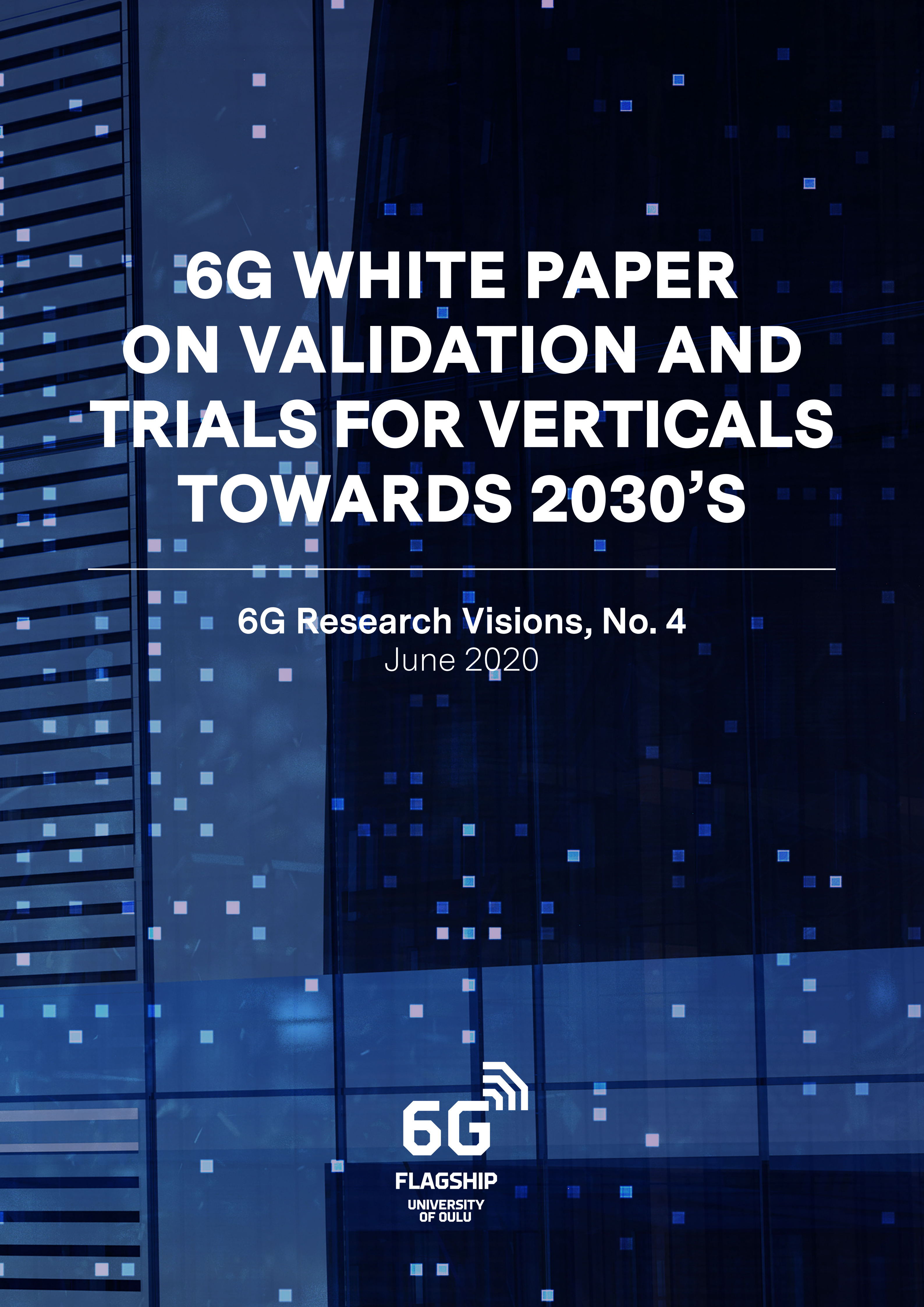

6G WHITE PAPER ON VALIDATION AND TRIALS FOR VERTICALS TOWARDS 2030'S

6G Research Visions, No. 4

June 2020

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

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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, and requires nomadic behavior or flexibility. In some situations, costs may favor wireless solutions (e.g. retrofitting). In many cases, however, a fiber optic solution remains a viable approach. Based on revenue expansion potential and the most opportunity-rich verticals, we have selected seven vertical businesses and future software-based testing for discussion: industry4.0; future mobility; eHealth; energy; finance and banking; public safety; and agribusiness. We describe the drivers in the respective verticals and the expected change. We also highlight the features within verticals that may require 6G capabilities and make an initial attempt to provide some key performance and value indicators for vertical businesses, highlighting the divergence in requirements to be experienced in the 2030s. We conclude the discussion by proposing some guidelines for trialing and validation activities within verticals to agree golden references that set a reference baseline against which any system provider can test their solutions. Finally, out of the white paper, we have formulated critical research questions to be answered during this decade to provide the foreseen vertical-specific solutions.

1

Introduction

The development of mobile cellular technology has been incredibly fast and immense new opportunities are arising. Where 1G/2G offered speech services, 3G/4G brought broadband Internet to our pockets. 5G/6G technological and architectural features that will shape the new access, networking, and management domains in mobile communications promise countless opportunities for service innovation and business efficiencies, creating an unprecedented impact on multiple vertical sectors. The role of 5G/6G is to cognitively connect every feasible device, process, and human to a global information grid. We are therefore only now at the brink of an information revolution, and new digitalization markets will offer significant revenue expansion possibilities for those who react 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 to the old communications service provider market in transforming toward digital services. However, important efforts are still required prior to making 5G a success and growth story for the industries developed around the 5G-beneficial vertical sectors. Considering the different development cycles of each vertical too, a full trolley of the potential advances and vertical transformations will also continue to be deployed in the 6G era. This view is also supported by the NTT DoCoMo [1] white paper, which proposes that whereas a new cellular generation emerges every ten years, new value markets emerge every twenty.

Among different verticals, it has been estimated that new communications technology will have the highest value creation potential in 2025 in factories according to McKinsey Global Institute [2], as can be seen in Figure 1 below, which envisages private 5G deployments.

