The 3D full “collaborative and immersive” experience is expected at home, in cinemas, theatres, public arenas, cars, vessels, trains, aircrafts and especially using the next generation of devices, without wearing polarized lenses or binaural receivers [5]. Beyond this, other emerging trends, such as augmented reality and wearable devices, ultra-dense deployments of radiating antennas and, especially, new enabling technologies such as software defined networking (SDN) and network functions virtualization (NFV), do provide momentum for new design principles toward IMT for the 2020 and beyond (5G), meeting the major requirements from Network and Service Providers, in terms of:

1. Cost saving (CAPEX and OPEX);
2. More flexibility (e.g., through virtualization and programmability of any type of resource and function); and
3. Shorter time-to-market for launching new services (e.g., following the best practices of the IT domain).

Moreover, SDN and NFV can be seen as the expression of a systemic trend, influencing not only the Telco by also other industries, which is called “IT-zation” or “Softwarization”. This overall trend is enabled by IT techno-economic drivers, e.g. increasing performance of processing and storage at continuously decreasing costs, and it will reduce costs through automation and optimization of several processes (from the Industry, to our daily life). As explained later in the article, this technology trends are likely to entail a shift in competition from CAPEX to OPEX-based model (e.g., “pay-per-use” of Cloud Computing) impacting value chains and roles.

For the latter question, though operators are constantly investing to enhance their network capabilities and improve its utilization, most of the values are actually captured by over-the-top (OTT) players, who provide services and apps directly to the end users competing with the core business (e.g., voice, SMS and MMS) of the operators. Looking at the users’ needs, there are plenty of cases where, for instance, unprotected data are stored in Internet servers without identifying, authenticating and authorizing the end user, thus creating the risk of violating privacy and bridging any type of security measure.

5G should be designed to overcome said limitations, as well as with the main goal of providing delay-critical and ultra-reliable, secure, and dependable services to billions of smart objects and cyber physical systems (from smart grid to telemedicine, from self-driving cars to advanced robots in Digital Factories) and to new mobile terminals [4,6].

This will materialize the fundamental shift from the Client-Server model to the new concept of “Neural Bearer” – not limited to the single dimensional case of end to end connectivity – efficiently enabled by the 5G open and flexible infrastructure, where “Anything”, or “Everything” (XaaS), may be offered as a Service. The XaaS refers to those services – beyond the current SPI model (SaaS, IaaS and PaaS) of cloud computing – such as Data as a Service (DaaS), Security as a Service (SaaS), Network as a Service (NaaS), Knowledge as a Service (KaaS), Machine as a Service (MaaS), Robot as a Service (RaaS), and so forth, that could be delivered over the advanced 5G infrastructure, without the need of owning hardware, software or the cognitive objects themselves. In other words, 5G will make it possible to create and provide new services and applications – at lower costs – for developing the Digital Economy, for improving our lives. In fact, communication

services will become commodities and increasingly packaged with other services. Voice telephony will progressively become “yet another OTT service”, beyond commoditization. Life, intended as Presence (full immersion in the physical environment that surrounds us away from disruptive thoughts of past and future, being offloaded from all tasks that can be performed by connected cyber and physical objects) or Dream (sober immersion in a virtual and augmented reality, which any human being will be able to define and, especially, where he or she will be truly free to live a complete three dimensional experience in all possible imaginable, conceivable and privacy preserving ways and at any age) will be also ameliorated as a Service (LaaS) [7].

One of the key drivers for developing new 5G infrastructure is the growing ecosystem of things (embedding processing, storage and communication capabilities) around the end user, or “prosumer”. The distinction between “Carriers’ Network” and what connects to it, i.e. “End-Users’ Terminals”, will vanish, and so will the Client-Server paradigm: any devices, machines, smart things, robots, drones, and so forth, will operate as network nodes (at the edge) providing the end users “any type of service”. In other words, new mobile terminals will retrieve and generate information through ephemeral networks of cognitive objects and cyber physical systems in their proximity, regardless the availability of the network infrastructure. It is the latter distributed intelligence in future smart phones, drones, robots, and any smart objects – with or without network assistance – that will provide the ultra-reliable, secure, privacy preserving, and dependable services with the necessary extreme low latency, when needed. The distributed intelligence in pervasive local sensors and actuators will be one of the fundamental catalysts in the interest of today’s Network Operators, beyond OTT services, which will keep monetizing mostly through innovation at the application layer only [8].

This calls even more for a global 5G infrastructure, aiming at catalyzing innovation at the lower layers across the network, where anyone will have the possibility of communicating and contributing to the good of our networked society, especially thanks to the automation of many tasks, during our daily activities, that could be offloaded to machine, robots and drones, in alignment with “Smart Factories”, “Smart Energy” and “Smart City” concepts.

The reminder of this paper is organized as follows. The next section consolidates the key recommendations from important stakeholders and the main expected features and capabilities of 5G. We then present our vision of the advanced 5G infrastructure and new services. The related key enabling technologies are discussed in the section that follows. We then give an overview of the major initiatives on 5G research and innovation ongoing globally. Finally we paint a possible scenario for Europe. Conclusions are drawn in the last section of the article.

