5G PPP

Supported by the European Commission

5G empowering vertical industries

5G VERTICAL SECTORS

With 5G, networks will be transformed into intelligent orchestration platforms.

By cementing strong relationships between vendors, operators and verticals, 5G will open the field to new business value propositions.

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.

EXECUTIVE SUMMARY

Europe is faced with economic and societal challenges such as ageing of populations, societal cohesion, sustainable development. The introduction of digital technologies in economic and societal processes is key to address these challenges. 5G network infrastructures will be a key asset to support this societal transformation, leading to the fourth industrial revolution impacting multiple sectors. In the next decade, it is expected that the manufacturing industry will evolve towards a distributed organisation of production, with connected goods, low energy processes, collaborative robots, integrated manufacturing and logistics. These concepts are notably embodied under the Industry 4.0 paradigm. The automotive and transportation sector will bring to market autonomous and cooperative vehicles by 2020 with significantly improved safety and security standards, as well as new multimodal transportation solutions. Due to the ongoing development of renewables, the traditional power grid will evolve into a smart grid, supporting a much more distributed generation and storage of power with real time dynamic routing of electricity flows using smart meters in houses. Entertainment and digital media sectors are working on the integration of broadcast TV and digital media, including an ever increasing amount of user generated content, high quality media and innovative real time interfaces such as haptics. E-health and M-health will optimise new, revolutionary concepts such as European "Personalised or Individualised Healthcare" and the transition from hospital and specialist centred care models towards distributed patient centred models.

As a result of these transformations, vertical industries will have enhanced technical capacity available to trigger the development of new products and services. Identifying key vertical sectors' requirements, anticipating relevant trends early and mapping them into the 5G design is a fundamental element for the 5G success. Therefore a close collaboration of vertical industries and 5G infrastructure providers will be mutually beneficial.

This paper presents innovative digital use cases from most important vertical sectors in Europe, namely: Factories of The Future, Automotive, Health, Energy and Media & Entertainment, and how their requirements impact 5G design. An inclusive analysis of the corresponding requirements shows that *latency* (below 5ms), *reliability* and *density* (up to 100 devices/m^2), along with tight constraints on territory and/or population coverage, are the most important performance targets 5G needs to achieve for supporting all possible services of the five investigated sectors.

Moreover, with universal availability of instantaneous communications, high level of guaranteed QoS, and cost levels appropriate for meeting customers' expectations, 5G will pave the way for new business opportunities. With 5G, networks will be transformed into intelligent orchestration platforms. By cementing strong relationships between vendors, operators and verticals, 5G will open the field to new business value propositions. Cross vertical collaboration fostered by 5G will benefit Small and Medium Enterprises' (SMEs) engagement and entrepreneurs. However, these opportunities depend on our ability to leverage 5G over previous investments and on a regulatory framework that incentivizes the deployment of 5G for Europe and will enable innovative services. Such services will be enabled by 5G networks which will ensure quality, security and safety. Deploying 5G for vertical sectors in Europe by the earliest date currently contemplated by the industry (2020) should thus be a common framing objective.

5G architecture is expected to accommodate a wide range of use cases with advanced requirements, especially in terms of latency, resilience, coverage, and bandwidth. Thus, another major challenge is to provide end-to-end network and cloud infrastructure slices over the same physical infrastructure in order to fulfil vertical-specific requirements as well as mobile broadband services in parallel.

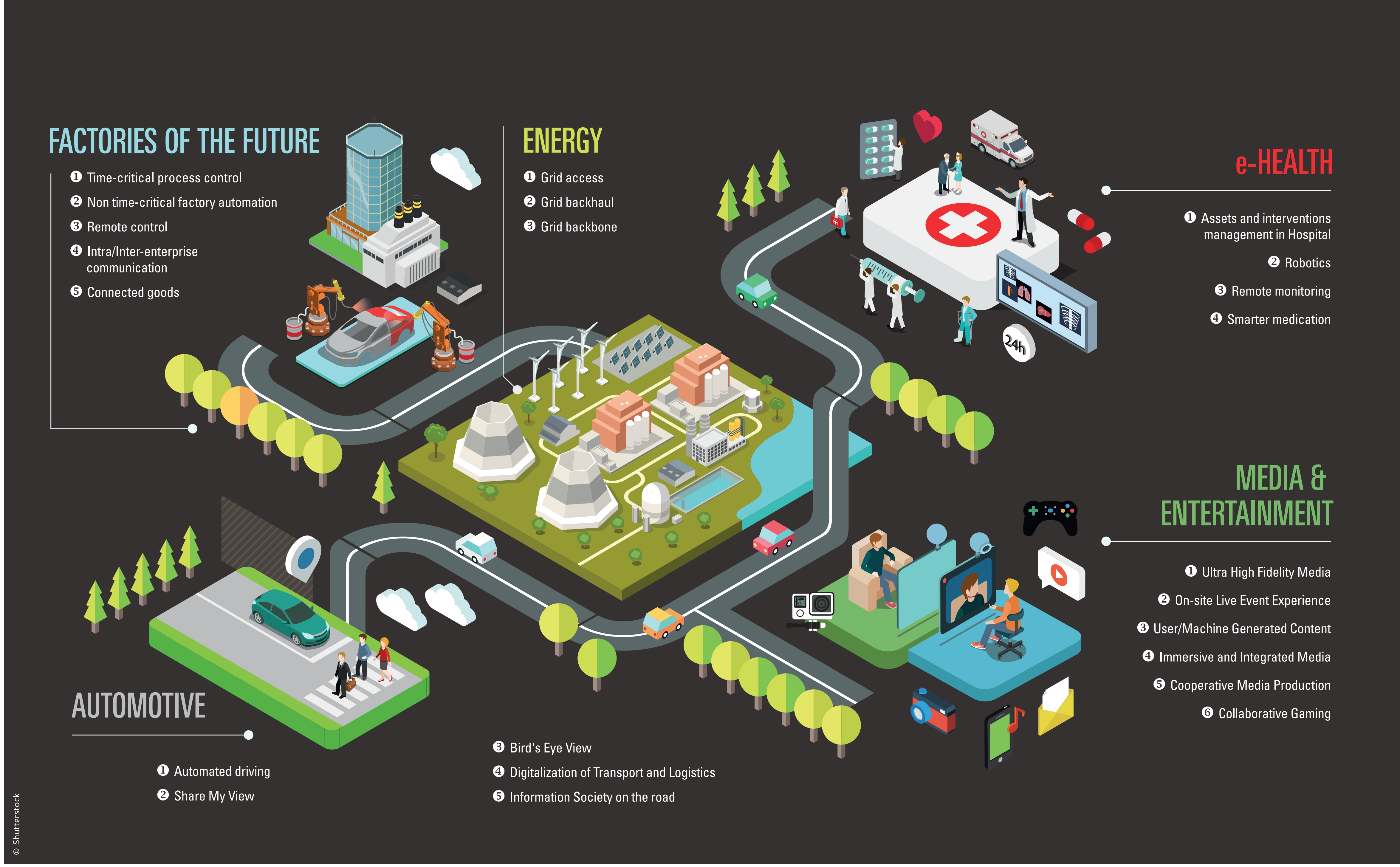
The 5G standardisation framework will be defined in 2016. Use-cases originating from verticals should be considered as drivers of 5G requirements from the onset with high priority and covered in the early phases of the standardisation process. 5G will also integrate different enabling technologies (e.g. 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. ■

5G - A DRIVER FOR INDUSTRIAL AND SOCIETAL CHANGES

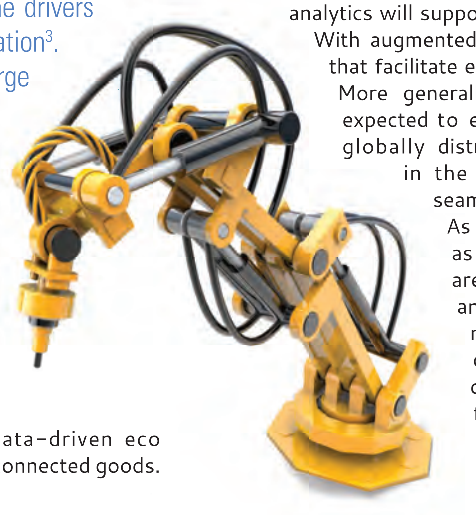
1

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 data[1] 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 share[2].