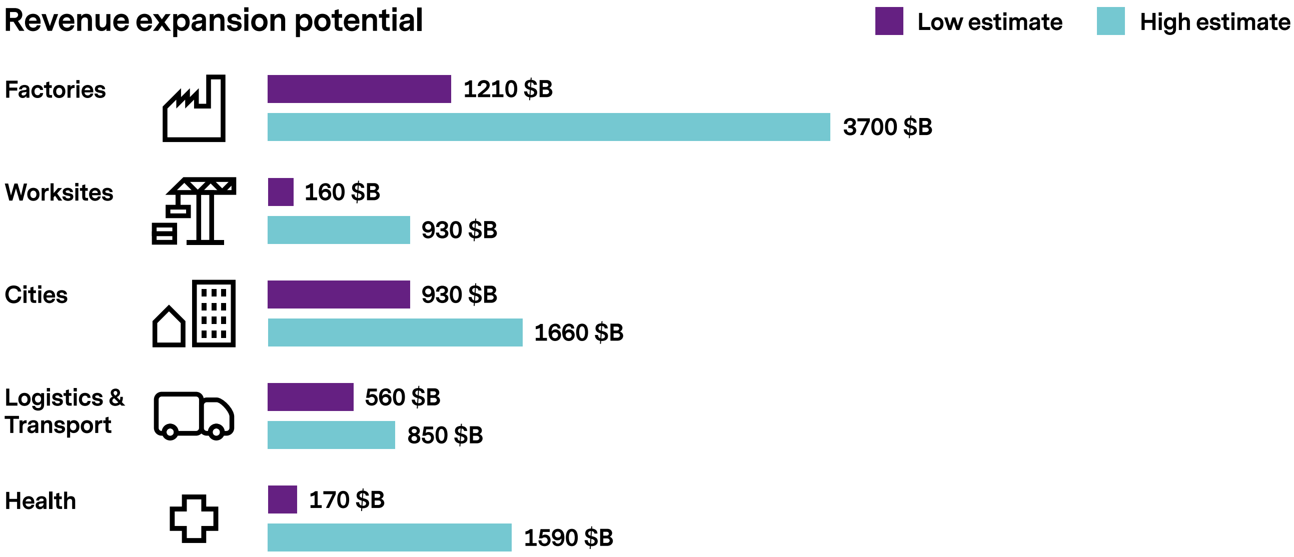

Figure 1. Market potential verticals according to McKinsey Global Institute [2]

Within the vertical context, the 5G Infrastructure Association (5G-IA), representing the private element of 5G-PPP, includes vertical engagement as a principal objective. The 5G-PPP Vertical Engagement Task Force (VTF) was established to coordinate and monitor activities related to working with vertical sectors. Specifically, it has the following objectives: 1) the enhancement of vertical engagement in 5G-PPP; 2) the promotion of relevant funding calls within vertical industries; 3) the gathering of vertical feedback on 5G needs and potential barriers for adoption; and 4) the raising of awareness of 5G's potential. As Figure 2 shows, the 5G-IA has assessed [3] that the most opportunity-rich verticals are smart cities, media, energy, automotive, emergency response, industry 4.0, and telecom itself.

6G Vision and scope of this White Paper

The trend toward higher data rates will continue as we approach 2030. Partially, this will be answered by future releases of 5G standard, but in the 2030s, it is expected that the peak data rates required will begin to approach the 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 a "true immersion" experience or holographic displays. This will necessitate a spectrum use beyond mmW, giving rise to (sub-) THz communications. However, a large portion of the verticals' data traffic will be measurement-based or actuation-related small data, which in many cases, however, requires extreme low latency, because many processes aspire to 1,000–2,000 Hz control loops, necessitating over-the-air latencies in the 100 µs domain to allow time for computation and decision making as well. At the same time, the reliability requirement (which is the opposite of low latency) in many industrial, automotive, or health applications is expected to be of the order of $1–10^{-9}$. Even more challengingly, industrial devices and processes, future haptic applications, and future multi-stream holographic applications require timing synchronization to set requirements for transmission jitter of less than a microsecond. Many verticals will also need a multitude of extremely inexpensive sensors or actuators that are transmit-only or receive-only devices, hence requiring the granting of free access, because either the uplink or downlink is missing, to reduce the cost [4]. In this whitepaper, we will omit broadband services but concentrate on vertical-specific use cases, highlighting the massive connectivity and reliability aspects, and the new localization, sensing, and imaging services.

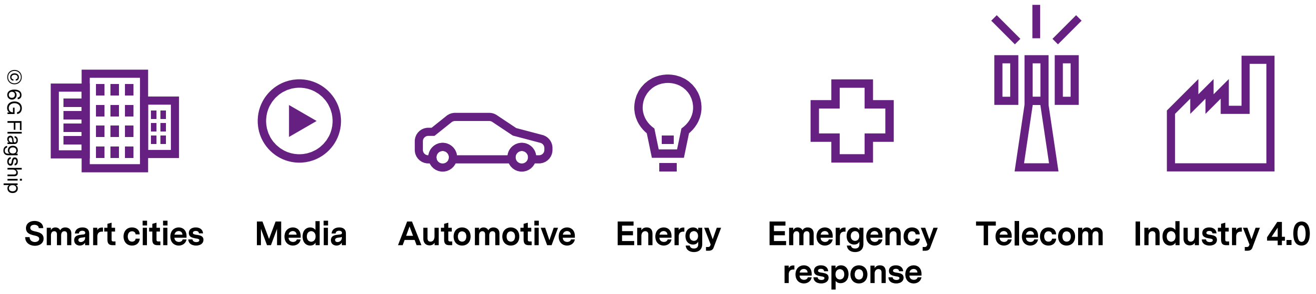

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Figure 2. The most opportunity-rich verticals according to the 5G-IA

