6G White Paper on Validation and Trials for Verticals towards 2030's[1]

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Executive Summary

This white paper discusses the different business verticals that are expected to gain productivity enhancements with the introduction of B5G/6G wireless services. It is evident that wireless offers benefits when the use case exhibits mobility, requires nomadic behavior or flexibility and in some situation, cost may be favoring wireless solutions (e.g. retrofitting). In many cases, however, fiber optic solution is still a viable approach. Based on revenue expansion potential as well as most opportunity rich verticals, we have chosen seven vertical businesses and future software based testing to be singled out for discussion. These include industry4.0, future mobility, eHealth, energy, finance and banking, public safety and agribusiness. We describe drivers in the respective verticals and the change expected. We also highlight the features within verticals that may require 6G capabilities and make a very first attempt to provide some key performance and value indicators for vertical businesses highlighting the divergence in requirements to be experienced in the 2030's. We conclude the discussion with proposing some guidelines for trialing and validation activities within verticals to agree golden references that give a reference baseline against which any system provider can test their solutions. Out of the white paper, we have finally formulated critical research questions to be answered during this decade to provide the vertical specific solutions foreseen.

1. Introduction

The development of mobile cellular technology has been incredibly fast and immense new opportunities are arising. Where 1G/2G offered speech services, the 3G/4G brought broadband internet to our pocket. 5G/6G technological and architectural features that will shape the new access, networking, and management domains in mobile communications are promising countless opportunities for service innovation and business efficiencies, creating an unprecedented impact on multiple vertical sectors. The role of 5G/6G is to connect all feasible devices, processes as well as humans to a global information grid in a cognitive fashion. Therefore, we are only now at the brink of information revolution and new digitalization markets shall offer significant revenue expansion possibilities for those who are reacting fastest to new opportunities. 5G and beyond 5G (B5G) network technology offers numerous opportunities for various verticals, and new value chains and business models are introducing a paradigm shift for

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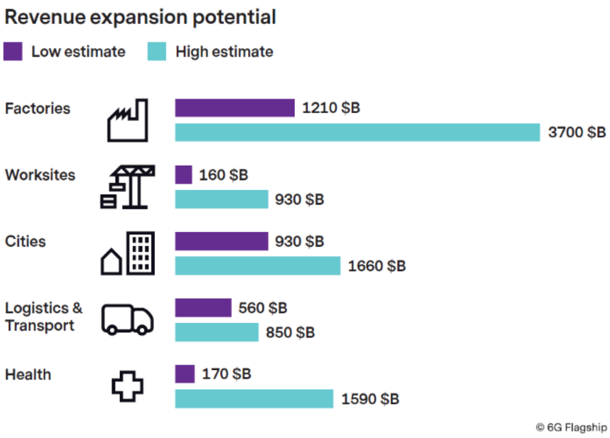


Figure 1. Market potential on verticals according to McKinsey Global Institute

the old communications service provider market transforming towards digital services. However, important efforts are still required prior making 5G a success and growth story for the industries developed around the 5G-beneficial vertical sectors. Considering also the different development cycles of each vertical, a full trolley of the potential advances and vertical transformations will continue to be deployed in the 6G era as well. This view is also supported by NTT DoCoMo [1] white paper, where they propose that whereas a new cellular generation emerges every 10 years, new value markets emerge every 20 years.

Among different verticals, new communications technology has been estimated having the highest value creation potential year 2025 in factories according to McKinsey Global Institute [2] as can be seen in the Figure 1 on left, where private 5G deployments are envisaged.

Within the vertical context, also the 5G Infrastructure Association (5G-IA), representing the private side in 5G-PPP, includes *verticals engagement* as a main objective. The 5G-PPP Vertical Engagement Task Force (VTF) was therefore established to coordinate and monitor activities related to working with vertical sectors. Specifically, it has the following objectives: 1) Enhance verticals engagement in 5G-PPP, 2) Promote relevant funding Calls within verticals industries, 3) Gather verticals feedback on 5G needs and potential barriers for adoption, and 4) Raise awareness of 5G potential. The 5G-IA has assessed [3] as in Figure 2 that the most opportunity rich verticals are smart cities, media, energy, automotive, emergency response, industry 4.0 and telecom itself.

Figure 2. The most opportunity rich verticals according to the 5G-IA

6G Vision and scope of this WP

The trend towards higher data rates continues as we go towards 2030. Partially this will be answered by the future releases of 5G standard but in 2030's it is expected that the peak data rates required start to approach Tbit/s regime indoors, which will require huge available bandwidths. Examples of such applications could be 16K video resolution in 360° with a refresh rate of 240 Hz for 'true immersion' experience or holographic displays. This will necessitate the spectrum use beyond mmW giving rise to (sub-) THz communications. On the other hand, a large portion of the verticals' data traffic will be measurement based or actuation related small data which in many cases, however, require extreme low latency as many processes are aspiring for 1000-2000 Hz control loops necessitating over the air latencies in 100 µs domain to allow time for computation and decision making as well. At the same time, the reliability requirement (which is contrary to low latency) in many industrial, automotive or health applications are expected to be of the order of $1\text{-}10^{-9}$. And to make things even more challenging, industrial devices and processes, future haptic applications as well as future multi-stream holographic applications require timing synchronization setting requirements for transmission jitter of less than microsecond. Many verticals shall also need a multitude of extremely low-cost sensors or actuators that are transmit-only or receive-only devices, which hence require grant free access as either the uplink or downlink is missing to reduce the cost [4]. In this whitepaper we shall omit the broadband services but concentrate on vertical specific use cases highlighting the massive connectivity and reliability aspects as well as the new services of localization, sensing and imaging.

2. Selected B5G/6G HW/SW and Verticals Service Roadmaps

Given the expansion potential of **factories (including worksites)**, it is a natural choice for a vertical to be assessed. Furthermore, **logistics and transport, energy** as well as **health** are among the highest beneficiaries of productivity increase with digitalization. Cities being rather vague, we are picking one vertical within, namely **banking and finance**. Further to the business verticals listed above, public safety (critical communications) has been singled out for the assessment. These verticals are also highlighted as the scope of this white paper in Figure 3.

The figure also illustrates an estimated roadmap towards 6G radio related equipment, core functionalities, IoT devices and platforms, support required for standardization and regulation as well as some enabling research themes supporting the emergence of the 6G. In the radio domain, the expectation is that some proof-of concept type of 6G (sub-) THz radios would be available around 2028. The air interface technologies and RF/spectrum issues are discussed in more detail in [9, 10, 11]. Similarly, the network core technologies develop towards zero-touch full SDNFV based core during 2023-2025 with local and even user centric micro-network support might be the target towards 2030's. The networking technologies are further discussed in [8]. In IoT device domain, energy-harvesting technologies are expected to remove the need for battery replacements and as the printed electronics technologies, mature; even biodegradable devices can be expected towards the end of the decade.

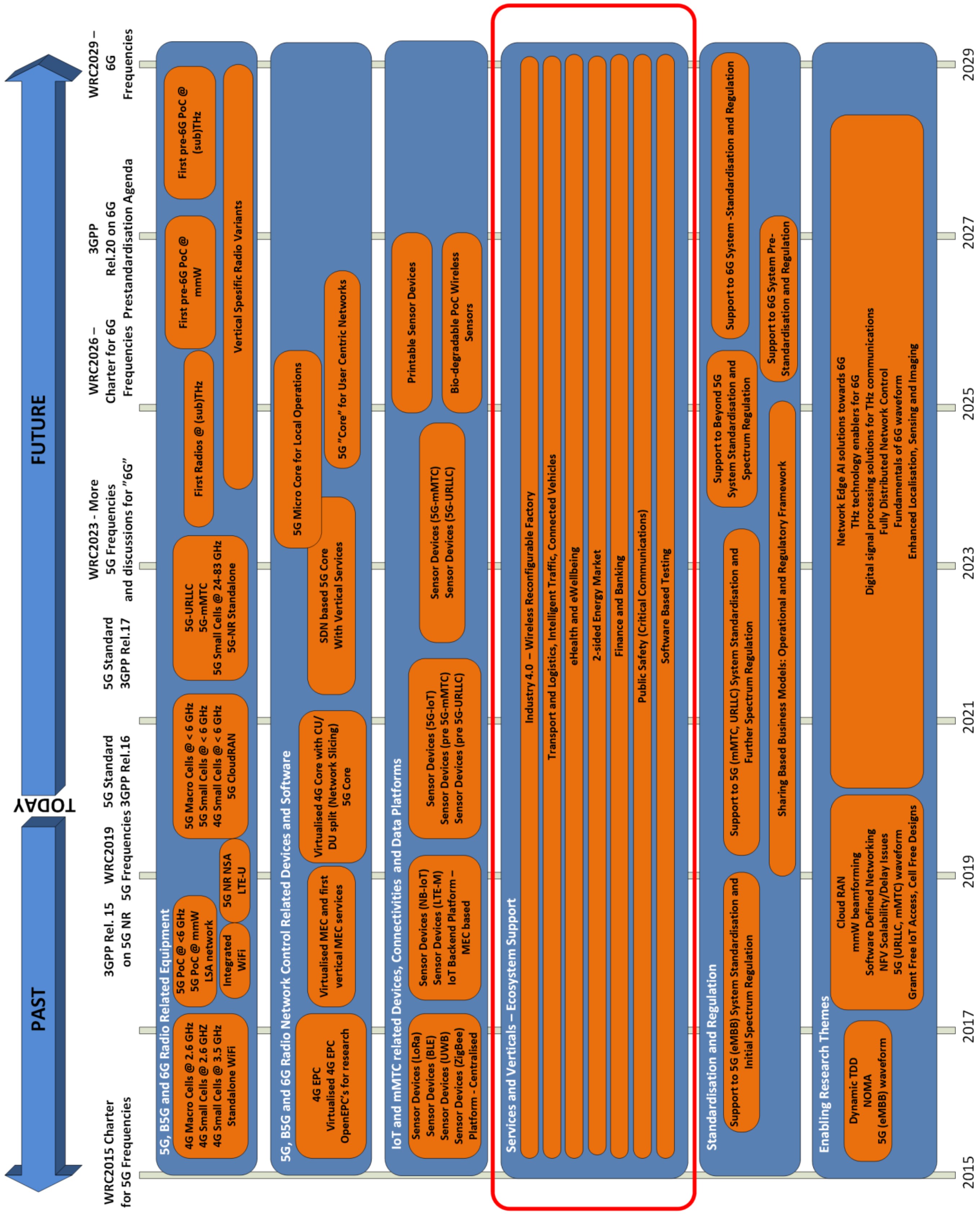


Figure 3. Estimated Roadmap towards 6G in several domains including Radio related, Network Control Related and IoT related HW/SW as well as the verticals discussed. Further roadmap on Standardization and Regulation and enabling Research Themes is offered. Red Box in the figure highlights the scope of this white paper.