Recommendations and Key Capabilities

The 5G key capabilities and recommendations from the global stakeholders are illustrated in Figure 2 [9]. With respect to IMT-2000 (3G), the IMT-Advanced (4G) has been designed for improving capacity, user data-rates, spectrum usage and latency. Future IMT (5G) will be, above all, suitable for “massive and mission-critical machine communication”; and latency, spectral efficiency, speed, mobility and reliability are among the most important performance metrics 5G technologies will improve.

The 5G wireless system is expected to be much more flexible in spectrum usage [10]. As depicted in Figure 3, frequencies below 6GHz (cellular band) are mostly suitable for macro-coverage (0.5-2 km radius). The cellular band is expected to increase at least twice as much

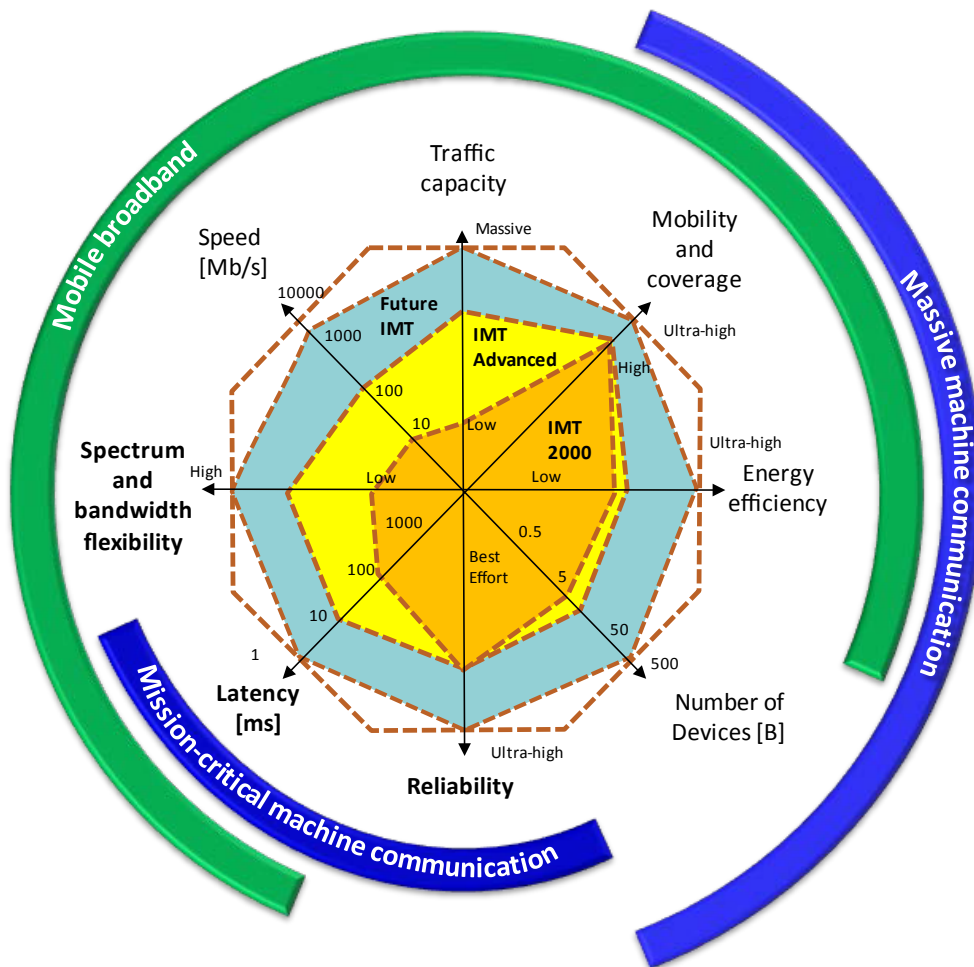


Figure 2: Recommendations and key 5G capabilities: a global perspective [9].

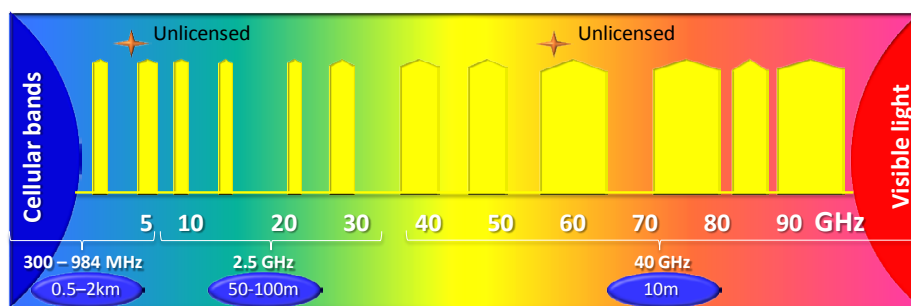


Figure 3: Spectrum for the next decade [10,11].

as it is today, i.e. from 300 to 984 MHz should be allocated already at WRC-15 [11]. In the range from 6 to 30 GHz, about 2.5 GHz could be made available for micro-coverage (50-100m radius). Frequencies from 30 to 90 GHz (visible light) would be particularly suitable for fronthauling and backhauling, and local deployment (10 m radius). In this range, about 40GHz could be made available for massive machine communications. These larger carrier bandwidths and spectrum at higher frequencies need to be identified at WRC-18/19.