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 innovation[3]. Unanticipated 5G features are likely to emerge from future technological, legal, societal and socio-economic considerations.



FACTORY OF THE FUTURE



The digitization of factories will be a key stake for the 2020s. New scenarios are emerging, that aim at increasing the efficiency of production lines inside the factory, based on the collaborative functions of a new generation of robots. Manufacturers are evolving to data-driven eco systems by exploiting product lifecycle data from connected goods. Energy efficient communication schemes as well as scalable data analytics will support these diverse data collection scenarios. With augmented reality, new remote services are arising that facilitate effective knowledge sharing in the factory. More generally, future connectivity solutions are expected to ensure connectivity between different globally distributed production sites and new actors in the value chain (e.g. suppliers, logistics) seamlessly, in real time and in a secure way. As a conclusion, innovative strategies such as Industry 4.0 and their design principles[4] are gaining more and more acceptance and will influence present and future 5G requirements. The main use cases identified on the Factory of the Future[5] are: Time-critical process control, Non time-critical factory automation, Remote control, Intra/Inter-enterprise communication and connected goods.

AUTOMOTIVE AND MOBILITY

The vision of advanced driver assistance systems and, in an even longer perspective, complete autonomous driving cars promise not only less fatal accidents, less traffic congestions and less congested cities, but also a wide range of new business opportunities for a broad range of industries and benefits for the environment. 5G will realise this vision by improving the cooperative automatic driving in such a way that sensor information will be exchanged in real time between thousands of cars connected in the same area. As an example, cooperative collision avoidance sets the pre-requisite that communications be operational everywhere, with reliability and performance levels with higher orders of magnitude compared to today. This connectivity should be possible even in areas without network coverage, e.g., due to shadowing or other obstructions, for example thanks to relaying signals between vehicles. Most foreseen applications cannot be implemented with today's communication technologies. This is why there are high expectations on 5G. With the introduction of technologies allowing improved performances there can be a myriad of new applications. For example, one can envision tele-operated driving – where a disabled individual could be driven with the help of a remote driver in areas where highly automatic driving is not possible. This would generate a new mobility dimension for disabled people and would enhance safety for frail and elderly people during complex traffic situations.

The main use cases identified on automotive industry[5] are: Automated driving, Share My View, Bird's Eye View, Digitalization of Transport and Logistics, and Information Society on the road.

HEALTHCARE

Healthcare is accounting for 9-10% of national Gross Domestic Products in Europe, a share that is likely to grow further over the next decades. The containment of this budget is one of the biggest socio-economic challenges of our times and there are high hopes that technologies such as 5G will be instrumental to mobilise efficiency reserves such as assisted self-management capabilities and empower less qualified personnel to conduct routine tasks on the behalf of higher qualified professionals[6]. Although the spread of e-health and m-health applications could be instrumental in reducing the societal burden, the results of a recent EU public consultation and study showed that their market uptake has been sluggish and lagged far behind expectations[7]. The most recent "European green paper on m-health" revealed that although m-health is expected to potentially cut costs of healthcare by 15% and increase the effectiveness and efficiency of the delivery of care, a central obstacle to its deployment is the fact that only one third of Europeans have internet access through their mobile phones[8]. Beyond extending coverage, 5G will enable the introduction of additional services such as "Personalised Medicine" analogue to the American "Precision Medicine" initiative following a distributed, patient centric approach benefitting from the 5G modular and more distributed architecture including Software defined Networking and Network Virtualization capability, Mobile Edge Cloud Computing and Security by design. Key topics in the health domain at this point in time are the real time integration of a massive number of "things" (IoT), processing of large amount of data (Big Data), the integration of data on the fly from different sources and across different networks, and aggregation of services across different domains to support integrated care models including billing and future universal care accounts, where patients are able to take control of their care and allocate resources in accordance with their perceived needs. Progress in the area of "Personalised Care" in connection with Smart Pharmaceuticals which will be deployed by the industry over the next 5 years will support the transition of pharmaceutical companies from manufacturers to service providers, reduce pharmaceutical side effects and drug consumption thus increasing the efficiency of pharmaceutical therapies significantly.
5G has huge potential to enhance the quality of experience of surgeons using operating robots by cutting latencies and allowing the remote use of these robots from everywhere. Ultra-low latencies can also allow for real time artificial perceptions (audio, vision, haptics) and augmented reality. The main use cases identified on healthcare[5] are: Assets and interventions management in Hospital, Robotics, Remote monitoring and Smarter medication.

ENERGY

The energy industry has developed over a prolonged period (in excess of 100 years) and has evolved in many different "silos": primary fuels for power generation, transport grids, heating systems etc. Due to this legacy, the demand side has been largely separated from the supply side. With the rising cost of energy to end users and the need for secured energy supply to national economies, combined with environmental concerns, a major change in the energy system is underway. Nowhere is this more evident than in the electricity supply industry. 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). The traditional stakeholders involved in the production, delivery and coordination of these functions are also changing. From state-owned monopolies we have moved to market driven (although regulated) independent companies.
The physical infrastructure will need to support a two-way energy flow originating from the distributed energy resources, which in turn implies new needs for communication technologies, intelligence, business models and market structure. In order to manage these needs, new "Smart Grids" are required and 5G will play a fundamental role to achieve this goal.
The main use cases identified for the energy sector[5] are: Grid access, Grid backhaul and Grid backbone.

MEDIA AND ENTERTAINMENT

User habits and expectations when it comes to media consumption and production are profoundly changing. While linear TV on a stationary display (TV set), possibly supported by local caching for non-real time viewing, will continue to be a very important element, the overall Media and Entertainment (M&E) user experience is broadening and deepening rapidly. This applies to types of services (linear media, on-demand content, user and semi-professional generated content, games etc.), conditions of consumption (on the move, at home, etc.) as well as user devices (TV sets, smartphones, tablets, wearables, watches, and virtual reality devices). M&E services have to face the increasing demand in terms of data rates, number of simultaneous users connected and/or more stringent QoS requirements. High quality and high-resolution audio-visual services are the most important drivers for increased downlink data rates, whereas user generated content, including sharing of social media, is the driver for increased uplink data rates[9].
5G will seamlessly integrate different network technologies – including unicast, multicast and broadcast – and capabilities (e.g. caching) which may be needed to cover all M&E use cases. Scalability of 5G networks, with management of rapidly varying traffic conditions in dense use case scenarios, will be of critical importance for sustainable business models for network operators as well as for applications, device and service providers and hence for continued device and service innovation. 5G shall also foster the media and entertainment innovation ecosystem by opening simple Application Programming Interfaces (APIs) / toolkits / environments to adapt the network capabilities to content application needs in real time.
5G shall enable at least six main families of M&E use cases[5] in the 2020s with an overall user experience that well exceeds that of 4G and other legacy networks: Ultra High Fidelity Media, On-site Live Event Experience, User/Machine Generated Content, Immersive and Integrated Media, Cooperative Media Production and Collaborative Gaming. ■