Selected B5G/6G HW/SW and vertical service roadmaps

2

Given the expansion potential of **factories** (**including worksites**), they are a natural choice for a vertical to be assessed. Furthermore, **logistics and transport, energy,** and **health** are among the biggest beneficiaries of the productivity increase with digitalization. Cities being somewhat vague, we select one vertical within them, 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 for 6G radio-related equipment, core functionalities, IoT devices and platforms, the support required for standardization and regulation, and some enabling research themes supporting the emergence of 6G. In the radio domain, the expectation is that some proof-of-concept types of 6G (sub-) THz radio will be available around 2028. The air interface technologies and RF/spectrum issues are discussed in more detail in [9, 10, 11]. Similarly, network core technologies developing toward a zero-touch full SDNFV-based core during 2023–2025 with local and even user-centric micro-network support might be the target toward the 2030s. Networking technologies are further discussed in [8]. In the IoT device domain, energy-harvesting technologies are expected to remove the need for battery replacements, and as printed electronics technologies mature, even biodegradable devices can be expected toward the end of the decade.

2.1 Vision of Industry 4.0 services toward 2030

The thriving forces in the manufacturing vertical will be the need to save resources (energy, water) and minimize the production of waste. Conscious consumers’ indirect channeling of market demand will have a direct financial effect on environmental integrity, societal equity, and companies’ financial prosperity. A total reconfiguration of the manufacturing sector may be necessary. Possibilities emerging through technological development enable e.g. distributed manufacturing and fabrication, disrupting current business models. A need of 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 designing products and processes effectively [12].

However, the increasing demand for mass customization, allowing consumers to purchase products that are customized to their specifications, will set requirements for the technologies [13]. From the supply chain perspective, 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 in keeping supply and demand balanced. 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, as well as change management in companies. There will be severe strategic corporate reorganization and a significant cultural shift toward ecosystems involving increasingly open-source elements of application interfaces and standards, partially shared data repositories and models of plants and products, and software repositories. Autonomous and independent decision making sets requirements for company policies and workforce contracts. For some processes, human intervention will no longer be required. However, digital technologies will enhance the ongoing change from blue-collar to white-collar workers. The required future