Network and Services Vision

A high level vision of network and services at horizon 2020 and

beyond is depicted in Figure 4. Unlike the previous generations of wireless mobile networks, 5G will allow the use of any authorized spectrum and any access technology through a software-defined and virtualized architecture. The spectrum authorization policies may endorse new efficient allocation schemes (unfeasible today) – not only dedicated (exclusive allocation) or unlicensed spectra, but also licensed shared access (LSA) and co-primary sharing of authorized spectra will be possible. New radio access paradigms will maximally exploit such new flexible spectrum usage schemes. Moreover, the service delivery will not be limited to any specific frequency band; rather, it will follow the optimal delivery over the best available spectra. In such innovative

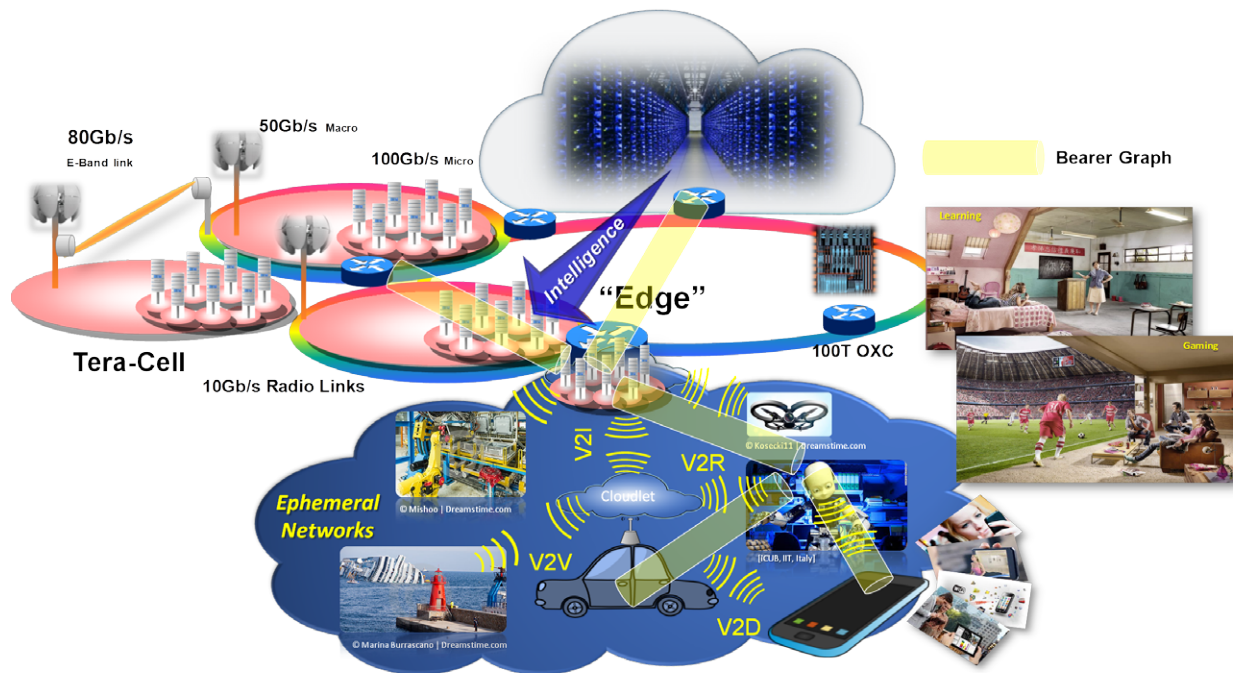


Figure 4: Network and services vision in horizon 2020 and beyond.

paradigm, all access technologies may be exploited as a single set of radio access capabilities. For instance, Wi-Fi with unlicensed spectrum access may become a service for a local area stationary or nomadic usage, whilst the licensed spectrum with macro and micro base-stations may deliver carrier grade mobility services. In order to better utilize the scarce frequencies availability for the mobile industry, with 5G, a true flexible and dynamic “re-farming” of spectrum becomes reality: a genuine spectrum license sharing will enable a variety of business models and ease the global spectrum regulatory framework. All these capabilities will be enabled by the new regime of “Software Defined Air-Interface” supported by edge computing and virtualized radio access networks.