2.1 Vision of Services of Industry 4.0 towards 2030

The thriving forces in manufacturing vertical will be the need to save resources (energy, water) and minimize the production of waste. The conscious consumers' indirect channeling of market demand will have a financial effect relating directly to environmental integrity, societal equity and economic prosperity of the companies. The total reconfiguration of the manufacturing sector might be necessary. Possibilities emerging through technological development enable e.g. distributed manufacturing and fabrication disrupting the current business models. The need for tools for fluent ecosystem collaboration is evident to connect supply networks, plants, devices and data. Our societies need to be able to identify, quantify, assess, and manage the flow of environmental waste while design products and processes effectively [12].

On the other hand, the increasing demand of mass customization, allowing consumers to purchase products that are customized to their specifications, sets requirements for the technologies. [13] From the supply chain point of view, this pull-type operation requires very clear transparency for material flows, customer demand, logistics and inventory. It is essential for the companies to be fast and proactive, keeping the supply and demand in balance. The process of planning, developing, sourcing, producing, shipping and selling products requires cognitive supply networks. The information from raw material suppliers, producers and logistics providers needs to be shared in real time and it must be incorporated into a company's decision-making cycle.

These changes require the convergence of multiple technologies but also change management in the companies. There will be severe strategic corporate reorganization and a significant cultural shift towards ecosystems involving increasingly open-source elements of application interfaces and standards, partially shared data repositories and models of the plants and products, and software repositories. Autonomous and independent decision-making sets requirements for company policies and workforce contracts. For some processes, no human intervention will be required anymore. On the other hand, the digital technologies will enhance the already ongoing change from blue collar to white collar. The future top skills required are critical thinking, programming and digital literacy.

The current leader manufacturers are engaged to the digital transformation and leverage connectivity, intelligence and flexible automation [14]. With the introduction of 4G/5G, the machines, devices and people are already being connected inside factories. This coupling of IoT technologies with plant automation is an ongoing effort in forerunner and early adopter factories. These plants can already improve their manufacturing processes through advanced analytics, by forming situation awareness and predicting maintenance needs measuring device specific parameters like vibration, temperature or noise levels, for example. The corporation intranets are being connected outside the firewalls to more versatile set of analytical tools. Control center operators of large global companies can monitor their factory networks remotely and identify common characteristics of success and failure of machinery, and processes with collected, historical data. Totally autonomous dark factories exist. Additionally, the cooperation of robots and humans is intensifying due to massive utilization of wirelessly connected sensors within the factory. Digital twins are being built for supply networks, plants, devices and humans. We are moving towards the circular economy, we plan to repair, reuse, refurbish, re-manufacture, and recycle materials and energy.

It can be expected that the currently not digitalized manufacturing sites will be connected within the next five years and the vertical will change in this time more than it has changed in the last 20 years. The 2020 Covid-19 situation will rush the development of remote telepresence as there are needs to limit personnel on the factory floors and educate people from distance. Remote telepresence requires advanced VR tools, computing, cognition and adaptation to human senses and physiology leading to requirements of very high-data-rate connectivity per device connectivity. Streaming all senses in real time 360 degrees calls for URLLC.

The advances listed above set requirements for the manufacturers to be able to modify their operation within the factories (**fluid production**), integrate supply networks seamlessly (**cognitive supply network/software-defined manufacturing**) and enable most efficient use of resources (**distributed manufacturing**) as depicted in Figure 4.

Fluid production: From the perspective of the factory the rise of fluid production concepts is a change in paradigm. It changes from the production centric view to a completely product centric view. So, the whole concept of production is reinvented with the goal of serving lot size 1 together with manifold nontechnical requirements that come attached with the production process as a service. One example for such a requirement could be the maximum guaranteed production time of a product. Depending on the customers need this time can be adapted, which results in the factory offering services of different value to the different customers. The foundation for this type of production as service is that the factory itself becomes highly configurable and customizable. One way to realize this is to create a Swiss tool type of production units that can easily adapt to any type of production request. This has some obvious drawbacks, so the other option is to provide mobility to the production environment. This means that platforms which carry the product to be, move through the factory and are visited by supply carriers, mobile robots, drones and of course human workers. To provide a picture, the production looks like a swarm of bees that take care of their queen, the product. There are many benefits to this type of production like optimized usage of restricted production resources, production balancing, optimized supply management and an inherent failsafe production. On the other hand, this requires solutions for new challenges which on the level of the communication system are addressable by 6G.

Basically, this means real-time control and status exchange of **thousands of collocated devices** with **latency requirements ranging from best effort to lower than 100µs**. To solve this 6G will need to provide a layered communication approach from device to device over edge communication to cloud communication. Essential to this will be **high accuracy positioning (< 1cm)** and the seamless integration of position-based services like sensors that are part of the fixed infrastructure and provide supplemental information for safe movement to the mobile agents of the factory. Obviously, the handling of this dynamic and highly complex system will rely on advanced artificial intelligence concepts (e.g. layered AI, distributed AI, explainable AI, etc.) and hardware solutions (e.g. neuromorphic hardware, DLI accelerators, AI processors, etc). The AI/ML techniques are discussed in more detail in [15]. It is essential that the factories are self-organizing are self-healing. These properties are requires also from the communication channels.

Cognitive supply network and software-defined manufacturing: The concepts of cognitive supply network and software-defined manufacturing [51], [52] highlight seamless integration of the supply networks within increasingly open software and service platforms and ecosystems, which become organized ever-more dynamically for emerging needs of manufacturing. Services and solutions will be developed in ecosystems throughout the life-cycle phases of the plants (partially plant-specific). These concepts address need for radically increasing exchange of data about the production process and product at hand throughout the supply network. As well, big data and intelligent, dynamic models and interfaces of the supply networks need to be available for parties that develop new digital services based on increasingly intelligent and reality-amending interfaces to manufacturing process-related services utilizing the data and digital twins of the manufacturing process itself (and its parts).

The adaptivity calls for high robustness and automatization. For example, intelligence embedded in digital twins increases so that the analytical results based on data reached from the field will be adjusted increasingly automatically back to the physical reality. Explosion of **big-data based, real-time analytical applications on digital twins will be enabled by 6G communication and edge intelligent capacities**. In cases, where humans still remain in the loop, ensuring their safety is critical. Through artificial intelligence, self-diagnostics and situation awareness will be enabled to produce optimal outcomes and automatic transactions throughout operations. It can be expected that the usage of AI to draw the right conclusion from the huge amount of data and the reduction of data and energy by transmitting only the relevant information.

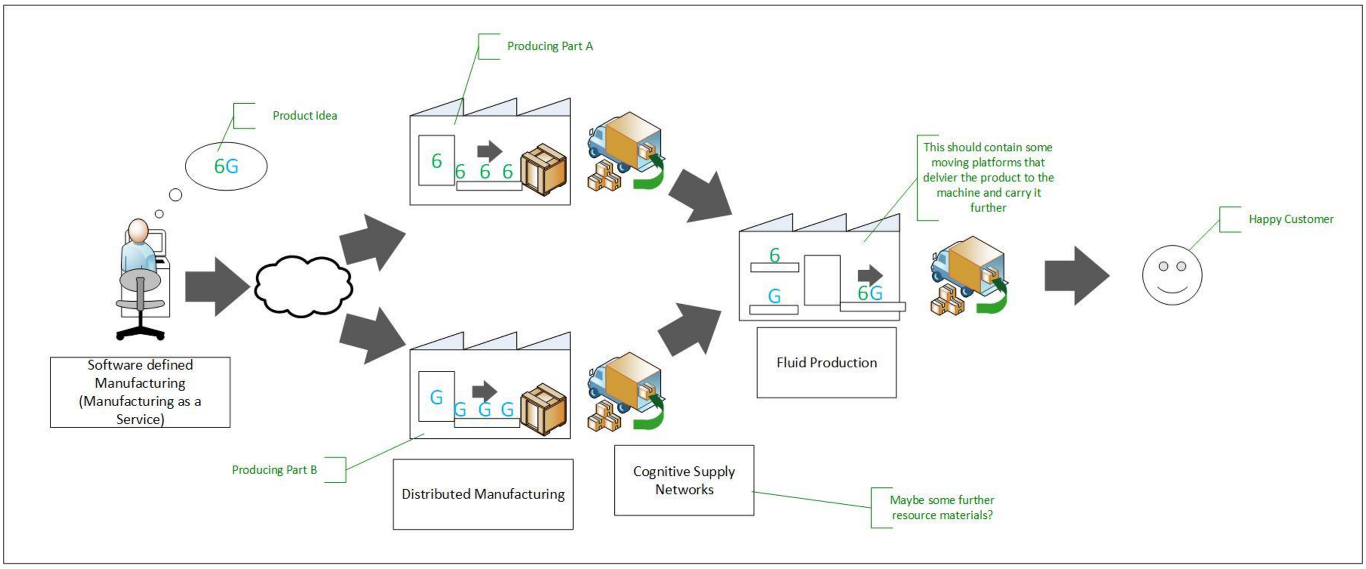


Figure 4. The future industrial manufacturing flow

Distributed manufacturing aims for ultimate levels of efficiency through networking factories, manufacturers, distributors and end consumers, and enables production on demand. Moving information rather than material has clear benefits. Operation requires opening the supply networks, infrastructure and contracting fast to the network but leads to reducing logistics costs, ability to recognize and leverage excess capacity available, reduce risk of production failure. If the customers are also integrated to the design process through simulation technologies, evolution of product development can be faster. Also here, the regulation and control of remotely manufactured products needs to be secured.

The current control systems for manufacturing plants consist of large monolith and centralized software packages difficult to implement and re-configure. The dispatching algorithms deciding on the usage of resources needs to have information on the demand, job status, deviations to the process, and most importantly, ability to recover from any failure. With distributed, intelligent technologies, the required flexibility can be achieved [53].