1. Thuemmler C, Müller J, Covaci S, Magedanz T, DePanfilis S, Jell T, Gavras A (2013) Applying the Software to Data Paradigm in Next Generation e-Health Hybrid Clouds, Conference proceedings ITNG 2013, Proceedings of the 10th International Conference on Information Technology, IEEE Computing Society, ISBN 978-0-7695-4967-5
2. Neidecker-Lutz B, Jeffery K (2010), The Future of Cloud Computing, Opportunities for European Cloud Computing Beyond 2010, European Commission, Information, Society and Media.
3. Christensen CM (1997), The Innovators Dilemma, Harvard Business Review Press
4. Hermann M, Pantek T, Otto B (2015), Working Paper 01/2015 Design Principles for Industry 4.0 Scenarios: A Literature Review, Audi Stiftungslehrstuhl Supply Net Order Management, Technische Universität Dortmund, www.snom.mb.tu-dortmund.de
5. These use cases are described in details in the whitepapers on vertical industries available on 5G PPP website here: https://5g-ppp.eu/white-papers/.
6. National Information Board (2014) Personalised Health and Care 2020 – Using Data and Technology to Transform Outcomes for Patients and Citizens, HM Government
7. European Commission (2012), Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of Regions – e-Health Action Plan 2012-2020 – Innovative healthcare for the 21st Century
8. European Commission (2014) Green Paper on mobile Health (MHealth)
9. Cisco Visual Networking Index: Forecast and Methodology, 2014 – 2019, White Paper, http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.html

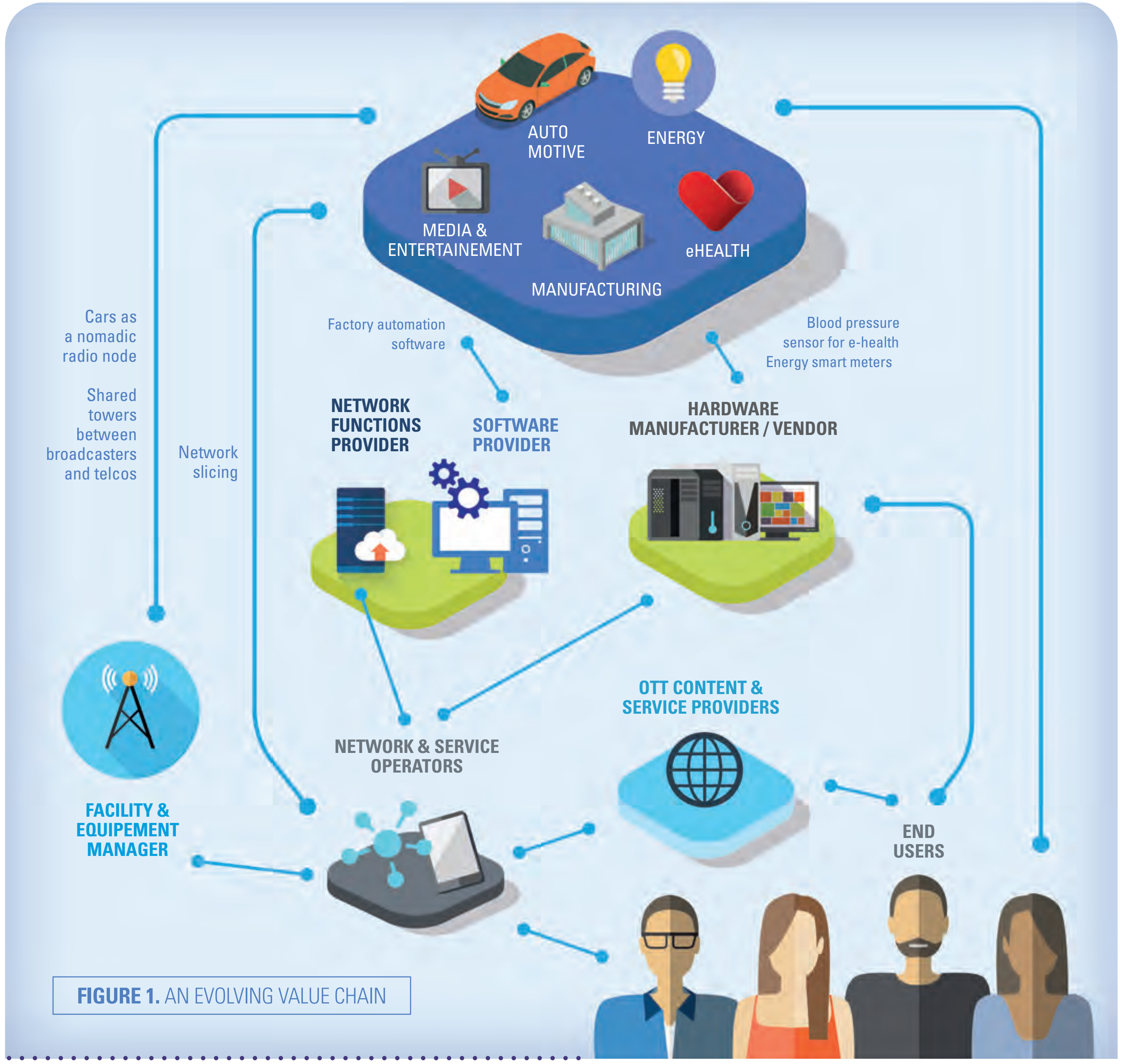


FIGURE 1. AN EVOLVING VALUE CHAIN

FOR EUROPE, 5G IS BUSINESS DRIVEN

2

As discussed in the previous chapter, the world is changing: everything becomes digital, smart, connected. These changes require new value propositions, new partnerships and business models and improved cost structures for the benefit of the whole European society and economy.

NETWORKS WILL BE TRANSFORMED INTO INTELLIGENT ORCHESTRATION PLATFORMS

Enhanced mobile broadband will be important for 5G development. 5G should help to accommodate satisfactorily the huge increase of mobile traffic (more than 15 additional ExaBytes (10^{18} bytes) per year in Europe by 2020) at a reasonable cost. Moreover, 5G will improve the mobile broadband experience in all situations: at cell borders, at stadiums, in shopping malls, on trains, airplanes, etc. Beyond that, the network should bring to the end user a seamless connectivity experience – meaning a seamless handover to the best access network – regardless of the device used. This Any Time, Any Where, Any Device paradigm will pave the way for business growth.
Key 5G opportunities however exist beyond the sole eMBB case. In 2020, Internet of Things will not be a niche market anymore. Ericsson[10] and Machina[11] estimate that there will be about 25 billion connected devices by 2020, much more than smartphones. 5G will help to scale up this business preparing the world for the next trillion connected objects by offering a global standard for low power and large coverage connectivity. Standards based solutions, like 5G, can bring economies of scale compared to proprietary solutions.

Whilst the per-bit value of IoT is rather low, the value generated by holistic orchestration and big data analytics is enormous. For example General Motors (GM) estimates that they could generate €725 revenue per car from telematics information[12]. Multi sector data hubs nurturing cross sector cooperation can create even more opportunities. By 2020, operators will have a worldwide IP infrastructure consolidated through roaming and interconnection agreements for Voice over Long Term Evolution networks. This infrastructure can be leveraged for 5G to support a global IoT control engine with unified authentication, security, billing and Service Level Agreement engines, as an umbrella layer on top of underlying heterogeneous access connectivity. In this line, 5G would transform the network infrastructure from being a mere pipe of bits to becoming a supervision and orchestration platform overlooking connectivity and data exchange.

By doing so, 5G will help to move from sensing to automating the world through real time processing and control capabilities. Firstly, mobile edge computing will provide a fluid processing environment with associated low latency. Secondly, specialised connectivity services will be available with guaranteed Quality of Service, latency and reliability for critical sectors' needs. In addition, 5G networks will bring the required trust to safely enable IoT industries for innovative services such as autonomous driving thanks to security by design principles.

Last but not least, beyond cloud computing, the "Anything or Everything as a Service" model (XaaS) will spread out in many domains: infrastructure, platforms and even network. It will enable completely new services and business models, such as for example "Data and Knowledge as a Service" thanks to on demand applications deployment at the edge of the network or even in the end user devices. This will enhance privacy and security and will enable XaaS providers to extend their offerings using "critical infrastructures".