As shown in Figure 4, in the horizon 2020 and beyond – under the assumption of conventional network planning for a full immersive and augmented reality – we envision the following wireless network capabilities:

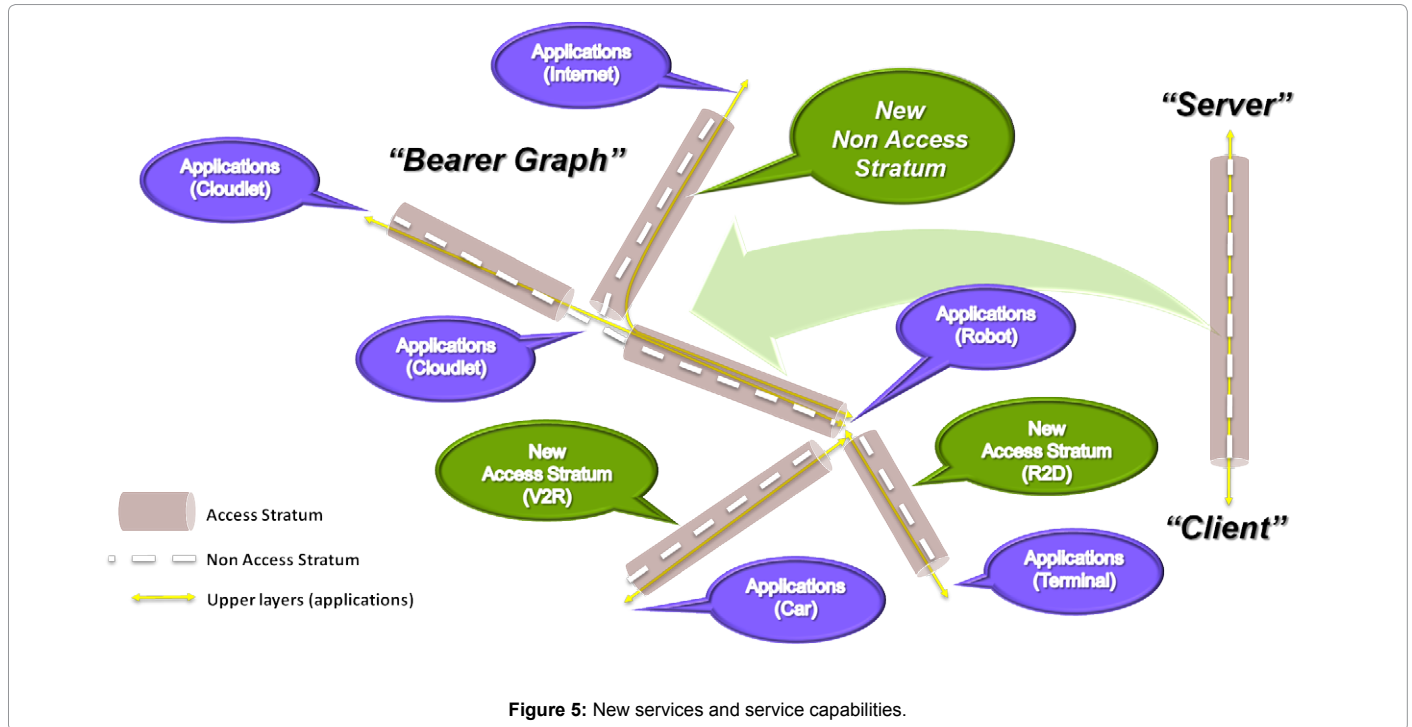
- 50 Gb/s Macro converge,
- 100 Gb/s Micro-Local coverage,
- 80 Gb/s E-Band back/front hauling links.

The re-design of the radio access nodes will require innovation in multiple areas of basic radio technologies, such as new air-interface, new virtualized radio access networks, new radio frequency transceiver architecture and new device radio architecture. New radio backhaul and new fiber access for the fixed network to support 5G Wireless are also required, as an integral part of the solution. The “Tera-cell architecture” and fully integrated wireless/optical infrastructure will be the “de facto” platform for future carrier networks at horizon 2020 and beyond.

Furthermore, most of the intelligence is expected to be placed and orchestrated at the edge of the network, i.e. in the aggregation, access segments up to the End Users premises [8,12,13]. Moreover, in the

last mile an enormous quantity of processing and storage capability will be accumulated, thus ensuring better levels of QoS. Virtualized network functions, services and related states will be optimally located around the prosumer (machine or human being). This will make it possible to efficiently deliver the expected experience and meet the target performance: 1000x higher wireless area capacity, 10Gb/s link speed for true immersive experience, hyper connectivity to 100B of things and, especially 5x lower E2E latency than 4G (1ms is the target for tactile Internet) and 90% energy saving per provided service [4]. The network services and service capabilities [14], as well as Access and Non Access Strata [15], will substantially evolve for providing delay-critical and ultra-reliable, secure, privacy preserving, and dependable services, such as full immersive (three dimensional) experience and vehicle to vehicle communications. The concept of bearer service – set of quality/capability parameters, currently defining the “virtual pipe” between service application entities in mobile terminal and related peers in the gateway to external packet data networks (PDN-GW) – will be replaced by a new concept denoted for the first time in this paper as neural bearer or, simply, bearer graph, which enables multidimensional carrier grade communication paths, well beyond the scope of the current bidirectional communication chain [14-17], as depicted in Figure 1. New technologies for establishing, maintaining and reconfiguring the bearer graph connecting multiple cognitive mobile objects, forming ephemeral networks (with and w/o network assistance), as illustrated in Figure 4, will allow operators to meet and exceed the performance targets, especially in terms of latency and speed, which are at present unachievable implementing today’s and upcoming 3GPP mobile services [14] and SDN solutions, being limited to the transport network layer of the infrastructure [12,18].