For distributed manufacturing, situation awareness and adaptivity are key issues. For facilities, we need to enable local computation with edge intelligence so that smart sensors co-operate using time-critical communication between end devices enabling situation awareness. Meanwhile, the data is used in dispatching algorithms leveraging factory and workforce data. The whole network of facilities/factories can be operated through an AI planner that integrates real world data in real time connecting the supply network, factories, devices. Resource sharing and book-keeping requires distributed ledgers, heavy security and trust between ecosystem partners. When the processes and product development can be simulated, the customers can participate in design of products.

2.2 Vision of Services of Future Mobility towards 2030

The future opportunities of automated transport include increased safety, effectivity and friendliness to the environment. Unmanned transport and especially widespread use of unmanned aviation are topics of current research and development. An identified requirement on wireless communications from all modalities of transport is guaranteed and stable quality of service. 5G, to some extent, and 6G provide means to fulfil this. The different modalities of transport, road, aviation, maritime and rail, are still developed in silos. However, they often impose quite similar future demands on wireless systems and digital infrastructure. For example, the connected vehicle opens the gate to a new world of service business for vehicle users. This is one of the main current trends of automotive, changing mobility rules while unveiling also a new opportunity for mobile network operators, now ready to widen their scope by offering customised solutions and E2E capacities to industrial OEMs. Moreover, the edge approach that is utilised in this use case fosters the development of new online services in the vehicle and a remarkable cost reduction of its embedded electronics by means of taking the vehicle driving data off to the cloud. Vertical use cases must be developed in parallel with and partially driving the development of future wireless systems. Wireless communication and positioning systems are essential parts of the digital infrastructure for future transport systems. Wireless systems should be included in the planning of future road, maritime, air and rail transport, as well as unmanned aviation and autonomous vehicles.

We need imagination and creativity across sectors to envision the opportunities brought by 6G. The best opportunities come from building new vertical services on new communication technologies and services. Quite often new vertical services are planned focusing on state-of-the-art wireless solutions. 6G will enable new ways of doing new things.

There is a clear chicken-egg problem in identifying the future needs of verticals and recognising the wireless solutions fulfilling those needs. Many future usage scenarios are not yet known. Also, verticals sometimes have impractical expectations for excellent coverage and quality of service everywhere, even in the air or at remote locations. Verticals need to work together with experts in the telecommunications sector. The vertical use cases should be defined and then translated into requirements on the communication systems and digital infrastructure. Such requirements include coverage, quality of service (e.g. rate, delay, delay jitter) and other key performance indicators. It is clear that one wireless solution will not fit all use cases.

In transport, especially maritime and aviation, safety lean on traditional and globally agreed radio systems and communications formats. Automated transport will require hybrid solutions, a mix of traditional communication and navigation systems with future mobile and satellite systems. It is also clear that we need to facilitate a mix of traditional vehicles and autonomous vehicles without compromising safety. At the end, reliability and safety should be ensured by back-up wireless systems and enabling change from autonomous mode to manually operated mode. One key question is how to ensure traffic safety in an environment with vehicles with different levels of automation.

Automated transport will be digitised, hyper-connected and data driven. From a communications point of view, vehicles can be seen as completely new kinds of wireless equipment or nodes. They will include several seamlessly utilised radio systems, gathering data from sensors and cameras and having advanced integrated antennas for very accurate positioning, sensing, imaging and communication. The windows can be utilised as displays e.g. for real-time augmented reality information. Some vehicles, vessels and drones will be robots optimised for gathering and sharing information about the environment. Vehicles will support sensing for situational awareness of their very dynamic environments, such as cars crowds and drone swarms. Wireless systems should support vehicles with different speeds and coverage requirements, including remote connectivity in the air. Computation and intelligence will move to the edge cloud. In the data driven transport system key questions are how to promote data sharing of crucial information, e.g. on weather and safety related conditions, and how to ensure data safety and security.

In future mesh-networks vehicles will be both base stations and terminals. Mesh-networks with vehicles as nodes will support super-efficient short-range connectivity, e.g. using Visible Light Communication between vehicles, but could also enhance remote area connectivity. Clearly, we need network architectural solutions beyond the MNO driven cellular systems. A key question is who will build, finance and operate the communication systems along transport routes? Transport routes are often public owned, whereas mobile networks are currently built based on market demand.

The cities we live in are becoming more and more crowded. An estimated 1.3 million people are migrating each week from rural areas into cities, increasing urbanization at a fantastic rate. By 2040, two-thirds of the world's population will be concentrated in urban centers. In an effort to address these incoming traffic problems, most of the mobility as a service (MaaS) initiatives address personal needs: bicycles, scooters, and electric kick-scooters are last-mile solutions for each of us as individually. Beyond 5G solutions can help the urban innovators to rethink and address public transportation needs, to develop technologies that support the new wave of urban mobility solutions globally, with the aim of radically improving capacity and speed of movement for city residents. This approach will target freeing up traffic, improving energy efficiency, increasing air quality, ultimately increasing comfort and shortening transit times for a large number of people. An updated public transportation system is an update of the city itself. The problem of urban mobility has a direct impact on people's health, as well as on the economic and real estate development of cities. An improvement in this area can have a snowball effect for the whole society. 6G architecture and enhancements could accelerate the revolution in urban mobility by unifying existing transportation alternatives and enabling new ones.

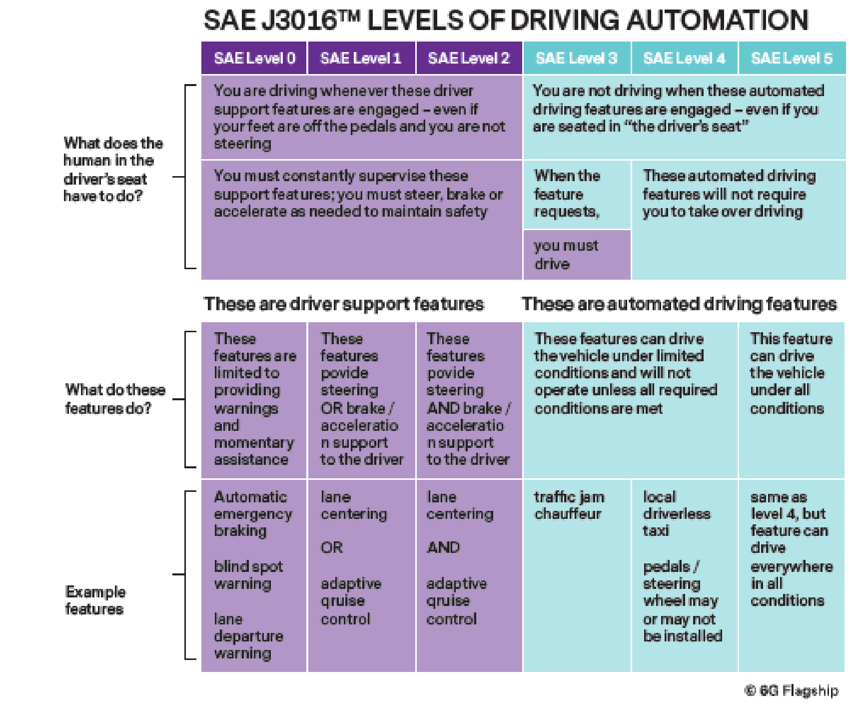
We change as individuals with time, the city around us grows and evolves, the traffic gets more intense, entire neighborhoods and communities are being re-designed by the economic forces. And yet, the bus-stop is today exactly where it was 30 years ago. Beyond 5G architectures should support MaaS long-term vision to bring up platforms for cities to adopt in order to optimize their public transport, which also implies a perfectly functional integration with other personal transport solutions. Future MaaS platforms' AI based algorithms will optimize the routes of buses, and other public transportation means so that anyone can practically hail a bus to take them from the corner and drop them off within 100 meters of the destination.

There were several phases where technology helped to digitize and optimize the urban mobility. Starting with 2010 the focus was on optimizing existing resources, gathering data and moving demand to consumer mobility apps. In the second phase since 2017, the technology fueled the creation of new location-specific mobility solutions, using data gathered and users driven by consumer apps. Nowadays new MaaS providers are driving local transportation revolutions. The future of mobility is multimodal. The present is fragmented. We need to make alternative transportation commoditized, dependable, available as we travel across the world. We need a hub to aggregate solutions and present a unitary mobility solution. This could be one of the main use cases for a more integrated beyond 5G cloud-native architecture.

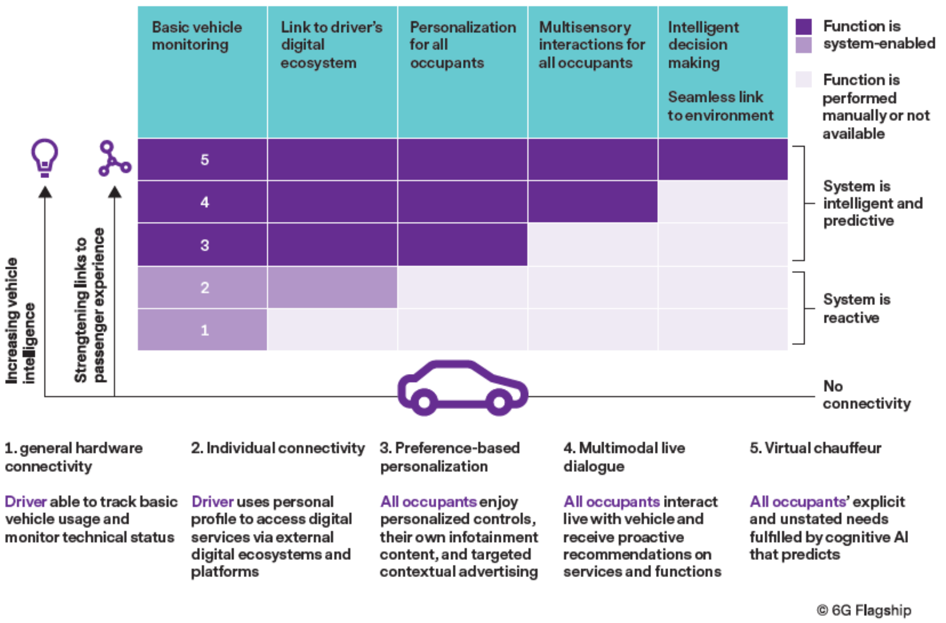
Commonly used framework for levels of vehicle autonomy was defined by the Society of Automotive Engineers (SAE) automation taxonomy as depicted in Figure 5 a).