NEW VALUE CHAINS FOR NEW BUSINESS MODELS

All sectors are now transforming into multi-polar decentralised value chains that are constantly reorganizing themselves around a multitude of players. The mobile ecosystem itself has evolved from being an environment of bilateral relationship between cellular operators and their customers, to a universe of specialised companies providing services at different positions of the value chain. The IoT offers clear illustrations that business relationships are no longer bilateral: consumers do not subscribe for a smart meter; it is rather their utility company that will choose to implement a smart meter and contract the related connectivity access on behalf of their clients. In addition, vendors play a key role in deployments of industrial IoT with long-lasting contracts with specific verticals. This will be complemented by the offerings of the operators building on their infrastructure as well as their experience in providing connectivity on a broad scale.

Virtualization will contribute to accelerate this trend. Some vertical industries will offer services on top of telco infrastructure, which is delivered in a Network as a Service (NaaS) mode. Some operators will restructure themselves in a series of connected partnering companies. The availability of resources at the network edge and the new QoS capabilities of 5G will allow vertical industries to deploy their critical applications on this shared infrastructure with the required level of security and process/data isolation. Indeed, 5G will encompass critical infrastructure intelligence. For example, trains today have their own network for signalization, which may be provided by 5G as a mission critical service.

With the advent of 5G, new actors are expected to emerge too. For example, facility managers that provide "Small Cells as a Service" will appear; it could be transportation players that carry small cells on-board of vehicles.

One of the main challenges for IoT operators is to customise product propositions; "sending bits that customers actually value"[13]. 5G will enable new ways for charging and pricing: throughput, data volume, latency, device movement, processing, storage, functions… or event based charging in real time.

10 Ericsson mobility report 11/2015; http://www.ericsson.com/res/docs/2015/mobility-report/ericsson-mobility-report-nov-2015.pdf

11 The connected life; http://www.gsma.com/connectedliving/wp-content/uploads/2013/03/JimMorrish_GSMA-Connected-Life-20130624-v4.pdf

12 DataFloq. 2014. Three use cases of how GM applies big data to become profitable again.

13 3GPP RAN workshop in Phoenix, Chris Pudney from Vodafone

14 "Guideline Life-Cycle-Management", http://www.zvei.org/en/association/publications/Pages/Guideline-Life-Cycle.aspx, ZVEI

15 See Communication COM(2015) 192 final available at http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52015DC0192&qid=1438594190467&from=EN .

> BY CEMENTING STRONG RELATIONSHIPS BETWEEN VENDORS, OPERATORS AND VERTICALS, 5G WILL OPEN THE FIELD TO NEW BUSINESS VALUE PROPOSITIONS.

5G: CEMENTING STRONG RELATIONSHIPS BETWEEN TELECOM INDUSTRY AND VERTICAL INDUSTRIES

5G will be instrumental for the digitalization of the traditional industry in its race for better productivity and competitiveness, especially if it can create synergies across verticals, lowering individual costs thanks to cost-sharing on infrastructure deployment and service operations.

As a matter of fact, while options to improve capacity - especially for media and entertainment services in dense areas – can be found thanks to Ultra Densification of Networks scenarios (an architecture which is envisioned for 5G), there are still several cost challenges like site acquisition and maintenance, energy provisioning as well as backhaul/fronthaul connectivity of antenna sites: for such issues, infrastructure sharing is a good approach to reduce infrastructure costs and redirect financial investments toward improved geographical coverage, as well as product and service innovation. This is why building a high capillarity network through third parties (e.g. diverse infrastructure owners such as city council services, broadcasting towers owners, subscribers…) in a win-win relationship could be a game changer in this field. Compared to the traditional ecosystem, 5G can create new grounds for cost sharing with innovative partnership models built on synergies between network operators and vertical industries, e.g. use of nomadic nodes carried by cars, of fibre optics deployed for connecting trains, or energy grid cabinets. Another positive side effect is that investors will be able to hedge investments into smaller opportunities and therefore diversify the telecoms investment portfolio.

5G: DESIGNED TO LEVERAGE PAST INVESTMENTS

Investment cycles of vertical industries are different compared to the telecom investment cycles: media and entertainment is typically shorter (2-3 years), automotive is somewhat equivalent (car: 7 - 8 years, Heavy Goods Vehicle: 15 - 20 years), and energy and manufacturing are longer (non-nuclear power plant: 25 years, universal machine tool: 25 years, oil & gas chemicals: 10 to 25 years)[14]. This is why, in the Netherlands, UtilityConnect has deployed its own dedicated network for smart energy grid applications rather than relying on 3G or 4G networks which were seen as too short lived. Vertical industries require the assurance that there will be a continuity of service, without unjustified price increases, for their equipment over its full life span. 5G stands as an enabler of this need because it will be designed to integrate multiple access technologies under a unified service enablement layer, ensuring backward and forward compatibility. Moreover, 5G will also endeavour to make radio access operations more flexible thanks to Cloud Radio Access Networks (C-RAN) and Software Defined communication modules in devices.

This compatibility with past infrastructure investments is very important for telecom operators – in Europe as well as in other world regions – it is essential that 5G deployment follows an evolutionary approach. Such an approach will allow for a gradual shift of infrastructure from 4G to 5G, thus allowing appropriate returns of investment from 4G deployments and upgrades but also to address operational considerations: deploying equipment over a large territory takes time and starting from a zero footprint might decrease the appeal of 5G, especially for some vertical industries that need a wider coverage in rural areas or indoor.

CROSS VERTICAL COOPERATION FOR SMES ENGAGEMENT AND ENTREPRENEURS BENEFITS

SMEs – including start-ups – play a substantial role in the vertical value chain as suppliers, service providers as well as original knowledge providers, but are often restricted by sector structures they operate in. Policies towards innovation friendly digital business ecosystems can help SMEs to break out of their traditional sector boundaries: the development of cross-sector industrial partnerships built within the framework of the 5G infrastructure may bring SMEs new opportunities for original products and services or for business development into other sectors. Combinations of 5G infrastructure capabilities, Big Data assets and the IoT development, may help them create more value, more sector knowledge, and ultimately more ground for new sector applications and services.

SMEs should benefit fully from the digitalization of the economy by promoting horizontal mobile business models. High quality standards are the best insurance for SMEs to access to the latest technology at an affordable price (avoid lock-in of dedicated solutions).

A FRAMEWORK THAT INCENTIVISES THE DEPLOYMENT OF 5G

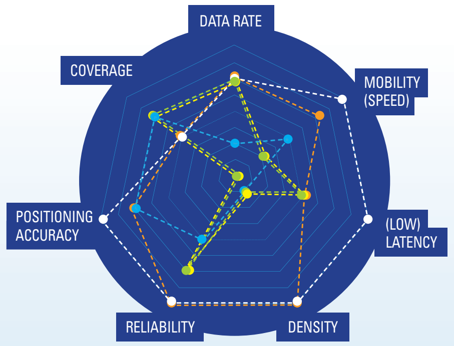
The creation of a Digital Single Market has been identified as a key priority for Europe[15]. The objective is to develop an inclusive digital economy and society across Europe, to the benefit of citizens, consumers and businesses.

Vertical sectors acknowledge the strong need for high performing and innovative communication networks and call for policies that would promote and reward such an investment. Yet, investments in networks are lower in Europe compared to other regions of the world, as a result of decreasing prices, decreasing revenues and hence, reduced profitability. The upcoming review of the telecommunications regulatory framework needs to make sure that operating a telecommunications network remains profitable enough to finance continuous network upgrades to match demand for speed and capacity at European Union scale. This point is even more important as it is the condition for the large scale deployment of 5G and the foundation for an IoT economy.