The proposed concept for connecting a cognitive robot is illustrated in Figure 5, in alignment with the scenario of Figure 4. The robot, as all other relevant cognitive objects, is expected to be handled as a new device type with own capabilities. Control entities for establishing, maintaining and reconfiguring the new bearer service, in dual mode



mobility, are distributed in the network, as well as in other vehicles around the robot in question, i.e. at the edge. In this case, the head of the robot is connected to a car, a device and to three peer entities in the network, including the Internet. The vehicle (robot) to X (V2X) networking, denoting X any other fixed or mobile element, consists of a local, opportunistic, and multi-hop communication with direct connections among objects, whenever beneficial and possible. The proposed concept goes well beyond the current 3GPP Device-to-Device (D2D) proximity services, limited to a single-hop and typically relying on assistance from the network infrastructure, and the well known ad hoc networks (MANET), based on multi-hop routing with limited network performance [16]. The "neural bearer" may enable several carrier grade communications, i.e. layer 1-7 links, simultaneously, through different radio interfaces with the availability of multiple transceivers, which is currently not possible in D2D, especially due to low battery consumption and hardware integration constraints.

As depicted in Figure 5, the protocols of the new non-access stratum enable entities located in the different connected nodes to exchange information, knowledge and any kind of service among them. In this sense, the notion of "bearer graph" defines capabilities beyond what is currently possible with "relay control" in "in-coverage" or "out-of-coverage" mode [16]. As shown in Figure 5, the service applications may run on each of the connected nodes and exchange services among themselves in a secure, reliable, dependable and low latency manner, not limited to the bidirectional communication chain "Client-Server".

Several issues need to be carefully studied, in order to support a carrier grade V2X in 5G. First of all, we need to define and evaluate techniques to make the vehicles capable of V2X discovery and communication, as well as techniques to manage the V2X links, especially in the case of mutual mobility, where more nodes move at the same time. Furthermore, we need to evaluate the impact of the new services, and service capabilities, on functional and non-functional metrics, such as: battery lives, existing operators' communication services, and carrier resources (e.g., amount of resources used by the

V2X discovery, selection and registration), under the assumption of massive adoption of cloud computing, software networks and network functions and services virtualization, which will make most of this possible.

The socio-economic and business implications of this vision are enormous. Today the main "control variables" of our "complex" economy are still human intelligence, attention, efforts and time: humans are still the most productive part of the current economy. As a matter of fact, we are witnessing the migration of industries to regions where labor costs are much lower. This vision will help us create a pervasive "machine intelligence" capable of reshaping this economy equation by taking over a lot of cognitive tasks that humans can do and improving quality of lives. Organizations should focus on harnessing and leveraging 5G technologies around machine intelligence, big data and connected vehicles and simultaneously create new and different jobs. We believe the advanced 5G infrastructure to be the most important catalyst of the Second Machine Age [19]: 5G will power intelligent Machines to "flood the landscape of jobs". There will be a number of socio-economic benefits: reduction of human efforts in jobs subject to computerization and robotization, aiming at: bringing down operating costs with much higher product quality, worker safety and improved operational conditions; increasing local production; reducing long distance transportation, and "optimizing" many socio-economic processes. As a result, human labor costs will no longer drive investments and the number of jobs created will be far greater than the numbers lost due to automation [20]. The network will be transformed from a sterile pipe to the nervous system of the Digital Society, and Network Operators, leveraging their edge assets, will have a chance of playing new business models, and be in a much stronger position in the value chain, e.g., opposed to the OTT, which will remain confined to the "Client-Server" model [21].

Last, but not least, in order to rapidly profit from 5G, first the environment around cognitive mobile objects needs to evolve to host them. For instance, a robot does not need to recognize that in front of

resource requests to embedding of links, memory, storage and computational capacity, to optimization of locations of network functions and corresponding states across virtual machines. Practically, it takes care of different steps involved in the provisioning of virtual functions and service, such as: creating, moving and shutting down virtual machines (VMs) in the virtual distributed infrastructure, as well as installing, configuring, monitoring, running and stopping software in the VMs [25]. It is located in the Cloud.

The control of multi-hop paths may be based on tables, following the <Match, Action> principle, analogue to Software Defined Networking (SDN) using OpenFlow [12]. The translation function may be performed at the edge: tell me what you want, not how to do that, which can be done later in a proactive or reactive manner. For example, in the case of mobility, handover decisions are pushed down to lower level controllers and at the same time the associated route between the moving entities is updated. Here, routing and location tracking update may be reactive or proactive, depending on the desired grade of service. When reactive, the controller establishes a new route for the flow only after a handover is completed. In the proactive mode, routing decisions may be formulated a priori using intelligent algorithms, which may take into account the history of the journey, context information, and long-term mobility behaviors at that network edge. The internal packet forwarding may be optimized through the orchestration function. The three levels of controllers present interfaces to the outer world for any type of application.