Today's cars use radar, sonar and camera to sense the environment and normal tele-network to connect to internet. Internally car contains numerous sensors to control the internal functions of the car. In the near future, the intelligence of the car will be dramatically advanced further by adding sensors to sense the environment, software and AI, and 5G and 6G connectivity to make the car behavior more intelligent and convenient for the driver and passengers. Connectivity, in large part, will be key to using car data to generate revenue, optimize costs, and improve safety. Artificial intelligence (AI) will be used to anticipate and respond to vehicle occupants' needs and commands, leveraging in-vehicle sensors and data on consumer preferences from multiple digital domains, including social media, connected home, and connected office. McKinsey Center for Future Mobility has developed a framework to measure vehicle connectivity and the user's experience: the McKinsey Connected Car Customer Experience (C^3X)

framework that describes five levels of user experience in connected cars, ranging from the most basic to the highly complex intelligence portrayed in Figure 5 b).



a)



b)

Figure 5. a) The SAE taxonomy and b) McKinsey Connected Car Customer Experience (C^3X) framework

McKinsey Connected Car Customer Experience (C^3X) framework - Under the C^3X framework, general hardware connectivity (level one) means that the vehicle allows for only basic monitoring of its use and technical status, and individual connectivity (level two) means that the vehicle can use a driver's personal profile to access services on external digital platforms such as Android Auto and Apple CarPlay. At level three, focus expands beyond the driver and onto all occupants, who are afforded personalized controls, infotainment, and advertising. Level four provides live interaction through various modes (such as voice and gestures), allowing drivers and passengers to have a "dialogue" that feels natural with the vehicle and that enables them to receive proactive recommendations on services and functions. At the top of the scale, level five, the system becomes a "virtual chauffeur"—cognitive AI performs highly complex communication and coordination tasks, enabling it to anticipate needs and fulfil complicated, unplanned tasks for the riders.

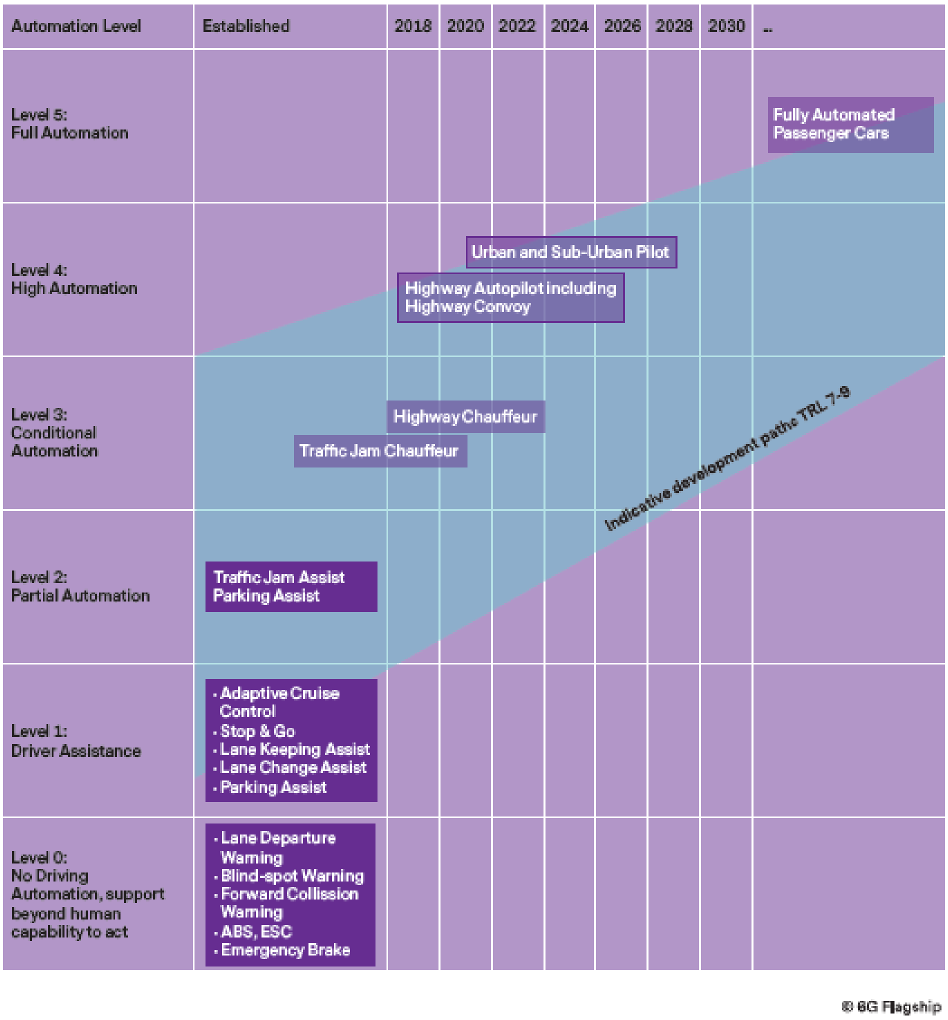


Figure 6. Development.of Automation Level in Passenger Vehicle path according to *ERTRAC - European Road Transport Research Advisory Council* [16]

Figure 6 describes the roadmap for automation development in passenger vehicle path according to ERTRAC - European Road Transport Research Advisory Council [16]. Similar roadmaps are presented in the white paper for automated freight vehicles path as well as urban mobility vehicles. All the roadmaps indicate that full automation will be achieved in early years of the 2030's. Cellular Vehicle-to-Everything (C-V2X) technology – currently based on 3GPP R14 LTE evolving into 5G R16 – provides good support for most of today's use cases. C-V2X defines two transmission modes: long-range communications via the mobile network, and direct short-range communications using PC5 interface, also known as sidelink [17]. Today's **standard car has the power of 20 personal computers,** features about 100 million lines of code, and processes up to 25 gigabytes of data an hour. Yet while digital automotive technology has traditionally focused on optimizing the vehicle's internal functions, attention is now turning to developing the car's ability to connect with the outside world and enhance the in-car experience. Today we speak about a connected car – a vehicle able to optimize its own operation and maintenance, as well as the convenience and comfort of passengers using on-board sensors and Internet connectivity. It is also called as Cooperative Intelligent Transportation Systems (CITS). These systems use communication between vehicles, as well as between vehicles and infrastructure, other road users and network, for exchanging information, enabling various applications for safety, efficiency and comfort. Cooperative vehicles, also referred to as connected vehicles, are a prelude to and pave the way towards road transport automation. Vehicle connectivity and information exchange will be an important asset for future highly-automated driving and smart traffic.

However, the latency nor positioning accuracy with these systems (3GPP Rel. 14 LTE-V2X or 5G Rel.16 V2X) are sufficient for self-driving fully automated vehicles. The better the positioning accuracy the safer the autonomous cars will be but **at least <10 cm accuracy in positioning** is expected and if E2E delay expectation is 1 ms, the **air interface latency must not exceed 100 μs.** The vehicles on the other hand can serve the network as in practice there is no energy limitation to **introduce massive computing capability into the vehicles** thus allowing constant supervision of traffic and road conditions, computation of camera feeds as well as traffic assist lidars. Furthermore, the computation capacity may also be used for cellular network optimization as well as providing ML computation platform for surrounding service requests.

The same paradigms hold true for **airplanes**; “According to Information is Beautiful, the Boeing 787 Dreamliners’ avionics and online support systems are made using between 6 and 7 million lines of code. The same source tells us that the total flight software of the 787 amounts to nearly 14 million lines of code.” [5]. It is clear, even for a casual observer, that despite the environmental concerns the demand for passenger and commercial flights remains; for example [6] states “Demand for air travel is soaring”. The BBC also state that whilst the technology exists for autonomous airplanes now there are many barriers including trade unions, insurance and legislation that need to be addressed. Nevertheless by the 2030’s it is entirely possible that planes will be a lot more autonomous than today with considerable efforts to minimize pollution through AI in airline routing and air traffic control systems.

There are plans (e.g. [7]) to extend 5G services to planes with slices for cabin, crew and airframe and this can be expected to continue and grow with 6G.

UAVs, in 6G era, can also serve several purposes, such as the enhancement of network connectivity, fire detection, emergency services in disaster, security and surveillance, pollution monitoring, parking monitoring, accident monitoring, and so on [50]. Therefore, UAV technology is recognized as one of the most important technologies for 6G communication.

From the network advances perspective, providing ubiquitous connectivity to diverse device types is the key challenge for beyond 5G (B5G) and 6G. Unmanned aerial vehicles (UAVs) or drones will be an important element in 6G wireless communications, since they can facilitate wireless broadcast and support high rate transmissions. In many cases, high-data-rate wireless connectivity will be provided using the UAV technology. Compared to the communications with fixed infrastructure, UAV has salient attributes, such as agile deployment that cannot be supported by fixed BS infrastructures, allowing the creation of powerful line-of-sight links in conjunction with controlled mobility [43] Especially, during emergency situations, such as natural disasters, the deployment of terrestrial communication infrastructures is not economically affordable and sometimes it is not possible to provide any service in volatile environments. UAVs can easily handle these situations. In the framework of 6G, the Internet of UAV will be the new paradigm in the field of wireless communication, supporting various sensing applications.

UAVs with onboard sensors can be used to support the deployment of various sensing services in the cellular networks, forming the so-called Internet of UAVs as airborne network [42]. In the airborne network (Internet of UAVs), the BS entities will be installed in UAVs to provide cellular connectivity and the sensory data will be transmitted to the terrestrial user equipment (UEs) directly or to a remote server through the base stations (BSs) according to different applications [44]. The UAV airborne network will multiplex the spectrum resources and infrastructure of the terrestrial cellular UEs, and will consume the communication services supported by the powerful hardware foundation in the 6G era.

In order to support this airborne network formed by UAVs as part of B5G and 6G networks, different types of communication are envisaged, which can be labelled as UAV-to-Everything (U2X) communications. The U2X communications will be used to realize the future airborne network of 6G, enabling the UAVs to adopt different transmission modes according to the specific requirements of their corresponding onboard applications. For example, UAV-to-Network (U2N), UAV-to-UAV (U2U), and UAV-to-Device (U2D) communications will be considered, depending on the UAV role in the mobile network, where the UAV can maintain either a direct link with the fixed BS, or an inter-UAV link, bypassing the BS, towards cooperative transmission, or a single-hop transmission to the destination node/device directly [45].