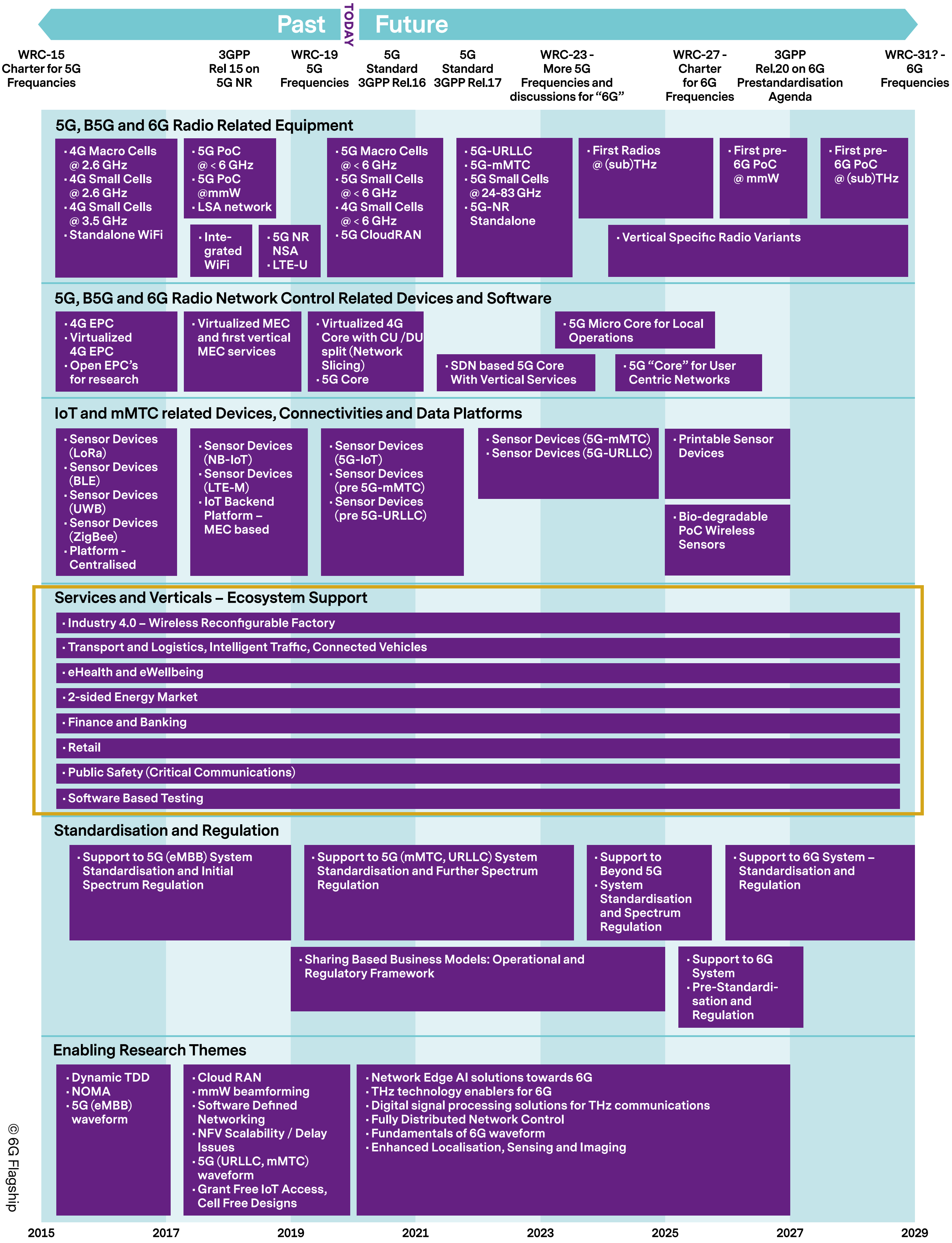


Figure 3. Estimated Roadmap towards 6G in several domains, including radio-related, network control-related, and IoT-related HW/SW, as well as the discussed verticals. Another roadmap for standardization and regulation, enabling the research themes is offered. The gold box in the figure highlights the scope of this white paper.

top skills will be critical thinking, programming, and digital literacy.

The current leading manufacturers are engaged in digital transformation and leverage connectivity, intelligence, and flexible automation [14]. With the introduction of 4G/5G, machines, devices, and people will already be 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, forming situation awareness, and predicting maintenance needs, measuring device-specific parameters like vibration, temperature, or noise levels. Corporation intranets will be connected outside the firewalls to a more versatile set of analytical tools. Control center operators of large global companies can monitor their factory networks remotely and identify the common characteristics of machinery success and failure, and processes with collected historical data. Totally autonomous dark factories will exist. Additionally, the cooperation of robots and humans will intensify due to the massive utilization of wirelessly connected sensors within the factory. Digital twins will be built for supply networks, plants, devices, and humans. We are moving toward the circular economy: We plan to repair, reuse, refurbish, re-manufacture, and recycle materials and energy.

It can be expected that the currently non-digitalized manufacturing sites will be connected within the next five years, and the verticals will change in this time more than has changed in the last twenty. The 2020 Covid-19 situation will rush the development of remote telepresence, because needs to limit personnel on the factory floors and educate people from a distance have emerged. A 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 over 360 degrees calls for URLLC.