In order to achieve the expected capacity, reliability, latency and improvements in energy consumption, the proposed logical architecture may run over a converged optical-wireless infrastructure for network backhauling and fronthauling, flexible spectrum usage and with the possibility of running the modulated and digital radio signals over fibers. Another approach would be to introduce an Active Remote Node (ARN), between the wireless access points and core network, that bypasses the metropolitan area network through adaptive ultra-long reach links, as proposed in [26].

In general, the core network will be characterized by an optical core interconnecting multiple edge networks (wired and wireless) supporting any sort of services by exploiting local processing and storage resources. Virtualization of resources allows the coexistence of several logical architectures, dynamically self-adapting for fitting business demands and operational objectives on the same physical core infrastructure.

Now, let's elaborate briefly on how this architecture would support the necessary capabilities of a Machine in the case of “Robot-as-a-Service”. The main problem is how to design the decision-making processes in the robot, i.e. the “brain”, which is actually an issue for any intelligent Machine providing any service. Complex and articulated tasks cannot be performed locally using the processing power of the robot, as it would immediately run out of battery. It will be necessary to complement the local processing power with computing and storage capabilities of Data Centers, where, by the way, big data (e.g., captured by sensors) are stored and then analyzed to infer decisions to local actuators. Therefore, we can immediately realize that a key requirement will be that the network latency, in interconnecting the local robot to the Data Center, should be extremely low, especially for motion control, beyond computer vision, as the network connection needs to respond with very short latency (order of units of ms) for the robot, or in general the intelligent Vehicle, to react in time! The “brain”

of the robot could be modeled using three different levels of reactive intelligence:

- **Automatic reactions:** fast and pre-defined actions for specific local contexts; these reactions could be designed and implemented, for example, by means of simple rules <Match, Action> deployed into local processing units.
- **Autonomic reactions:** actions cascaded by data analytics systems and methods, which imply the elaboration of a large amount of local information. These reactions may be enforced via unsupervised learning capabilities. These intelligent tasks will be performed at the Edge Data Centers.
- **Orchestrated behavior:** actions mainly based on data analytics systems and methods and with the elaboration of very huge amount of data, coming from different local contexts. These capabilities reside also in the Cloud.

In this example the three level of intelligence of a robot are perfectly matching with the three levels of control (Device, Edge and Orchestrator) previously described. Hence, the network will become the de facto “nervous system” of the distributed intelligence of the Second Machine Age.

In this evolution, software will be the true challenge. Future 5G infrastructures will rely more and more on software, which will accelerate the pace of innovation, as in computing and storage domains, and it will dramatically reduce costs. This trend, together with the giant economic drive given by a myriad of new players entering in the market, will lead to a shift of paradigm, capable of leading investment outside of the network infrastructure boundaries and stimulate the advent of the new paradigms proposed by this vision.

Main initiatives on 5G ongoing globally

Many initiatives on 5G are currently ongoing globally and only some of them are illustrated in Figure 7. For example, in USA, the three main activities carried out on 5G are: Intel Strategic Research Alliance (ISRA), 4G Americas and NYU Wireless Research Center. In China, it is ongoing the MOST 863 Research Program (Chinese: 863计划) and IMT-2020 (5G) Promotion Group. In Japan, the 2020 and Beyond Ad-Hoc Group is under the ARIB's advance wireless communications study committee. In Korea, the main activity is the 5G Forum. The most important initiatives in EU are the 5G Private Public Partnership (5G PPP) and the 5G Innovation Centre (5G IC), at the University of Surrey, in UK.

The 5G PPP is within the EU Horizon 2020 – The EU Framework Programme for Research and Innovation – under one of the most important EU Industrial Leadership challenges: ICT-14 Advanced 5G Network Infrastructure [27]. Within this research and innovation framework, the European Commission (EC), under the approval of the European Parliament (EP), has already committed 700M€ of Public funds over 6 years (2015-2021). From two to ten times higher is expected to be the investment from Private Party: Industry, SME, and Research Institutes [27].

As depicted in Figure 8, most of efforts are currently being placed on research work; after that, intensive standardization activities, field tests and large scale trials will take place to accelerate industrial pre-adoption; commercial products will be likely available in the market around 2020 and beyond [10]. These approximate milestones apply to infrastructures and devices for human and, in particular, machine type of traffic (MTC).