To provide global mobile collectivity, 6G is expected to tightly integrate with satellites. Integrating terrestrial, satellite, and airborne networks into a single wireless system will be crucial for 6G towards the so-called 3D networking [46]. The 6G system will integrate the ground and airborne networks to support communications for users in the vertical extension. The 3D BSs will be provided through low orbit satellites and UAVs [47], while the utilization of on-board processing capabilities at the satellites in conjunction with SDN/NFV will bring novel opportunities and business models in the communication industry [48]. The addition of new dimensions in terms of altitude and related degrees of freedom makes 3D connectivity considerably different from the conventional 2D networks, allowing to 6G to consider novel business cases and multimedia services [49].

2.3 Vision of Services of eHealth towards 2030

The eHealth vision is going towards more personalized health services; care outside hospitals [27]. Individualized care and being always connected will allow health professionals to monitor and get access to various health related data produced by (out)patients. Even more importantly, moving care outside care institutions will create possibilities for entirely new care models where patients can be active themselves in maintaining their health. This will create new models for preventive care, and increases the role of self-management of conditions, especially chronic conditions [28, 29]. This will change the role of patients and care professionals into a more collaborative one and requires new care models and tools that utilize shared decision-making [30].

The amount of collected individual health data will increase significantly in the coming years. —some sources suggest an annual growth rate of 48% [31]. Clinical decision support systems should utilize automated AI based systems that will process the collected big data, correlating and finding similarities between symptoms to predict individuals' health related prognoses, utilizing ML. In addition to automating parts of care related decision making, there is huge potential in supporting shared decision making through intelligent presentations of health data. Hyper-personalization of care allows real-time sensor fusion to adapt care through detecting individual variations through trend analysis and context awareness. Multimodal sensor fusion need to be utilized and available modalities depends on the location. Thus, eHealth services are also relying on location tracking, dynamic resource allocation. This requires distributed approaches in different decision-making levels, as well as in fog/edge computation services. High security and secrecy are required for data, as well as extremely robust communications.

Future connectivity solutions will enable implementation of infrastructures for ubiquitous human-centered healthcare services. Development of technology, such as medical sensing and imaging, and digitalization of healthcare records have created a reality where the amount of clinical data grows in a rapid pace [31]. Also, the shift from curing diseases into proactive prevention of health problems [28, 29] will change the healthcare delivery models so that clinical data alone is not enough. The healthcare models of the future will combine clinical and medical data with data about mundane everyday lives of the people to help people to manage their health and wellbeing. What characterizes health data is that as it accumulates over a lifetime of a person, the amount of data is enormous – it has been estimated that the clinical data accumulated during a life of a person is 0.4 terabytes , and other data relevant for health exceeds 1,100 terabytes [31]. Also, health related data such as genomics or chemical processes related to medication are very detailed and rich in nature. Therefore, intelligent real-time processing of anomaly detection and personalization requires distributed processing in different parts of the network as data cannot be stored solely in the mobile device, and it cannot be moved back and forth from cloud for real-time decision-making. Entirely new ways for storing and processing data need to be available.

The move to open ecosystems and data-driven interoperable service concepts can challenge the prevailing healthcare information system paradigm based on proprietary information systems. Open standards can provide a more scalable, interoperable and flexible solution to proprietary health information systems (e.g [32]). As the availability of digital data grows, model-based health information systems can be used to create care models, which include data-driven personalization of care pathway. Open standardized approaches in storing and processing sensor and context data in the cloud are required.

To create an immersive VR/AR healthcare environment to treat diseases accordingly and achieve pre-disease predictions will require intensive computational capability and **ultra-high communication bandwidth with ultra-low latency to transmit high resolution frame-rate videos**. Due to technology limitation in today's wireless networks, most of the VR/AR healthcare applications do not support real-time interaction of multiple mobile users. It is necessary to employ B5G/6G to design wireless communication systems with high frequency, low latency, stable and multi-user transmissions.

Virtual Reality (VR) and Augmented Reality (AR) facilitate vivid immersive virtual and augmented reality experience in e-healthcare services. Compared with the traditional video streaming, VR/AR involves streaming of <u>360-degree video scenes</u> requires much higher network bandwidth and much lower packet delivery latency, and user's quality of experience is highly sensitive to the dynamics in both network environment and user viewing behaviors. VA/AR applications require in developing **novel <u>360-degree video</u> coding and delivery solutions** to enable high quality interactive, on-demand, and live video streaming.

Mobile edge computing and edge caching are among the potential B5G/6G technologies that bring frequently accessed content and computing resources close to the users, thus reducing latency and load on the backhaul. The selection of what to cache and where to cache VR/AR frames, and the decision of what to offload and how to offload computing to network edge for high resolution VR/AR frame rendering are important. As edge caching breaks the network into a **distributed cloud structure where training data reside at the network edges**, the network will exacerbate the trend of moving towards **even smaller cells for more capacity and less latency in 6G**.

Along with the fast coming of aging era, the populations with cognitive impairment grow rapidly. Cognitive function has multiple dimensions, such as: memory, attention, visual space ability, computing power, execution function, etc. In addition to the treatment of medication, evidences have showed that intensive cognitive training may delay the development of disease for patients at stage of mild-cognitive impairments (MCI). To this regard, VR/AR is proposed to simulate a variety of daily-life scenarios as task modules for cognitive training in order to strengthen cognitive functions in patients with cognitive impairment disease and improve their quality of life [36]. Moreover, wearable sensors, such as EEG, EMG, eye tracking, motion capture, HRV, etc., are integrated with VR/AR systems therefore to gather a variety of neuro-behavior data as well as the task-performance data, including reaction time, correct rate, completion time, and number of completions (see Fig. 7). Based on the rich data collected via VR systems, AI methods may be applied to develop models for the purpose of automatic assessment which may assist with the diagnose of Alzheimer's disease or screening of MCI populations. Combing with Internet of Things (IoT), neuro-behavioral data and task performance of VR/AR system are able to transfer to cloud database and AI computing on the data may be performed remotely on cloud or edge. As a result, innovative healthcare services on cognitive training and automatic assessment may be provided. While healthy ageing is proposed by WHO and cognitive reserve is recommended by Harvard Medical School, the service mentioned above is not only for patients but also for health populations. The next generation of VR/AR healthcare systems will be operated in the cloud and with the help of B5G/6G wirelessly connected VR/AR displays and wearable devices.

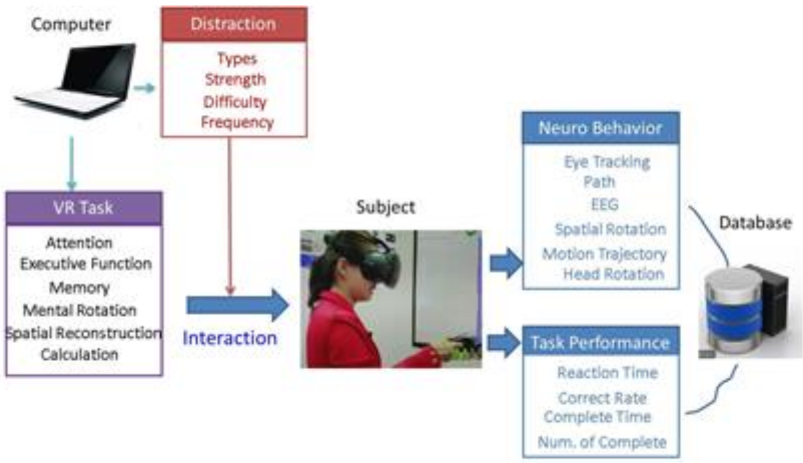


Figure 7. Using XR for assessing neuro-behavior through task performance

Haptic technology adds the sense of 'touch' to traditional audio/visual communication. A tactile electronic display as an alternative to visual or auditory sensation is the key to unlock the potential of VR/AR [37]. The progress in VR/AR based on holographic communication generates a binocular vision display. **These services will require varied degree of latency and reliability. For reliable remote surgery, it will require latency to be less than 1ms** which is not yet achievable in the upcoming 5G systems. With massive amount of real-time data transfer over the air, it will need 6G to meet the end-to-end latency requirements.

Besides the high cost, the current major limitation of eHealth services is the **lack of real-time tactile feedback** which will challenge the ability to meet their stringent Quality of Service (QoS) requirements, i.e., **continuous connection availability (99.99999% reliability), the ultralow latency (sub-ms), and mobility support [38**. By eliminating time and space barriers through remote surgery and guaranteeing healthcare workflow optimizations, 6G will revolutionize the healthcare sector.

2.4 Vision of Services of Energy towards 2030

The global energy system is undergoing a slow but massive change, initiated by environmental concerns but it is increasingly driven also by the zero-marginal cost of renewable energy. This change includes an increase in the effort to make the electric power system the main transport path for energy in the future. A massive research and development effort has henceforth been put into modernizing the electricity grid towards a so-called Smart Grid, by combining the power grid with communication networks and automation, as well as modernized market systems and structures. The increasing renewable production now necessitates demand side management, in which the traditional practice of power production being adjusted to the demand is at least partially dropped and flexibility in the demand is used to match the supply – as such technologies are deemed crucial to integrate the unsteady supply from renewable resources, like wind and solar power. [18]

These developments are leading to increasingly complex supply and demand power flows, pressurising the transmission and distribution networks currently in use. The historical “fit-and-forget” design of Low Voltage (LV) distribution networks was consistent with the unidirectional power flows from generator to the end user and their predictable load profiles. Nowadays however, Distribution System Operators (DSOs) are facing more variable and less predictable power flows, as well as increasing (local) peaks in production and consumption. The increase in amplitude of these bidirectional power flows is making the historic passive and over-dimensioned distribution network planning and operation approach economically infeasible. Furthermore, a significant loss of efficiency is evident in the electricity markets, since a mainly inelastic demand has to meet supply at different periods, with only limited storage capacity. Negative electricity prices have recently been observed in different European electricity markets, as well on the day-ahead, intra-day as on balancing markets [19].