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

Fluid production: From the factory perspective, the rise of fluid production concepts presents a paradigm shift. It is changed from the production-centric view to a completely product-centric view. Thus, the whole concept of production is reinvented with the goal of serving lot size 1 with manifold non-technical requirements that are attached with the production process as a service. One example of such a requirement could be the maximum guaranteed production time of a product. Depending on the customer's need, this time can be adapted, which results in the factory offering services of different value to 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 unit that can easily adapt to any kind 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 future product move through the factory and are visited by supply carriers, mobile robots, drones, and of course, human workers. Production looks like a swarm of bees taking care of their queen, the product. There are many benefits such production: the optimized use of restricted production resources; production balancing; optimized supply management; and inherently failsafe production. Yet this requires solutions for new challenges, which at the level of the communication system are addressable by 6G.

Basically, this means the real-time control and status exchange of **thousands of collocated devices**, with **latency requirements ranging from best effort to lower**

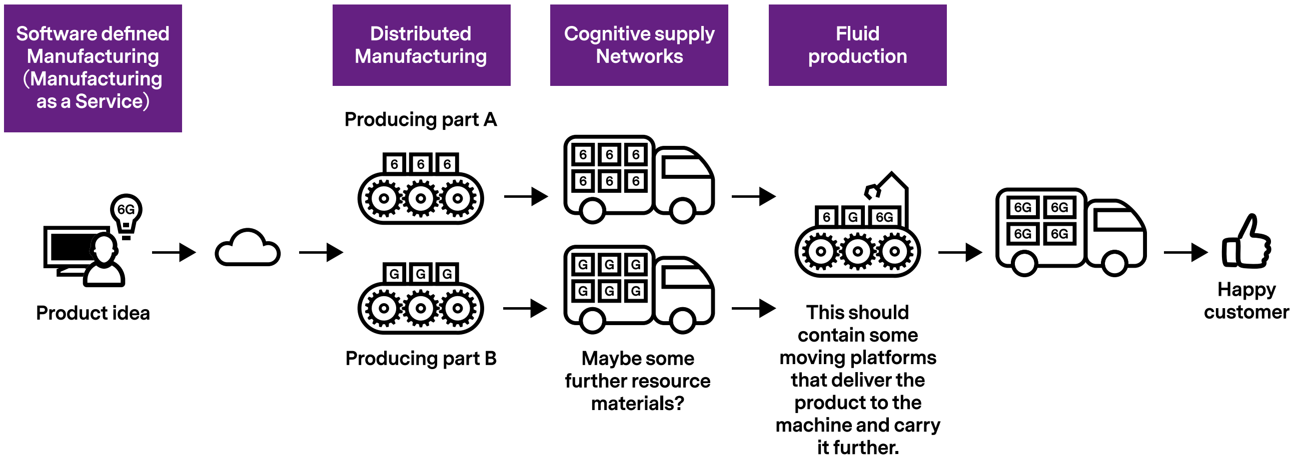


Figure 4. The future industrial manufacturing flow

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 factory's mobile agents. 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 factories are self-organizing and self-healing. These properties will also be required from the communication channels.

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

Adaptivity will call for high robustness and automatization. For example, intelligence embedded in digital twins will increase so that the analytical results based on data attained from the field is adjusted increasingly automatically back to physical reality. The explosion of **big data-based, real-time analytical applications for digital twins will be enabled by 6G communication and edge-intelligent capacities**. In cases where humans remain in the loop, ensuring their safety will be 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 AI will be used in drawing the right conclusion from the huge amount of data, and the reduction of data and energy by transmitting only the relevant information.