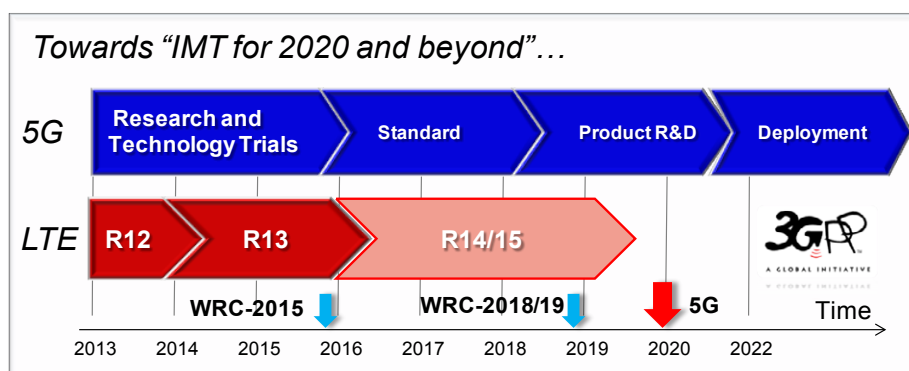
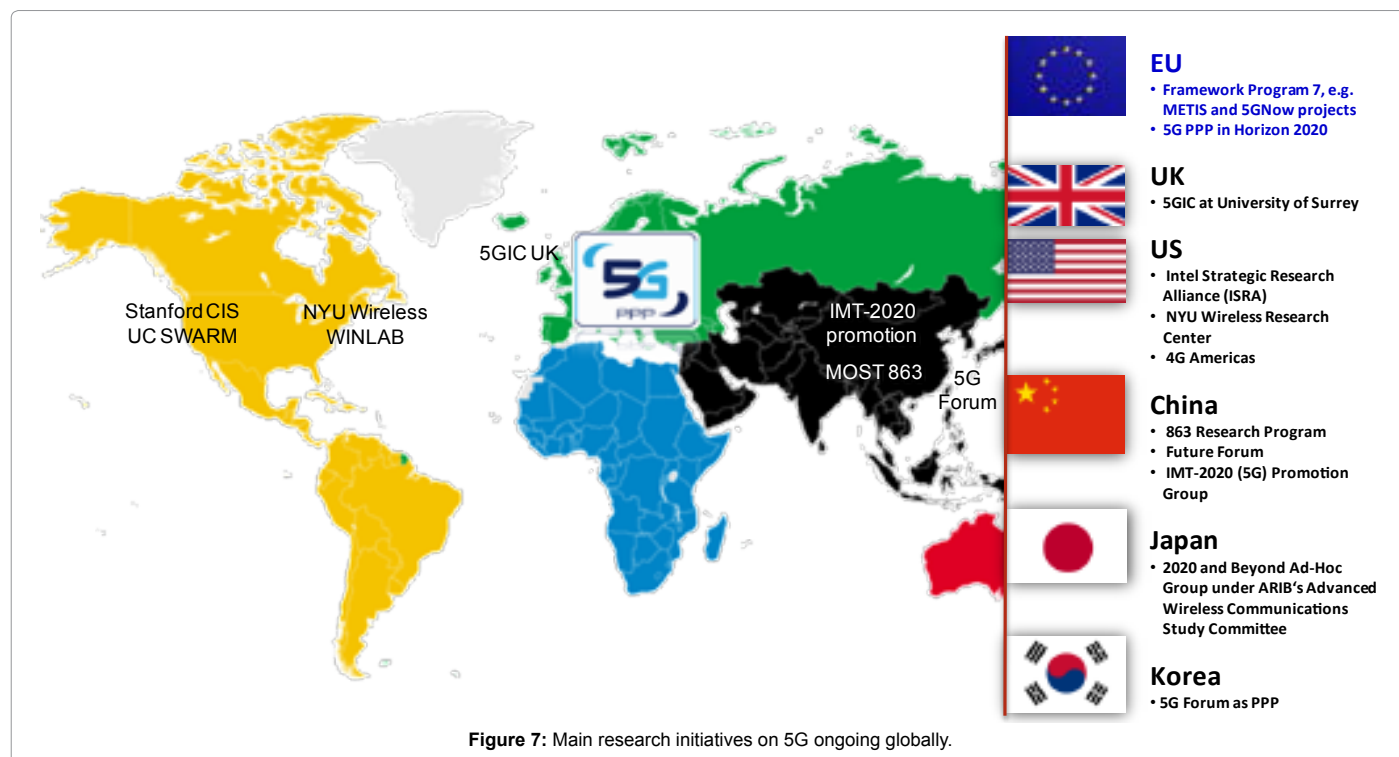


Figure 8: High level roadmap towards the IMT for 2020 and beyond.

A Scenario for Europe

In summary, the previous sections argued that ultra-high bandwidth connectivity, together with a high performance and low cost hardware (processing and storage power), has determined the ongoing “IT-zation or Softwarization” of Telecom industry. Software will be the true challenge, especially for mission critical machine communications. It is of course intended that future networks, relying more and more on software, will accelerate the pace of innovation, similarly to what has been happening in the computing and storage domains, and reduce costs, while maintaining, or even improving, Carriers class levels of performance. Technology is going to become basically world-wide accessible to all enterprises on an equal basis, in any part of the world, reducing most of today’s competitive advantages of hardware. This will reduce the thresholds for new Players to enter the market, leading to a shift in paradigm, where the main value propositions will be in software solutions, and the business model will be Opex-oriented.