With the rise of available compute power on embedded devices, there is an opportunity to push additional intelligence and applications to the edge of the network. This is a paradigm shift in which the applications are moved from the Cloud closer to the data at the edge to overcome latency and control requirements of critical systems, while delivering the benefits of Cloud computing. The capability of running applications at the edge allows a new degree of virtualisation to occur where a collection of virtual software based “devices” can all run within a single piece of hardware. The same way virtualisation has revolutionised the way Cloud scale servers operate, Edge software-based platforms converge many functions into a single device that will contain multiple personalities / functionalities executing in parallel. Virtualisation solutions are mainly available for cellular communication functions. In the smart grid era, the control functions will face many challenges. They have to adapt to the reconfiguration of distribution feeders (or installation of new ones) and the growth of prosumers and renewable energy sources, they need to support fast recovery in case of controller failure, and they have to be resilient to the threats imposed by cyber-attacks on the communication networks. To cope with these challenges, the control, trading and forecasting functions need to be virtualised as software instances in cloud servers, enabling the dynamic placement of the virtualised control functions (VCFs) is needed. The general overview of virtualised smart grid functions of a typical micro-grid of future are depicted in Figure 8.

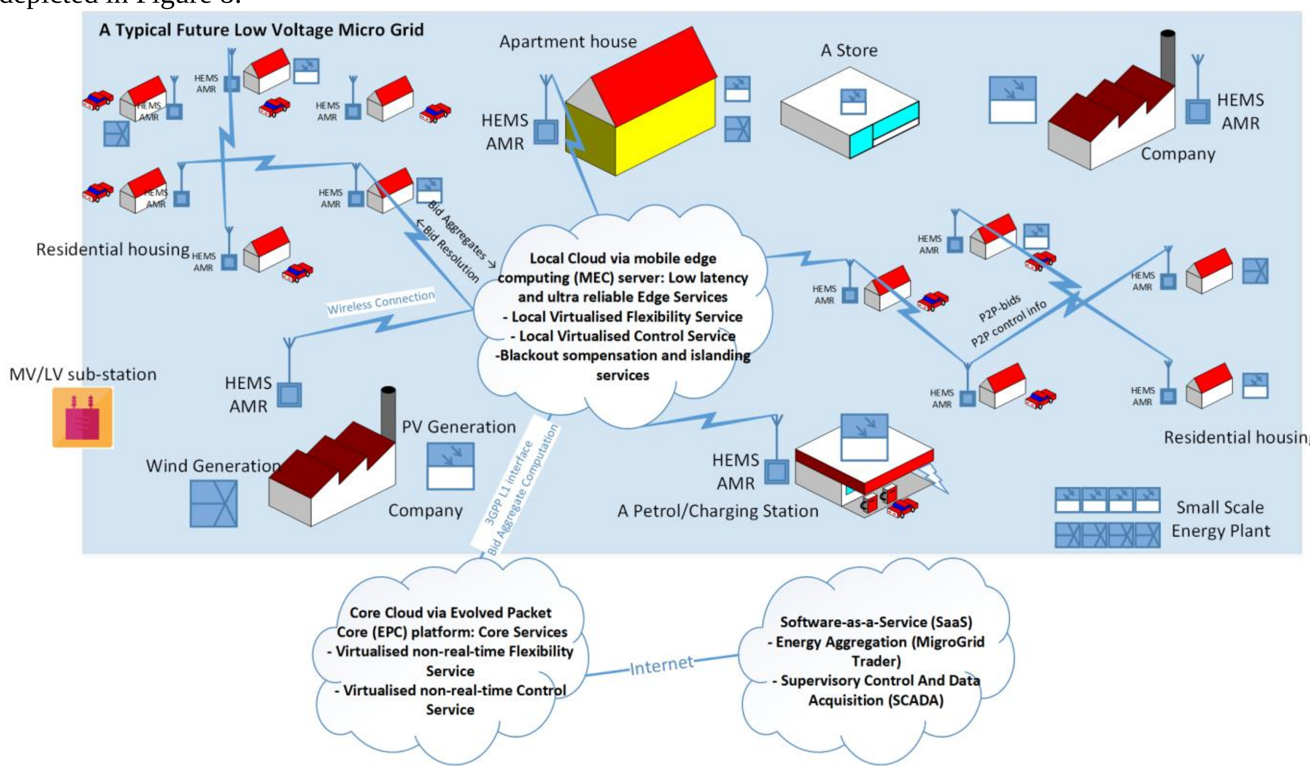


Figure 8. A model of future micro-grid with virtualised services

Many of the aforementioned services can be provided by existing wireless solutions including 5G. However, the transformation of both transmission and distribution grid is an enormous undertaking and it is expected that the 2030’s will be the decade for revolution in micro-generation, electric vehicles and demand response pointing to 6G era. Some specific notions on control solutions already today can also be made pointing to advanced wireless operation **substation automation throughout the grid require time sensitive networking** with jitter control in the microsecond domain. Some actions to introduce TSN functions to 5G/B5G standards are on-going but will this level of jitter control be achieved remains to be seen. Second aspect in distributed control is that the **number of sensing/actuation devices in the grid** will increase tremendously if the above mentioned distributed control and energy trading is to be realised. Due to the number of such devices, the cost must be maintained low and hence transmit/receive only devices may be needed. A third feature causing a lot of operational costs is the fuses in the system. Today, a maintenance crew needs to be dispatched to fix fuses. **Active protection circuitry** could be used to protect the grid from congestions and short circuits but this technology may require **control latencies in the sub ms range** which again points to specific need for the air interface latencies of the wireless solution.

2.5 Vision of Services of Finance and Banking towards 2030

Increasingly the banking and financial services (BFS) are blurring their boundaries with other services and products like energy, retail, transport etc. Many of the business paradigms that we know today will change drastically in the shared economy. This will also impact audit, regulations, compliance and governance models across the next decade. Both insurance and banking domains will require one-way communication, primarily of asset tracking. Extremely **low-latency requirements** will be important for some of the **high value transactions**. Distributed ledgers and their expanding usage in the financial realm will also benefit from extremely low latency transactions. We expect 360-degree mixed reality scenarios to improve customer experiences, especially in rural and remote areas, as well as aid in comprehensive solutions with extremely high accuracy for biometrics-based authentication [20].

Financial inclusion and Banking beyond brick and mortar branches – despite all our progress in the metropolitan areas, the bottom four billion or so will not be first class citizens in the realm of digital connectivity. This may cause their exclusion in financial realm unless we create novel solutions to accommodate them and simplify the technology for them. E.g. in India usage of Aadhaar (primarily finger-based bio-metric) has helped reach out to hundreds of millions of people in a trustworthy manner [20]. Such solutions still need to extend for better network reach, better user education to improve trust, alternate forms of biometric, non-biometric identity, natural user experience in mixed reality etc. This will also require interoperability to increase with other connectivity solutions like satellite communications for the sparsely populated areas. Self-healing networks and multiple/heterogeneous connectivity coupled with edge compute and mixed-reality can deliver significantly better user experiences beyond the traditional brick and mortar branches of today.

Shared, metered and green economy – another trend relates to shared economy, where people prefer to pay for what they use. Newer incentive models will emerge that will subsidize shared usage of products and services in an eco-friendly manner. Besides monetary transactions, green incentives and related transactions will increase. This leads to **micro and nano transactions** – as opposed to the coarse granularity of products and services that are prevalent today, sachet size payments and insurance will be the order of the day. With fine grain metering of services and solutions, **massive numbers of m-2-m transactions** will become the order of the day. Today the predominant origin of payments are humans, or instruments carried by humans (e.g. mobile phone, smart cards, wearables etc.), over the next ten years it will predominantly be machines making the payments (on behalf of entities [human, machine or organization]). Today examples of such payments are around vehicles automatically paying the toll on roads or parking lots, or the transactions related to electric power supply. In future the diversity of such devices will increase. In addition to the number of transactions, security, and audits of such transactions will be a big challenge on the 6G networks.

Privacy and data Monetization – As the technologies like distributed ledgers and crypto currencies transition through the trough of disillusionment in this decade, novel financial scenarios will emerge. Many of these systems will provide a negotiated tradeoff between opportunity-discovery, end-point identity, transaction auditability and privacy. As entities (including machines) increase on the network, identity management will be a big challenge. - both people and devices will require **privacy preserving management of their identities**. Single entity may have multiple personas and multiple entities may come together to create a new persona. Contextual transactions and encounters will have to be captured and archived for audit in a privacy preserving manner. Both customers and financial institutions will want to generate leads, often with competing goals. The custodian models for various types of data, and their flow across the financial networks will become important. Usage of distributed ledgers will also bring in extreme demands in terms of reliability and latency on the network.

Ethical sourcing of personal data for transaction including insurance-claims, loans-sanction etc. will be important processing and subsequently for compliance. Though multiple approaches exist today, most of them are operating in silos and the role of data custodians is still being formalized. 6G architecture, with its modular support for various services and isolated slices, will provide improved architectural elements to enable such solutions.

Financial services beyond the planet – as of now we only have governments involved in financial matters w.r.t. deep space exploration. In the next ten years we expect to transition to retail space tourism. Just like other verticals, BFS systems will have to adopt to challenges thrown because of the volatile nature of such communication systems.

Infra Sharing across industries

Increasingly the service providers are under financial stress and are not in a position to provide service in some of the challenging geographies. Local communities are expected to deploy and operate their **own edge infrastructure** in such scenarios. **Shared infra between telecom and BFS** may involve sharing of base station and ATM sites. Even some of the compute, network, power and storage can be shared. Some of the next level resources can also be shared with other verticals - e.g. cameras near bank sites can be utilized for smart city applications. Rather than local community or BFS deploying and operating the shared infrastructure white label solutions utilizing the Uber model for edge deployment may also evolve. **A sustainable shared 6G kiosk** designed to deliver cutting edge experiences will provide additional revenue sources for people who operate it (similar to car drivers of today). A 6G mobile setup with its own low power base station, ATM capabilities, 360-degree mixed reality for gaming or immersive communication can be envisioned for the future. They will allow on-demand sustainable delivery of services to sparse remote communities while limiting the radiation concerns.

2.6 Vision of Services of Public Safety (Critical Communications) towards 2030

Security of European citizens in large scale events is a major concern for governments, especially in the last 10 years due to terrorist attacks. As well as the acute nature of protecting against terrorism, there is also a requirement to support every day public safety at these events. Public Protection and Disaster Relief (PPDR) authorities include public officials who work in emergency and disaster situations, for example, policemen, first responders, firemen, and border guards. To ensure the successful emergency response and to support operation management, PPDR authorities have high requirements for communication. Essentially, secure communication services need to be available everywhere, in all situations at all times.

To ensure availability, secure communication services must have a good geographical coverage. Further, high service level requires traffic prioritization and pre-emption functionalities. To meet these needs, PPDR authorities often need mobile or deployable communications systems which bring additional coverage or capacity [33].