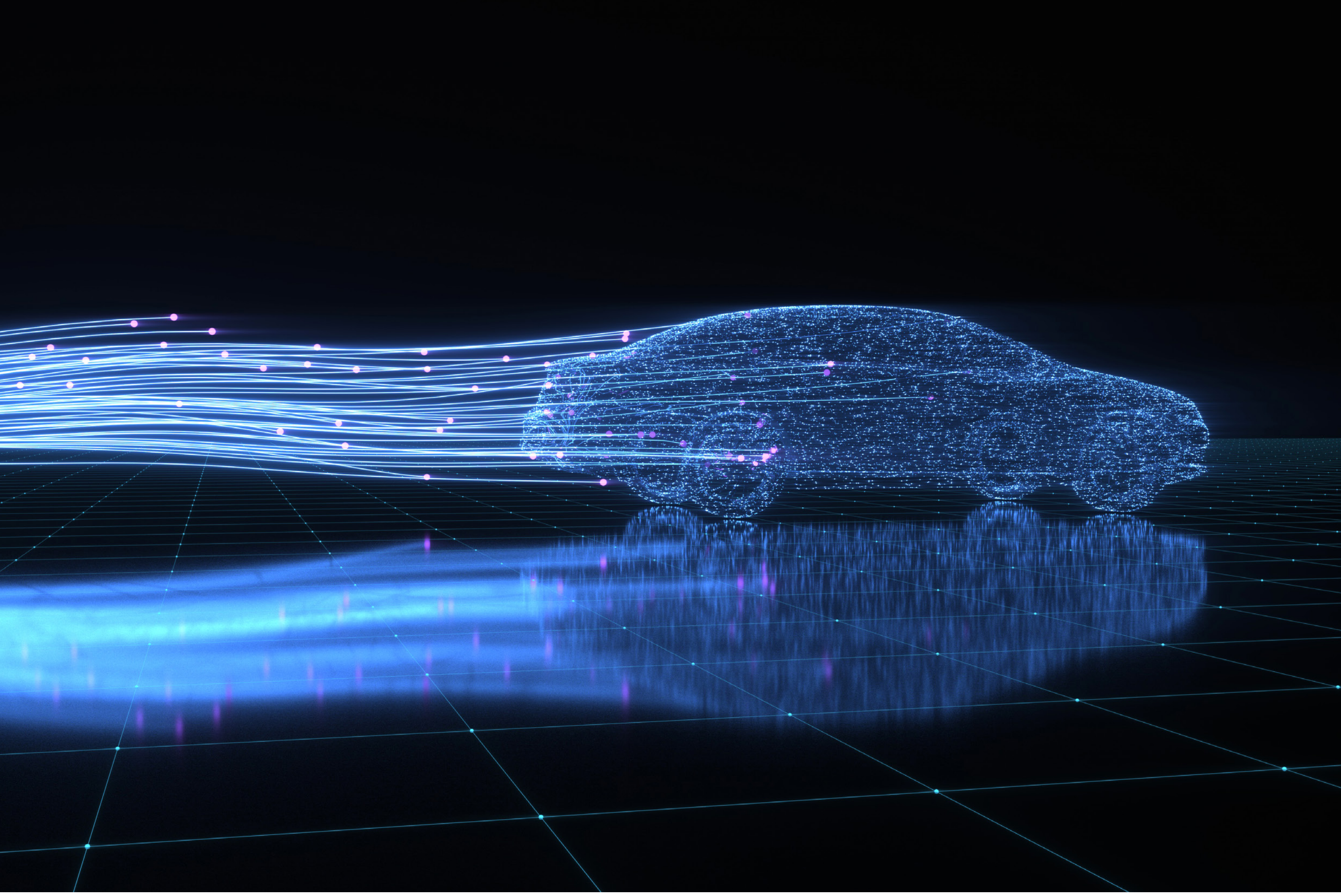
Distributed manufacturing aims for ultimate levels of efficiency through networking factories, manufacturers, distributors, and end consumers, enabling production on demand. Moving information rather than material has clear benefits. Operation requires the opening of supply networks and infrastructure,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