Telecommunications network operators should be allowed to invest in network capacity and improvements with the assurance that they can offer specialised services – in particular IoT services, such as Tele-care and Tele-health, smart cities and connected cars – that are based on specific commercial agreements and Quality-of-Service levels. The lead for network investment needs to be stimulated by a reviewed telecommunications regulatory framework in a way that reduces sector-specific ex-ante regulation and ensures a level playing field across market players in the digital value chain. ■

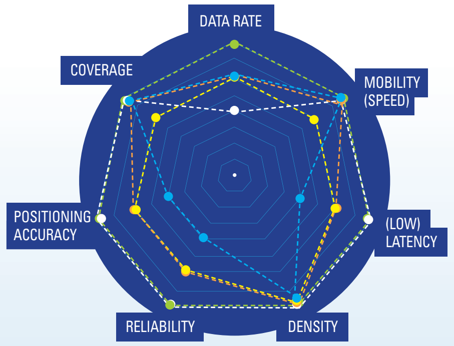
FIGURE 2: VERTICALS SECTORS' CAPABILITIES AND REQUIREMENTS SPIDERS CHARTS

FACTORIES



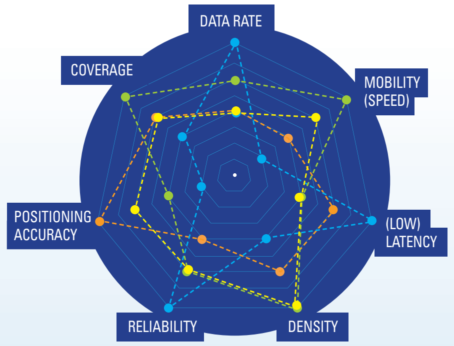
- Time-critical process control
- Non time-critical factory automation
- Remote control
- Intra/Inter-enterprise communication
- Connected goods

AUTOMOTIVE



- Automated driving
- Share my view
- Bird's eye view
- Digitalization of transport and logistics
- Information society on the road

e-HEALTH



- Assets and interventions management in Hospital
- Robotics
- Remote monitoring
- Smarter medication

3 TECHNICAL REQUIREMENTS

The following chapter reviews the target performance parameters for 5G, currently being assessed globally and discuss the key performance parameters derived from a comprehensive analysis of the use cases introduced in Chapter 1, as well as present a mapping of the most plausible vertical scenarios onto the new fundamental capabilities of 5G.

5G KEY CAPABILITIES AND KPIs

As described in the 5G Infrastructure PPP Vision (March 2015[16]), the 5G capabilities will provide ubiquitous access to a wide range of applications and services with increased resilience, continuity, and much higher resource efficiency, while protecting security and privacy. In addition, 5G will provide enormous improvements in capacity and boost user data rates. The highly demanding capabilities of 5G require an outstanding research and innovation effort to reach orders of magnitude of improvement over the current technology and infrastructure.
The following 5G targets, which are under further discussion worldwide, in bodies such as International Telecommunication Union-Radiocommunication Sector (ITU-R), 3rd Generation Partnership Project (3GPP), and Next Generation Mobile Networks (NGMN) Alliance, indicate the advances of 5G systems compared to previous generation:

- 1,000 X in mobile data volume per geographical area reaching a target of 0.75 Tb/s for a stadium.
- 1,000 X in number of connected devices reaching a density ≥ 1M terminals/km^2.
- 100 X in user data rate reaching a peak terminal data rate ≥1 Gb/s for cloud applications inside offices.
- 1/10 X in energy consumption compared to 2010 while traffic is increasing dramatically at the same time.
- 1/5 X in end-to-end latency reaching delays ≤ 5 ms.
- 1/5 X in network management Operational Expenditure (OPEX).
- 1/1,000 X in service deployment time reaching a complete deployment in ≤ 90 minutes.
- Guaranteed user data rate ≥ 50 Mb/s.
- Capable of IoT terminals ≥ 1 trillion.
- Service reliability ≥ 99.999% for specific mission critical services.
- Mobility support at speed ≥ 500 km/h for ground transportation.
- Accuracy of outdoor terminal location ≤ 1 m.

IDENTIFYING 5G VERTICAL SECTORS USE CASES AND REQUIREMENTS

There is a worldwide effort on the further characterization of 5G use cases and related requirements (e.g. ITU, 3GPP SMARTER, NGMN...). The 5G Infrastructure Public Private Partnership (PPP) is progressing on the identification of uses cases with a clear effort on verticals markets, e.g. the five white papers addressing Factories, Automotive, eHealth, Energy as well as Media and Entertainment.
Considering the 5G Infrastructure Association vertical use cases introduced in Chapter 1, the three ITU-R usage scenarios[17] (Enhanced Mobile Broadband, Ultra-reliable and Low Latency Communications and Massive Machine Type Communications and the related spider diagram capabilities), the eight NGMN use case families[18] and the four 3GPP use cases groups[19] (Enhanced Mobile Broadband (eMBB), Massive IoT (mIoT), Critical Communications (CriC) and Network Operation (NEO)) covering more than seventy distinct use cases, this section presents the 5G Infrastructure PPP vertical use cases capabilities spiders, considering the major relevant capabilities of each vertical sector.
Several ITU-like capabilities can be considered as critical parameters for the different vertical sectors:

- Data Rate: Required bit rate for the application to function correctly. It corresponds to the user experienced data rate as defined by ITU. The most demanding vertical use cases are related to Media & Entertainment with maximum values in the order of Gb/s.
- Mobility (speed): Maximum relative speed under which the specified reliability should be achieved. The most demanding vertical use cases are related to Automotive and eHealth with maximum value in the order of 500 km/h..
- E2E Latency: Maximum tolerable elapsed time from the instant a data packet is generated at the source application to the instant it is received by the destination application. If direct mode is used, this is essentially the maximum tolerable air interface latency. If infrastructure mode is used, this includes the time needed for uplink, any necessary routing in the infrastructure, and downlink. The most demanding vertical use cases are related to Factories with minimum values of 100 µs to 10 ms.
- Density (number of devices): Maximum number of devices (vehicles in the case of Automotive) per unit area that are 5G capable, although they might not all be generating traffic simultaneously for the specified application. The most demanding vertical use cases are related to Factories with up to 100/m^2.
- Reliability: Maximum tolerable packet loss rate at the application layer within the maximum tolerable end-to-end latency for that application. The most demanding vertical use cases are related to eHealth with values up to 99.99999%.
- Position Accuracy (Location): Maximum positioning error tolerated by the application. The most demanding vertical use cases are related to Automotive with minimum values in the order of 0.3 m.

In addition to these ITU-like capabilities, the Coverage capability is also assessed as critical for the different vertical sectors:

- Coverage: Area within which or population for which the application should function correctly, i.e. the specified requirements (latency, reliability and data rate) are achieved. Most of the vertical sectors have strong requirements based on geographic and/or population coverage.

The analysis of the key requirements from the different vertical sectors on this critical baseline lead to the spider charts captured in **Figure 2**. The quantification is based on the following ranking: (0) No requirement, (1) Low level of requirement or no specific constraint, (2) Medium level of requirement, which could be satisfied with existing legacy systems (3) High level of requirement, which may be at the limit or not satisfied with the existing legacy systems and (4) Very high level of requirement, corresponding to the 5G Infrastructure PPP targets and Key Performance Indicators (KPIs).
No single vertical use case requires the full set of 5G capabilities to be met at the same time. The 5G system will be relying on a dynamic and flexible function allocation and configuration and 5G networks will highly rely on software networking, virtualization and slicing techniques. It is expected that the softwarisation of infrastructure composition and usage will allow addressing various use cases from the vertical sectors, as detailed in Chapter 4.
The following additional capabilities are also assessed as key from the vertical sectors perspectives:

- Service Deployment Time: Duration required for setting up end-to-end logical network slices characterised by respective network level guarantees (such as bandwidth guarantees, End-to-End (E2E) latency, reliability...) required for supporting services of that particular vertical sector. Programmable networks and multi-tenant capability in 5G will ensure speedy deployment of services (e.g. 5G Infrastructure PPP targets 90 minutes for service deployment).
- Data Volume: Quantity of information transferred (downlink and uplink) per time interval over a dedicated area (e.g. 5G Infrastructure PPP targets a maximum of 10 Tb/s/km^2).
- Autonomy: Time duration for a component to be operational without power being supplied. It relates to battery lifetime, battery load capacity and energy efficiency.
- Security: System characteristic ensuring globally the protection of resources and encompassing several dimensions such as authentication, data confidentiality, data integrity, access control, non-repudiation...
- Identity: Characteristic to identify sources of content and recognise entities in the system.