Most likely future transport networks will become less and less

hierarchical, with a limited number of core optical nodes, inter-connecting metropolitan areas via fibers. In turn, these areas, at the edge, are going to be densely populated by thousands of small aggregation nodes (with processing and storage capabilities) and by an incredible number of devices, machines, assembling around Users. The number of devices connected to the network is growing exponentially. Today, every smart phone integrates already several sensors and by the end of this decade there will be more than hundred sensors in each device, dramatically increasing the number of connections. Still, by far, Operators tend to keep a distinction between the “network” and what connects to it: the mobile terminal. This distinction will gradually fade away, as more and more tasks are being performed either in the network or/and in terminals. As illustrated in Figure 4, at the edges dynamic (ephemeral) virtual networks will be created out of a variety of aggregation nodes, devices, drones, robots, etc. These elements need to be considered as an integral part of the infrastructure. In other words, such an enormous number of nodes and elements aggregated in an application-driven way will be the “Edge Fabric” enabling the shift

from the Client-Server paradigm to the new services paradigms, such as "Full Immersive Experience", enriched by "Context Information", and "Anything as a Service".

In particular, the "Edge Fabric" will be controlled by few hierarchical entities (Edge Controllers) and actuated locally, as a result of decisions made by autonomous entities (Device Controllers). For example, an Edge Controller could be instantiated in a mini Data Center, located in a kiosk, and the ambient around the kiosk could be defined by consistent surroundings of dynamic collections of devices creating locally a well-defined context. All these consistent surroundings of devices are interconnected through the advanced 5G network (i.e., via optical/radio communication pipes) forming a much larger, and sometimes overlapping new ambient, like a smart city, a campus, a network of malls or schools. This transformation will present a number of business implications with some risks and plenty of opportunities (disruptions) for the incumbent industry players: what if this transition will accelerate and technology disruption adopted widely?

As an example, let's imagine a scenario where in each European Member State (MS) there are two, or more, Software-Defined Operators (SDO) leasing hardware resources from two, or more, Infrastructure Providers (IP). The operators will own virtual networks and services in software platforms, i.e., network services and functions (from Layer 2 to Layer 7) fully developed, implemented and operated in software, executed in data centers. Infrastructure Providers will own and make available to SDOs basic radiating elements, fibers and raw hardware, i.e. the Layer 0-1 of the networks.

As a result, under this assumption, the Software-Defined Operators will undeniably observe dramatic cost reductions (e.g. 40%-50% savings in energy), improve efficiency in overall operations and reduce substantially the time-to-market when deploying new services.

In this scenario, let's now picture what would happen if SDOs provided "Anything as a Service" to all European Citizens, within a Single Digital Market, through any terminal, device, machine, smart thing, robot or drone... or whatever they have connected at the edge by means of ultra-fast low cost access: This would create several industrial opportunities and new fast growing socio-economic developments in Europe. This would be about an unparalleled industry transformation: not only the big incumbent Players, but also SME and Citizens would be positively affected and all society would have the chance of benefiting from the new technological landscape. Citizens would see improving their quality of lives and there would be plenty of opportunities for SMEs, for example, looking at, but not limited to, a concrete development of smart cities, villages, houses, etc., with a massive adoption of services and applications using intelligent machines to cope with most of our current and future societal challenges, such as ageing citizens' needs, food, water, energy, pollution, etc., or for the "digitization" of Europe's cultural heritage.

Conclusion

In this paper, we painted a vision of the advanced 5G infrastructure. It was argued that the ubiquitous ultra-broadband network will become the "Nervous System" of the Digital Society and Digital Economy. In fact, the adoption of new service models enabled by 5G, such as "Full Immersive Experience", enriched by "Context Information", and "Anything as a Service" will truly contribute to an inclusive and sustainable economical growth and help cope with the grand challenges of our Society systemically.

Low latency and ultra-high reliability are the most stringent performance indicators to support a pervasive "machine intelligence"

capable of offloading humans from many tasks and, especially, improving our life considerably. "IT-zation" will be at the very center of this techno-economic evolution (or, better, revolution). This will have a considerable socio-economic impact from a number of intertwined perspectives. In fact, socio-economic variables of the Digital Society and Digital Economy will be interconnected systemically.

The competition will move from HW to SW, from CAPEX to OPEX-based mode. This will change the current value chains and business models. Socio-economic impact will concern also the need of creating new skills (merging IT and Telco KH) and new jobs – even for those who are susceptible of IT-zation: the risk of unemployment will be definitely mitigated by the development of new ecosystems.

Eventually, due to this evolution, several economists, as well as technologists, have started wondering whether the usual representation of relationships between a myriad of players in a certain area can still be modelled on the bases of value chains or value networks. There is a growing consensus that value chains modelling needs to be complemented by a broader view that takes into account the whole business ecosystem.

Cooperation among stakeholders (Automotive, Robotics, Vendors, Carriers and related Suppliers) is indisputably required to successfully introduce the new 5G enabling technologies, and current regulation frameworks need to evolve in order to support this new "complex" market and make it sustainable to realize this long-term vision.

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Ultimately, we would like to state clearly that the views expressed herein are solely those of the authors and do not necessarily represent the ones of their affiliates.

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