PPDR authorities now use narrowband radio technologies like Tetra, Tetrapol and P25 in their daily operations, which consist predominantly of voice centric group communication and short messages [34]. However, many countries are planning to enhance the existing narrowband technologies with broadband technologies like LTE, 5G and beyond 5G [35]. Broadband technologies allow new services such as wearable sensors and mMTC, which advance more detailed real-time situational awareness. The UK is deploying a 4G based Emergency Services Network that relies in part on satellite backhaul to ensure total coverage and benefit overall service availability [54].

Further, such services work towards the future goal of utilization of sensor data from different sources. Third party IoT systems could enable data-driven incident prediction, detection and tracking, thus supporting PPDR operations. Indeed, various intelligent systems gather data from public places like railway stations or city squares. Such systems include video surveillance cameras, or specialized sensors deployed by private companies and individuals. Further, PPDR officers themselves use more and more wearable sensors and integrated cameras to generate data from emergency scene. PPDR authorities can also have permanently installed sensors in critical locations.

Sensors and cameras can also be integrated into **mobile robots** such as unmanned aerial systems (UAS). Such robots offer a safe and efficient way to gather data during dangerous operations and can be used to reduce the immediate risk to human life. Further, mobile robots are suitable for 24/7 automatic monitoring of incidents.

Real time videos and extended or cross reality (XR) solutions are a powerful tool for **visualizing incident situations**. XR technologies enable the delivery of immersive experiences of an emergency scene, fusing virtual environments and ubiquitous sensor/actuator networks. Virtual and XR reality can be utilized for **pre-incident planning and trainings of emergency situations**. XR technologies can be a new way to communicate and share information with crowds. Future XR technologies and holograms, together with advanced AI methods, make it possible to transfer rich information to and from field operations.

Advanced situational awareness solutions require efficient identity and object recognition. New personal identity management technologies such as face or fingerprint recognition or iris scanning identify, authenticate and authorize individuals or groups of people in crises. Further, real-time object recognition (vehicle registration plates, firearms) as well location information is essential to PPRD operation management.

For PPDR authorities, (i) reliability (especially critical for alarms from the **wearable sensors**); (ii) low latency (to support real-time network-based video analytic and blockchain processing); (iii) high bandwidth in particular for **mission critical video** (MCVideo), (iv) **security** for communication and enabling technologies remain key requirements in the foreseeable future, and (v) **imaging and sensing functionalities** very useful tools PPDR operations. Mobile networks, offering services for PPDR authorities, need **special features like hardening, prioritization and security functions**. Rapid responsiveness is also important with video analysis of targets and suspects thereby supporting timely force mobilization via transmission of commands and synchronization of first responders in the field and so forth. Finally, ensuring the fulfillment of the high requirements of public safety officials calls for validation and quality assurance.

2.7 Vision of Services of Agribusiness towards 2030

Since the advent of mobile communications, each new mobile network generation has improved the system capacity and introduced new services, but only focusing on urban environment, where high population density assures many potential subscribers per cell. This is still the case of 5G networks, where the all applications scenarios, i.e., eMBB (enhanced Mobile Networks), URLLC (Ultra Reliable Low Latency Communications) and mMTC (massive Machine Type Communications), imposes the reduction of the cell size and deploy ultra-dense networks [21]. Once again, connectivity in remote and rural areas are being neglected by the mobile operators, industry and standardization bodies.

The future mobile network, expected for 2030, must **overcome the connectivity gap in rural and remote areas** by providing **large cell coverage and new approaches for spectrum access and spectrum sharing**. A true universal Internet access, that can grant reliable connectivity everywhere, has several social and economic benefits. Nowadays, hundreds of millions of people live in underserved or uncovered areas [22] and they are segregated from the Information Era. A mobile network for remote areas can bring new opportunities for those living in these regions and provide new customers for mobile operators.

Besides the relevant social impact, future mobile networks have an important role in the development of agrobusiness. Food demand is constantly increasing, pressing the farms to increase the production. In developing countries, where agrobusiness plays a prominent role in the gross domestic product, the increase in agricultural production is commonly associated with large exploitation of the natural environment, such as forest and other protected areas. A reliable mobile wireless network that provides coverage in remote and rural areas can support the informatization of the fields and farms, trigging new services and applications and opening new markets for mobile operators. With the proper coverage, IoT devices can be used to measure the soil properties and the local weather conditions, feeding online algorithms that can determine the best time for watering, deploying fertilizers, seeding or harvesting. Online drones equipped with multispectral cameras can detected early stage of plagues or insect swarm. Drones for pulverization can be automatically sent to precisely pulverize fertilizers or pesticides in the affected areas, reducing the chemicals waste and environment contamination. Cattle can also be constantly monitored, and biological data of each animal can be collected and sent to the cloud. Unconventional behavior, fevers or other symptoms of diseases can be detected before spreading for large areas, avoiding embargoes over the entire production of a given region. Finally, the remote and rural area network can be an important tool to compensate the lack of manpower in rural areas. Nowadays, there are more people living in urban areas than in the countryside [23] and this migration movement is reducing the available human resources in the farms. A rural mobile network is essential to implement the automation in the farms, since it is necessary to provide connectivity for autonomous machinery and communication for the control loop in automatized processes. All these technological improvements increase the efficiency and reduce the costs in agricultural production. Also, the reliable Internet availability in remote and rural areas can help reducing this migratory movement, since new job and education opportunities will rise in the countryside.

Rural and remote areas networks must cover a huge set of requirements, some of them contradictory to each other. **Cell coverage must guarantee a sustainable number of subscribers per base station**, while throughput must support broadband applications with the Quality of Experience (QoE) observed in urban areas. The use of frequencies below 1 GHz is interesting for this goal, since the propagation properties in VHF and UHF bands allow the signal to reach long-distances. Exploitation of vacant TV white spaces (TVWS) as secondary network, using cognitive radio approach, is also very attractive because MNOs operating in remote areas would avoid paying high prices for using the spectrum in regions where the average revenue per user (ARPU) can lower than the ones observed in urban areas. In this case, a narrow band control channel in conventional 3GPP bands, i.e., a band 28 1.4 MHz channel, can be used to organizing the network, informing new devices about the channels currently occupied by the mobile network. Spectrum sensing performed by the mobile nodes upon request of the base station can be combined with geolocation databases to provide accurate information about which channels can be used by the secondary network, without causing harm to incumbents.

Control processes in automated farms and autonomous tractors may require **low latency communication over the rural 6G network**. Since the future remote area network can also be used to provide road and train coverage, **high mobility must also be supported**. Tables 1, 2 and 3 summarize the main KPIs for the agribusiness scenario. It is clear that a remote and rural area network to cover all these applications must be flexible and self-configurable, able to dynamically share its resource among users with competing requirements.

Since 6G networks are more than just communication, agribusiness can take advantage of the new foreseen use cases to improve productivity in the farms. High precision positioning, high definition imaging and mapping and sensing are some of the new features that will be introduced by 6G Networks. Accurate positioning and high-resolution mapping will allow robots and drones to precisely navigate in crops, applying pesticides and fertilizer only in plants that needs these chemicals. Sensing based on THz signals can be used to detect volatile pheromones from insects, allowing the deployment of non-toxic substances that jams the insects' chemical communication. The new 6G features can boost the agrobusiness productivity to an unprecedented level.

The remote and rural areas scenario is very challenging, and it requires **different network configurations** to support all the necessary services. Trials under real conditions are mandatory to validate new architectures and techniques for the network, MAC and PHY layers. Besides testing the performance of proposed solutions, the field trials and performance evaluations will provide data for the system optimization. Only by stressing the future remote areas networks in terms of throughput, coverage, latency, power consumption, spectral agility, out-of-band emissions and quality of service/experience, the researchers and engineers will have reliable data to guarantee that the future networks will definitely close the connectivity gap between urban and rural areas.

2.8 Vision of Software Vertical Testing and Monitoring towards 2030

Self-driving cars, farm automation, robots, and other non-human actors will become increasingly common in the 6G environment. This increases the needed quality of such systems as malfunctions can lead to life-threating situations. History has shown that shortcutting software testing and monitoring can lead to devastating consequences. A well-known example is the space rocket Arianne 5 that crashed due to software malfunction. The same software worked with Arianne 4 but due to more powerful engines and short cutting of software testing the software malfunctioned in Arianne 5. To ensure that non-human actors in 6G do not cause harm increases the needs for software test automation. Furthermore, if malfunctions do occur continuous monitoring should terminate non-human before any harm can occur.

Software testing advances that are needed in 6G come from fields such as Search-based testing. Fuzzing, Concolic testing, Metamorphic testing, Combinatorial Testing, Model-Based Testing, for reviews see [24]. The application of these techniques has been limited in the industry due to their complexity and cost. Yet, their application does lead to superior Test Coverage. Thus, there is not only a need for scientific advances in these but also practical testing tools that can help software developers ensure the needed level of quality.

Monitoring non-human actors is a new challenge in the 6G environment. Monitoring shares the Oracle problem with software testing, i.e. how do we know when a system is malfunctioning. This problem has haunted software testing researchers for decades [25]. Unfortunately, the problem is getting worse due to increasing AI that is used in the modern systems. When there previously was documentation that under such and such conditions system would behave in a certain way, this all changes with AI-systems. The systems are no longer pre-programmed rather they become self-learning and detecting malfunctions becomes increasingly difficult [26]. The solution must lie in automated system execution monitoring. Recently many AI-based solutions have been proposed for monitoring traditional (non-AI) systems. It remains to be seen what happens when AI-based monitoring oversees AI-based systems. Perhaps, this AI-monitoring vs. AI-system can be validated through self-play like scenarios that have recently reached super-human performance in many modern and classic games like Chess, Go, Poker, Dota2, and StarCraft 2.

3. Vertical Specific KPVIs

As discussed in Chapter 2, different verticals have very specific needs in terms of performance metrics and value offering. Any vertical can and will benefit from the mobile broadband offering data rates up to 1 Tbps. If we look at the other needs of verticals, the massive connectivity and high reliability is becoming more prominent. Furthermore, new capabilities such as positioning, imaging and sensing will offer disruptive new services for verticals. If we omit the broadband services for verticals and assess the more vertical specific use cases a set of KPI's are provided in Tables 1 and 2. Please note that the KPI values proposed are the most stringent estimated KPI values per category and hence not all KPIs per vertical use case are valid at the same time within a use case. This would suggest that in KPI assessment within the vertical community, more use case oriented studies need to be performed to come up with final values for vertical specific KPIs. For categories where values are not given, nominal means at par with 5G, high and low mean higher and lower performance need than in 5G, respectively.