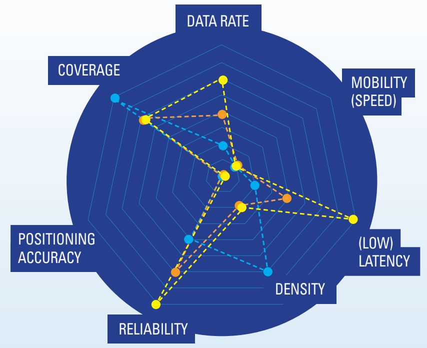
One key parameter to guarantee the fast adoption of 5G is the possibility to access low cost solutions in several use cases of the vertical sectors.

5G VERTICAL SECTORS: BEYOND TODAY'S NETWORK CAPABILITIES

Through an integration of various radio access technologies and Device-to-Device (D2D) communication, 5G is expected to provide the coverage needed to support road safety applications everywhere. Additionally, by targeting an end-to-end latency of 5 ms (down to 1 ms for direct mode) with extreme network reliability and enabling scalability of solutions by providing deterministic performances also at high load, 5G is envisioned to be a key enabler for automated driving and related critical services for which the stringent requirements could not yet met by existing technologies.
Manufacturing is one of the most demanding industry in terms of 5G networking support (mobility and wireless broadband), requiring ultra-high reliability, latencies down to 1 ms (for real time process control), and densities of more than 10 to 100 machine sensor streams per square meter. Existing legacy technologies however do not handle mobility, especially in terms of handovers. In addition, the bandwidth per object is very limited (100 b/s, < 1ko/day) and the latency is high (one full second may be needed to transmit a message), thus not allowing the deployment of real time applications. Also, due to the utilization of unlicensed bands, these technologies lack dedicated quality-of-service guarantees. ■

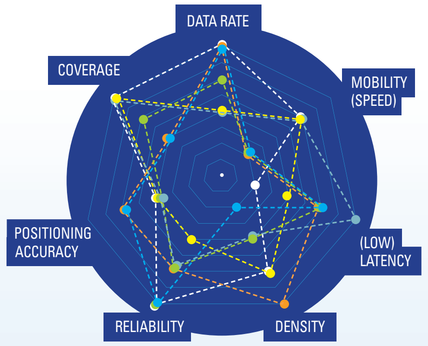
16 http://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Brochure-v1.pdf
17 http://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf
18 https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf
19 http://www.3gpp.org/ftp/Specs/archive/22_series/22.891/22891-110.zip

ENERGY



- Grid access
- Grid backhaul
- Grid backbone

MEDIA & ENTERTAINMENT



- Ultra high fidelity media
- On-site Live Event Experience
- User/Machine generated content
- Immersive and integrated media
- Cooperative media production
- Collaborative gaming

Additional Capabilities

- Service Deployment Time.
- Data Volume.
- Autonomy.
- Security.
- Identity.

4 5G ARCHITECTURE FOR DISTRIBUTED AND FLEXIBLE ALLOCATION OF VERTICAL-SPECIFIC NETWORK FUNCTIONS

It is envisioned that billions of heterogeneous devices and terminals for advanced mobile broadband services and IoT services from different verticals will be connected to the Internet. The vast amount of connected devices will generate an aggregated huge volume of data, which poses a tremendous challenge to processing and information transport.

At the processing level, 5G requires massive distributed computing and storage infrastructures in order to process all this information (e.g. temperature monitoring, distance measurement, energy consumption measurement, big data analytics, etc.). Additionally, emerging technologies such as Network Functions Virtualization (NFV), Software Defined Networking (SDN), Mobile Edge Computing (MEC), and Cloud Radio Access Network (C-RAN) require high performance computing capabilities for the deployment of network functions such as mobile Evolved Packet Core (EPC), firewalls, local cache, virtual base station, etc. Up to now such functions were typically deployed in specialised and dedicated hardware. Thus, 5G is required to dynamically allocate computing and storage resources to flexibly deploy functions in distributed cloud infrastructures wherever needed, and at the transport level, to embed the required end-to-end control and data plane connectivity between software peer entities and devices/terminals, in order to achieve the target end-to-end service performance.
The 5G architecture shall accommodate a wide range of use cases from verticals with different requirements in terms of networking (e.g., security, latency, resiliency, and bandwidth) as discussed in Chapter 3. Thus, another main challenge is to realise multiple, highly flexible, end-to-end dedicated network and cloud infrastructure slices over the same physical infrastructure, in order to fulfil vertical-specific requirements as well as mobile broadband services in parallel. **Fig. 3** depicts the proposed integrated 5G architecture to meet all the above challenges and requirements. It is composed of 5 layers, as described in the next section.

> *"5G ARCHITECTURE WILL PROVIDE MULTIPLE, HIGHLY FLEXIBLE, END-TO-END NETWORK AND CLOUD INFRASTRUCTURE SLICES OVER THE SAME PHYSICAL INFRASTRUCTURE.*

BUSINESS SERVICE LAYER

The Business Service Layer defines and implements the business processes of the verticals along specific value chains. Thus, it makes possible to support more business applications, e.g. manufacturing of a product, autonomous driving, energy production and delivery. These processes typically combine sets of vertical-specific activities. The activities can be carried out as application-related sequences of services, defined by orchestration of functions provided by the Business Function Layer. Each of the activities is characterised by application-related constraints, such as due dates, energy consumption, accuracy, quality requirements, security and safety requirements, and other KPIs. These constraints set the Quality of Service (QoS) requirements for the underlying layers. For example, different resources implementing a drilling function may offer a drilling service required for a product manufacturing activity. For a given material and a given surface roughness, only those services fulfilling the requirements can be selected.

BUSINESS FUNCTION LAYER

The Business Function Layer contains sets of application-related functions, organised in Function Repositories. Typically, they are defined according to the application requirements of the specific vertical sector. Examples include sensor and actuator functions, closed-loop control, electrical drive control, drilling, welding, HMI, distance measurement, energy consumption measurement, positioning, etc. There may be a set of vertical-independent functions, like persisting data, logging, etc.
The functions are typically defined on an abstract and implementation-independent level. They may expose a service interface to the orchestration process in the Business Service Level. Each function defines rules and policies for its invoking, operating, and its results. It also defines capabilities that can be used for matching of requirements of the Business Service Layer.
Functions can be deployed to resources, either during the production process of a resource (e.g. a sensor with a fixed distance measurement function), during the engineering phase (e.g. downloaded to an embedded device), or during operation phase (flexible deployment of functions to smart devices or to the cloud). Depending on the deployment, the capabilities are affected. Since the functions are typically deployed to a specific set of networked resources, they define the QoS requirements for the underlying communications in terms of latency, throughput, jitter, availability, security, etc.

MULTI-SERVICE CONTROL LAYER

The overall purpose of the Multi-service Control layer is to enable the creation, operation, and control of multiple dedicated communication networks running on top of a common infrastructure. Each of these networks is configured in a way that it exhibits specific functionality and capabilities addressing the requirements as defined by the respective network tenant. The Multi-service Control Layer acts as an intermediary between the vertical-centric service layers and the network-centric service layers. Efficient control frameworks allow for an abstraction of controllable resources and functions and expose uniform control APIs on different architectural levels. Northbound APIs are used by business-centric layers. In southbound direction, the layer makes use of the interfaces provided by the network-centric function layers. For the commissioning of a network service, the Multi-service Control layer performs mapping between business service requirements and network service topology and configuration. It selects appropriate service function chains, decomposes them into physical and virtual network functions, and decides on the placement of the network functions within the existing infrastructure. Subsequently, the dedicated network service can be instantiated and lifecycle management as well as runtime optimization are performed. Since the fragmentation of administrative domains considerably increases, tenant isolation management and shared function control constitute key enablers for native multi-tenancy support. They guarantee the required level of isolation and enforce QoS level according to contractual service level agreements.

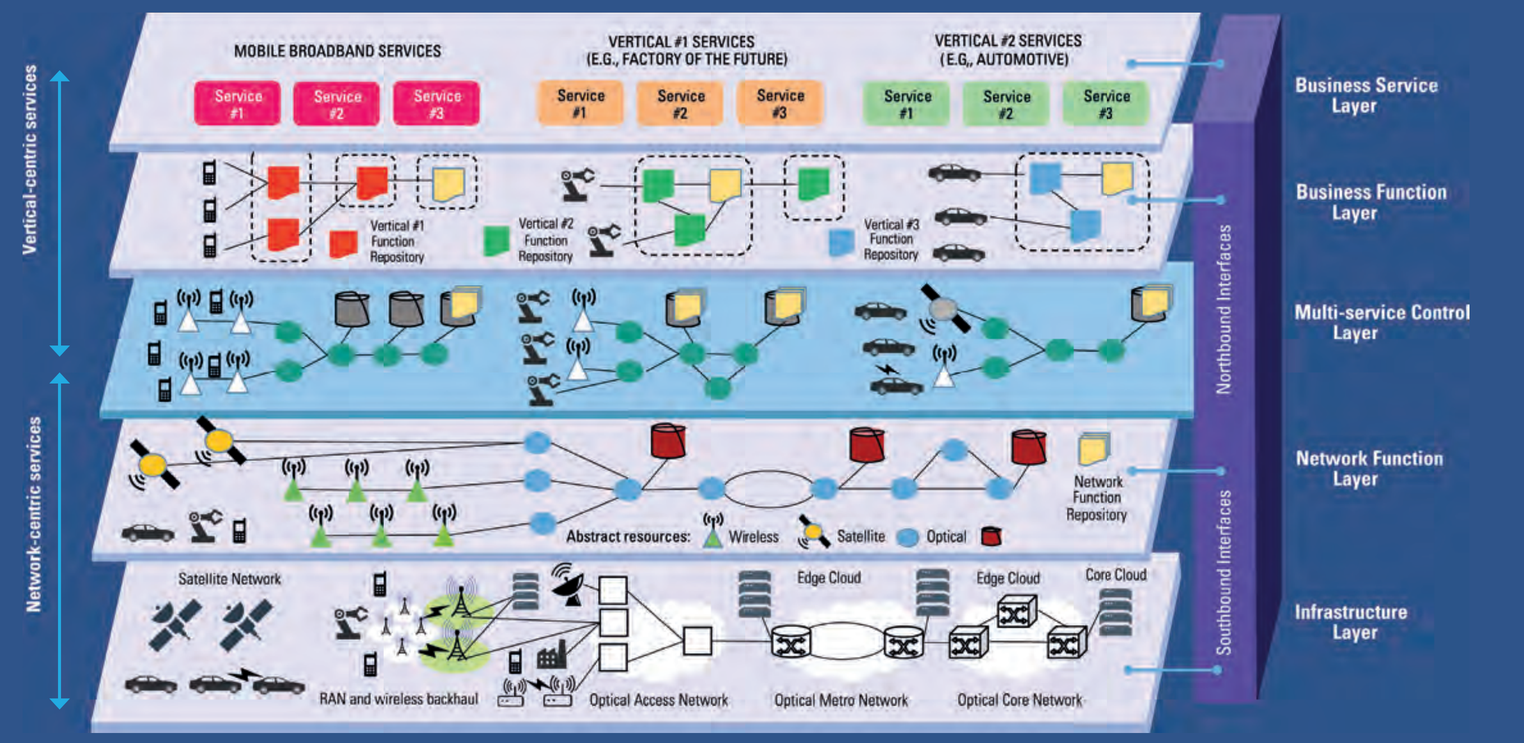
NETWORK FUNCTION LAYER

The Network Function layer implements the abstractions provided by Software Networks technologies (essentially SDN and NFV) to support an abstracted model for any 5G network function, independent of its nature (network, computational, storage) and the implied resources (optical, wireless, satellite, cloud...). Based on these abstractions, this layer allows the network functionalities to be offered as services to the users/sectors.
The core elements of this layer incorporate the management and orchestration mechanisms required to assemble the supported virtual resources running network functions and making them available to the upper layer during their lifetime.

INFRASTRUCTURE LAYER

The lowest layer of the integrated 5G architecture is the infrastructure, involving an end-to-end heterogeneous network and distributed cloud platform. This infrastructure consists of i) a data communications network spanning all network segments to provide end-to-end connectivity services, covering large scale heterogeneous access systems (cellular, fixed, satellite, Wi-Fi, personal area networks), optical/wireless backhaul/fronthaul, metro aggregation packet networks and high-capacity optical core transport networks; ii) massive distributed cloud computing and storage centres, including core data centres for high-computational capability and long-term response time, edge data centres with