Table 1. Some Key Performance Indicators for Verticals

Vertical	Link Data Rate	Latency	Link Budget	Jitter	Density	Energy Efficiency	Reliability	Capacity per BS	Mobility
Industry mMTC	< 1 Mbps	< 100 ms	+ 10 dB	100 µs	100/m3	High	$1\text{-}10^{-6}$	< 10 Gbps	240 km/h
Industry eURLLC	< 5 Mbps	< 100 µs	+20 dB	< 1 µs	$10/m^3$	Nominal	$1\text{-}10^{-9}$	< 100 Mbps	240 km/h
Mobility	<10 Gbps	< 100 µs	+20 dB		$100/m^3$	Nominal	$1\text{-}10^{-7}$	1 Tbps	1200 km/h
eHealth	< 1 Gbps	< 1 ms	+10 dB	100 µs	$1/m^3$	High	$1\text{-}10^{-9}$	< 10 Gbps	240 km/h
Energy	<1 Mbps	<500 µs	+40 dB	< 1 µs	$10/m^3$	Nominal	$1\text{-}10^{-6}$	< 100 Mbps	N/A
Finance	< 1 Gbps	< 10 ms	varies	N/A	$1/m^3$	High	$1\text{-}10^{-9}$	< 10 Gbps	Low
Public Safety	<1 Gbps	< 1 ms	+20 dB	100 µs	$1/m^3$	Nominal	$1\text{-}10^{-7}$	< 10 Gbps	240 km/h
Agribusiness	100 Mbps	< 10 ms	+ 40 dB	100 µs	$100/km^2$	Nominal	$1\text{-}10^{-7}$	1 Gbps	240 km/h

Table 2. Some Key Performance Indicators for Verticals

Vertical	Cost Importance	Position	RF Imaging Resolution	EMF values	Security	Coverage
Industry mMTC	High	< 1 cm	Nominal	Nominal	Nominal	< 1km
Industry eURLLC	Nominal	< 1cm	High	Nominal	High	< 50m
Mobility	Nominal	<10 cm	High	High	High	< 10 km
eHealth	High	< 1 cm	High	Nominal	High	< 500 m
Energy	Nominal	< 1 m	Low	Nominal	High	< 1 km
Finance	High	< 1 m	High (biometrics)	Nominal	High	< 500 m
Public Safety	Nominal	<10 cm	High	Low	High	>10 km
Agribusiness	High	<10 cm	High (Precision agriculture)	Low	High	> 50 km

However, we would like to point out that potential technical KPIs are currently under discussion mainly in the scientific community with respect to the envisaged usage of future systems, cost implications, business cases and technical feasibility. For the time being no KPIs are agreed. ITU-R WP5D has initiated the development of a "Technology Trends Report", which will lead to an updated vision document to agree technical KPIs on global level. In the coming years association in the commercial domain such as NGMN, GSMA, 5GAA, 5GACIA as well as regional associations, e.g. 5G IA and international counterparts will contribute to this discussion to achieve a global consensus.

As for the key value indicators, numerical values are not given but rather indication how a category is related to the 5G as we start to develop 6G technologies thus indicating whether legislative, regulative or standardization activities are needed. For more discussion on these topics, the reader is referred to [55] and [56].

Table 3. Some Key Value Indicators (compared to 5G)

Vertical	Ethics	Trust	Privacy	Security	Inclusion
Industry mMTC	Nominal	High	High	High	Low
Industry eURLLC	High	High	High	High	Low
Mobility	High	High	High	High	High
eHealth	High	High	High	High	High
Energy	Nominal	High	High	High	Nominal
Finance	High	High	High	High	High
Public Safety	High	High	High	High	Nominal
Agribusiness	Nominal	High	Nominal	Nominal	High

4. Need for Trials

As we have seen above, the divergent needs of different vertical business areas set the question whether one testbed/system design can actually answer the needs of all or many verticals. This view is supported by [1] where it is stated that in the future, there will be use cases that require extreme performance that even 5G cannot achieve, as well as new combinations of requirements that do not fall into the three categories of 5G: eMBB, URLLC, and massive machine type communication (mMTC). There are verticals that require coverage (e.g. mobility, agrobusiness, energy) whereas many are confined in small areas (e.g. Industry 4.0, retail). In some verticals, the aspiration for latencies are of order of 100 µs and some survive with 10 ms latencies or greater. Many services can provide good QoE with reliability of $1\text{-}10^{-3}$ but some require $1\text{-}10^{-9}$.

As a solution for ever increasing and diverging requirements, softwarization of networks and open source platforms and cloud native solutions have been proposed. Does it offer flexibility sufficient to test many verticals in one test bed is an open question. Furthermore, with the SDNFV type of networks three open questions remain for research. What is the eventual energy consumption of such networks? How do you control the latency and especially jitter in such networks? How do you ensure compatibility of multitude of vendors' devices and software?

The development of a new technology typically is first done in simulation. When theory has been proven in a sufficiently accurate way then the technology is brought to the real world via implementation in hardware as a proof of concept, optimized and then turned into a product. These steps yield one major topic, the implementation loss. This means that even if a system seems to work perfectly in the simulation there are various reasons why it does not do so in the real world. A very simple example would be that simulation may utilize floating point data formats while on the hardware only integer data formats are used which basically will cause differences in the accuracy of the calculations. This leads to the conclusion that at the emergence of a new technology one must be aware about the fact that the system will be and must be trialed in depth in hardware.

Such trials of course are only significant if they rely on well defined, relevant test cases and can be repeated by basically anyone who is willing to invest the effort. Else no fair and neutral comparison and evaluation is possible but would come down to trusting the self evaluation benchmarks of a producer. This may be acceptable considering streaming services or voice calls but is not acceptable in case of mission critical communication. From this it can be derived that for each KPI which is defined for system at the same time also the conditions for which this value has to be achieved, need to be defined.

This nevertheless is not as straight forward as it seems to be because "relevant test cases" as stated above is a wide field and may be depending on individual industry types. This of course has been addressed already in many use cases and statistical approaches but again, considering mission critical communication it boils down to challenging corner-test cases which need to be fulfilled. For example, considering that a radio controlled device is moved inside an obstructing object like a metal box. This will not be covered by statistical approaches, as it clearly is one of the scenarios where a wireless communication system typically fails. However, this is actually the interesting area where real trust in a wireless system needs to be created.

In addition to the environments blocking and reflecting properties also the interference and coexistence situation needs to be addressed to include realistic disturbances and by that provide an estimate of actual and not only best case performance. This also indicates that a certain typical traffic load needs to be present.

When the above test cases have been defined then a trial methodology is needed to be defined, specifying in detail the selected test-case, including:

- UML (Unified Modeling Language) diagrams to visualize, and document the use case, including actors and relationships.
- Service requirements, describing the characteristics of the services to be demonstrated in the UC from the viewpoint of the vertical industries and end-users who will use them.
- Technical requirements. The business requirements will be converted into technical requirements at application and network levels.
- Application-level specifications. The components, architecture, network interfaces, operational context, terminals, etc., of the applications will be specified.
- Network-level specifications, including network slice specifications. The characteristics (e.g. functions, KPIs) of the network slice needed to support the applications in the UC will be specified. The network slice specifications will be built upon GSMA Generic Slice Template (GST) and Network Slice Type (NEST) concepts intended to consolidate a common method that the industry can refer to in order to describe the characteristics of any slice. The technical characteristics of the network elements (e.g. MEC nodes) required to deploy the services will also be specified.

Moreover, a reference system needs to be established which acts as the **golden reference for other testing facilities**. This reference shall include a standard deployment but also a golden reference device. Toward that direction, some initiatives for supporting 5G trial platforms have been established in Europe, supporting experimentation in an automated environment [39], [40], [41].

To address the fact the different vertical industries may have considerable differences in their working environments, it may be worthwhile to **define testing environments which are individual to a certain industry type**. So the goal should be to create a flexible and portable testing solution. With this it becomes possible to evaluate new testing ranges regarding their compliance to the reference testing system and by that the compliance to the given performance criteria can be evaluated by different neutral bodies. **Only by taking this approach the industry required certification of 6G-industrial components becomes possible**. And only with such a certification will the technology be adopted inside critical environments.

5. Open Research Questions

In the table below, we have gathered some important research questions to be answered within this decade to extract vertical productivity with the aid of B5G and 6G systems.

Vertical	Research Questions
Industry	• How can (self)-optimization of fluid/agile production systems be achieved? • How can AI (also in the communication system) be tested, monitored and optimized during runtime? • How can functional safety requirements be ensured by 6G in an efficient way?
Mobility	• How can we achieve 1-10 cm position accuracy with high mobility? • How can we accommodate in wirelessly controlled car 100/m^3 wireless sensors/actuators?
eHealth	• How to develop a real time multi-model health information system with high security and secrecy? • How to create an immersive VR/AR cognitive reserve-training environment for healthy ageing? • How to enhance a robotic assisted surgery system with tactile feedback on holographic display?
Energy	• How to achieve time sensitive networking in a wide are network? • Is mesh networking needed to penetrate deep into the buildings where smart meters reside?
Finance	• How can anonymity, privacy and auditability be balanced in 6G deployments? • Distributed ledgers as a technology for financial systems would require extremely low latency and extremely high reliability. How will 6G deployments make it affordable for low value transactions? • Rural/remote reach will require affordable and sustainable solutions. Financial systems add security and reliability on top of it. With shared infrastructure we will need better tools and policies to audit and manage these networks with diverse goals.
Public Safety	• How could imaging and sensing be used in PPDR (e.g. fires)? • What are the mechanisms to fast deploy pop-up networks?

Agribusiness	• How can the spectrum be shared in rural areas in order to allow local communities to deploy mobile networks where major MNOs are nor present? • How can low-latency services can be supported in rural areas when the backhaul link presents high latency? • How can AI be used to share the frequency-time-power resources among different applications in rural areas? • How can spectrum and power efficiency can be improved in remote areas, where massive MIMO and small cells cannot be easily used? • How can radio-over-fiber be used to deploy low-cost dummy transceiver in remote areas, whereas the base-band processing runs in the cloud?
Testing	• How to test and monitor non-human actors that are operated by AI in 6g? • What are golden references for different verticals?

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