FIG. 3. INTEGRATED 5G ARCHITECTURE FOR MOBILE BROADBAND AND VERTICAL SERVICES

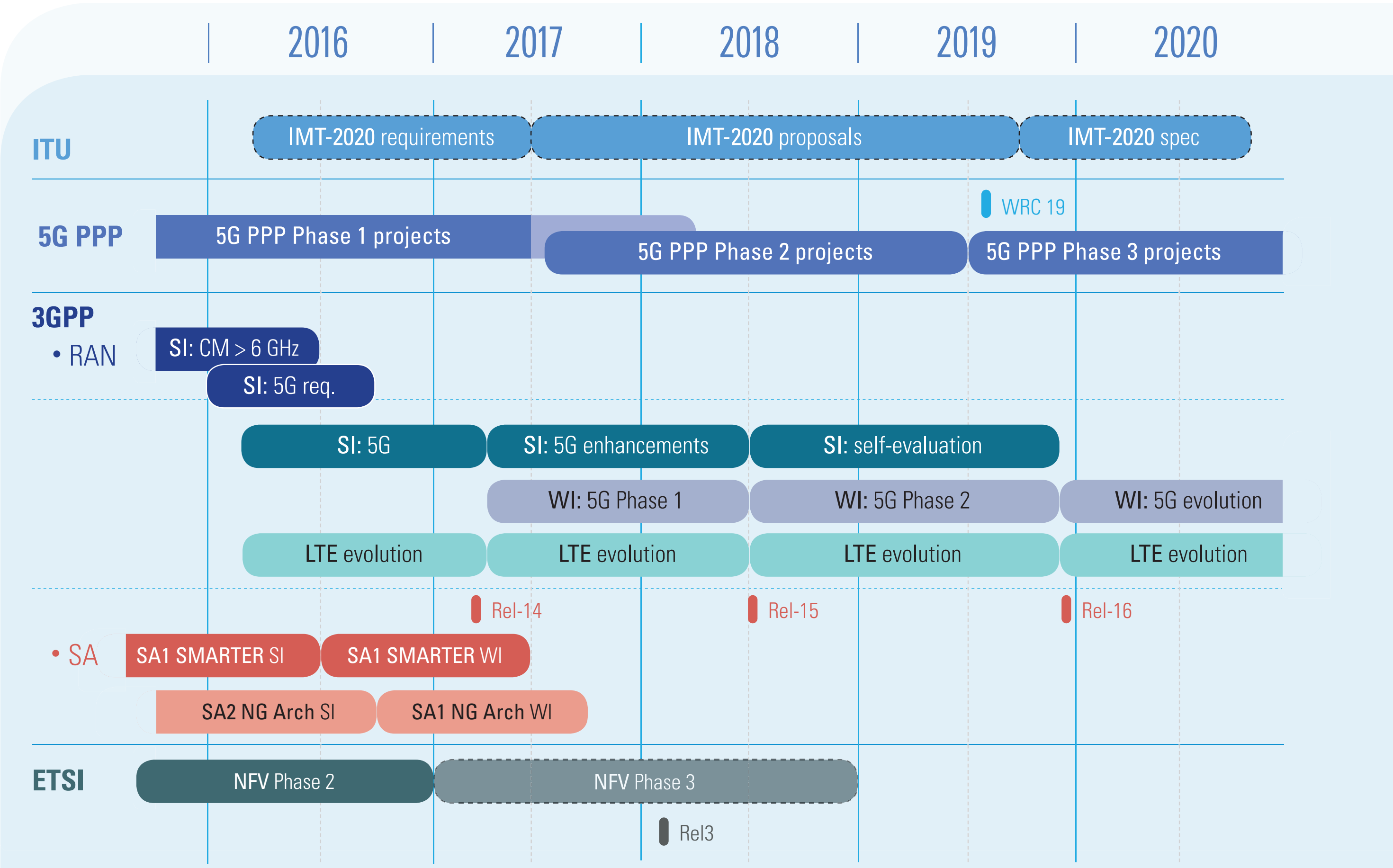


lower capabilities but fast response time, and network nodes or base stations with cloud capabilities for ultra-low latency, and iii) billions of heterogeneous smart devices and terminals for traditional mobile broadband services (e.g., smartphones, tablets, etc.), IoT services (e.g. sensors, actuators, etc.) and autonomous IoT devices (e.g. robots, cars, drones, etc.). The 5G infrastructure may belong to different infrastructure providers (mobile, cloud, transport, etc.) that interrelate in complex business relationships. It will also integrate on premise/private Information and Communication Technologies (ICT) facilities in both virtual and physical dimensions.

EXAMPLE FOR THE VERTICAL "FACTORY OF THE FUTURE"

This scenario describes the production of metal workpieces. Customer orders are processed at Enterprise Resource Planning (ERP) level. They define requirements like delivery dates, shipping details etc. At Manufacturing Operations Management (MOM) level, customer orders are combined to production orders, e.g. as production lots with due dates, material assignments (e.g. a specific alloy of metal), and quality requirements. The production process itself represents a sequence of services, e.g. for retrieving raw material from stock, transportation, processing on several machines, quality testing etc. The processing service may again be a sequence of other business services, e.g. cutting, milling, and drilling services. Each service defines requirements, e.g. for machining speed, material roughness, etc.
The business services are handled based on business functions. A drilling function assigns a set of operating data, e.g. diameter, material, quality, throughput. The capabilities of a specific drilling machine are characterised by maximum diameter, maximum drilling speed, level of roughness, etc. These capabilities need to be considered for orchestration and for deployment of the services to specific resources. Business function "drilling" itself combines activities like tool mounting, positioning, drilling at a certain speed, countersinking, or in-line quality inspection.
Each of these functions is deployed or implemented by networked resources (sensors, actuators, controllers). The requirements for the communication services of the network vary depending on the specific functions. For example, controlling the position of the drilling head requires data transfer of coordinates in milliseconds. Changing set points for position may be requested within minutes or seconds. Logging of quality data results in bulk data transfer of camera images and logs. At the same time the network needs to guarantee cyclic, low latency services with low jitter for the control loops. Since communication is more and more provided by one network instead of dedicated, specialised ones, this single network is expected to be capable of fulfilling the specific requirements of all communication relations. This calls for network slicing and flexible network operation. ■

FIGURE 4. STANDARDISATION TIME-LINE



5 NEXT STEPS IN STANDARDISATION AND SPECTRUM CONSIDERATIONS

5G BUSINESS AND POLICY DRIVERS

Standards play a key role in providing technological, economic and societal benefits. Standardised solutions provide end-users with services that are safe, reliable and of good quality. For businesses, standards create the interoperability that is necessary to save costs and provide access to global markets. When the 5G standards are in place, entirely new eco-systems are expected to emerge. In the European context, 5G networks are a key pillar to realise the wider ambitions of the Digital Single Market, see Section "A framework that incentivises the deployment of 5G", page 9.
The trend towards a digitised economy is shared globally, with multiple world-wide initiatives to develop digital automotive, health, factories, and many more. The next convergence wave is expected to target industrial and professional businesses with very specific communication requirements. 5G is the platform of choice to support this industrial and economic transformation. Global 5G Standardisation is at the heart of achieving this[20].

VERTICALS INTEGRATED FROM THE START

The integration of verticals is one of the key differentiators between 4G and 5G systems to open truly global markets for innovative digital business models. Use-cases originating from verticals have to be considered as drivers of 5G requirements from the onset with high priority and covered in the early phases of the standardisation process. The vision of 5G is driving the standards developments needed to address the entire network, including new and evolved Radio Access Technologies (RAT), new Radio Access Networks (RAN), and core network architectures based on fundamental changes to business models and eco-system.
In 5G the communication network is an inherent part of the product/service, e.g. an IoT service includes the device, network, and cloud service; e.g. for remote robot-assisted surgery or care, and the liability will then include more than just the device. This leads to a set of security, privacy, identity and liability issues that have to be addressed natively in the standardisation and regulation processes according to the "Security by Design" approach to allow widespread introduction of new 5G services.

MULTIPLE STANDARDISATION BODIES

5G will integrate different telecommunication technologies (e.g. mobile, fixed, satellite and optical), spectrum-regulatory frameworks (e.g. licensed and unlicensed) and enabling capabilities (e.g. IoT) for the benefit of vertical industries. The corresponding standards organisations should work together very closely in order to optimise the 5G capabilities. The standardisation process should be inclusive of vertical industries though each vertical industry typically has its own standard body and association. This is needed to ensure a globally applicable and consistent set of 5G mobile communication standards which can benefit all industrial sectors at large. Key standardisation bodies like ITU-R and 3GPP should thus put in place the needed communication channels with the vertical industries, preferably by key actors from the vertical industries getting directly involved in 3GPP. The 5G community and each of the vertical industries must work together towards joint cost/benefit analysis of vertical industries' requirements and how they can be best supported by 5G networks. The 5G PPP research and innovation framework should be leveraged to catalyse these partnerships.
Beyond ITU-R and 3GPP that are identified as core 5G standardisation bodies, several standardisation bodies are expected to contribute to the overall standardisation efforts. In addition to RAN and core network standardisation, also the slicing of the 5G network to serve tenants with different service requirements has to be addressed. The 5G research community has to actively contribute its requirements and findings to relevant standardisation bodies, e.g. ITU Telecommunication Standardisation Sector (ITU-T), European Telecommunications Standards Institute (ETSI), Internet Engineering Task Force (IETF), Institute of Electrical and Electronics Engineers (IEEE), Open Networking Foundation (ONF), Broadband Forum (BBF), as well as relevant open-source projects. The 5G standardisation time plan currently adopted by 3GPP, which is gradually realizing the full 5G capabilities in three consecutive releases, needs to be shared with other relevant standardisation bodies[21] and appropriate liaisons established, such that the holistic 5G perspective can be smoothly developed over the envisaged 2016-2019 time span.

SPECTRUM CONSIDERATIONS

To meet the expected growth in traffic and requirements associated with new applications, the success of 5G systems and services depends on the timely availability of spectrum bands in order to support new capabilities for which demand exists. The decisions of the World Radiocommunication Conference 2015 (WRC-15) offer opportunities for 5G systems, identifying both more spectrum below 6 GHz for IMT (mobile broadband applications) and a number of spectrum bands above 6 GHz for studies which could result in new mobile primary allocations and/or identification for the future development of IMT. Concerning bands above 6 GHz the relevant WRC-15 resolution calls for appropriate studies to be conducted and completed in time for WRC-19 to determine the spectrum needs and the appropriate sharing and compatibility conditions with the incumbent services. These bands also require in-depth analyses to assess their suitability for 5G and their potential for global availability and harmonization. Vertical use cases compatible with the use of frequency bands below 6 GHz should be considered an initial priority bearing in mind that several bands in this range have been the subject of additional harmonised allocations at WRC 15, while study work continues on bands above 24 GHz which may be identified for IMT 2020 usage around 2019. ■

[20] Digital Single Market public consultation: https://ec.europa.eu/digital-agenda/en/news/have-your-say-standards-help-achieve-digital-single-market

[21] "This includes e.g. the above-mentioned SDN-related standardisation bodies and open-source projects, as well as standardization bodies of the individual verticals.

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