The current control systems for manufacturing plants consist of large monolithic and centralized software packages that are difficult to implement and reconfigure. The dispatching algorithms deciding on the usage of resources need information on demand, job status, deviations to the process, and most importantly, the 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 cooperate using time-critical communication between end devices, enabling situation awareness. Meanwhile, the data is used in dispatching algorithms leveraging factory and workforce data. The entire network of facilities/factories can be operated through an AI planner that integrates real-world data in real time, connecting the supply network, factories, and devices. Resource sharing and bookkeeping require distributed ledgers, heavy security, and trust between ecosystem partners. When the processes and product development can be simulated, customers can participate in the design of products.

2.2 Vision of future mobility services toward 2030

The future opportunities of automated transportation include increased safety, effectivity, and environmental friendliness. Unmanned transportation and especially the widespread use of unmanned aviation are current research and development topics. The identified requirement for wireless communications from all modalities of transportation is guaranteed, as is stable service quality. 5G, to some extent, and 6G provide the means to fulfill this. The different modalities of transportation, roads, 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 automotive trends, changing mobility rules while unveiling a new opportunity for mobile network operators who are now ready to widen their scope by offering customized solutions and E2E capacities to



industrial OEMs. Moreover, the edge approach that is utilized in this use case will foster the development of new online services in the vehicle and a remarkable cost reduction of its embedded electronics by transferring vehicle driving data 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 of future transportation systems. Wireless systems should be included in the planning of future road, maritime, air, and rail transportation, 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 will come from building new vertical services for new communication technologies and services. New vertical services will often be planned that focus on state-of-the-art wireless solutions. 6G will enable new ways of doing new things.

Clearly, there is a chicken-and-egg problem in identifying the future needs of verticals and recognizing the wireless solutions fulfilling them. Many future usage scenarios are as yet unknown. Verticals also sometimes have unrealistic expectations of excellent coverage and quality of service everywhere, even in the air or in remote locations. Verticals need to collaborate with experts in the telecommunications sector. Vertical use cases should be defined and then translated into requirements for 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 transportation, especially maritime and aviation, safety depends on traditional and globally agreed radio systems and communication formats. Automated transportation 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 and autonomous vehicles, without compromising safety. Ultimately, reliability and safety should be ensured by back-up wireless systems and enabling the switch from autonomous to manually operated mode. A key question is how to ensure traffic safety in an environment with vehicles with different levels of automation.

Automated transportation will be digitized, hyper-connected, and data-driven. From the communications perspective, vehicles can be seen as completely new kinds of wireless equipment or nodes. They will include several seamlessly utilized radio systems, gathering data from sensors and cameras, and featuring advanced integrated antennae for very accurate positioning, sensing, imaging, and communication. Windows can be utilized as displays, e.g. for real-time augmented reality informa-

tion. Some vehicles, vessels, and drones will be robots that are optimized to gather and share information about the environment. Vehicles will support sensing for the situational awareness of their very dynamic environments, such as traffic flows 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 transportation system, key questions concern how to promote the sharing of crucial information, e.g. about weather and safety 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. by using Visible Light Communication between vehicles, but may also enhance remote area connectivity. Clearly, we need network architectural solutions beyond MNO-driven cellular systems. A key question concerns who will build, finance, and operate the communication systems along transportation routes. Transportation routes are often publicly owned, whereas mobile networks are currently built based on market demand.

The cities in which we live are becoming increasingly crowded. An estimated 1.3 million people migrate 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 mobility as a service (MaaS) initiatives address personal needs: bicycles; scooters; and electric kick scooters are last-mile solutions for each of us. Beyond 5G, it is possible that solutions will help 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 the freeing up of 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 cities' economic and real estate development. An improvement in this area may have a snowball effect on the whole of society. It is possible that 6G architecture and enhancements will accelerate the urban mobility revolution by unifying existing transportation alternatives and enabling new ones.

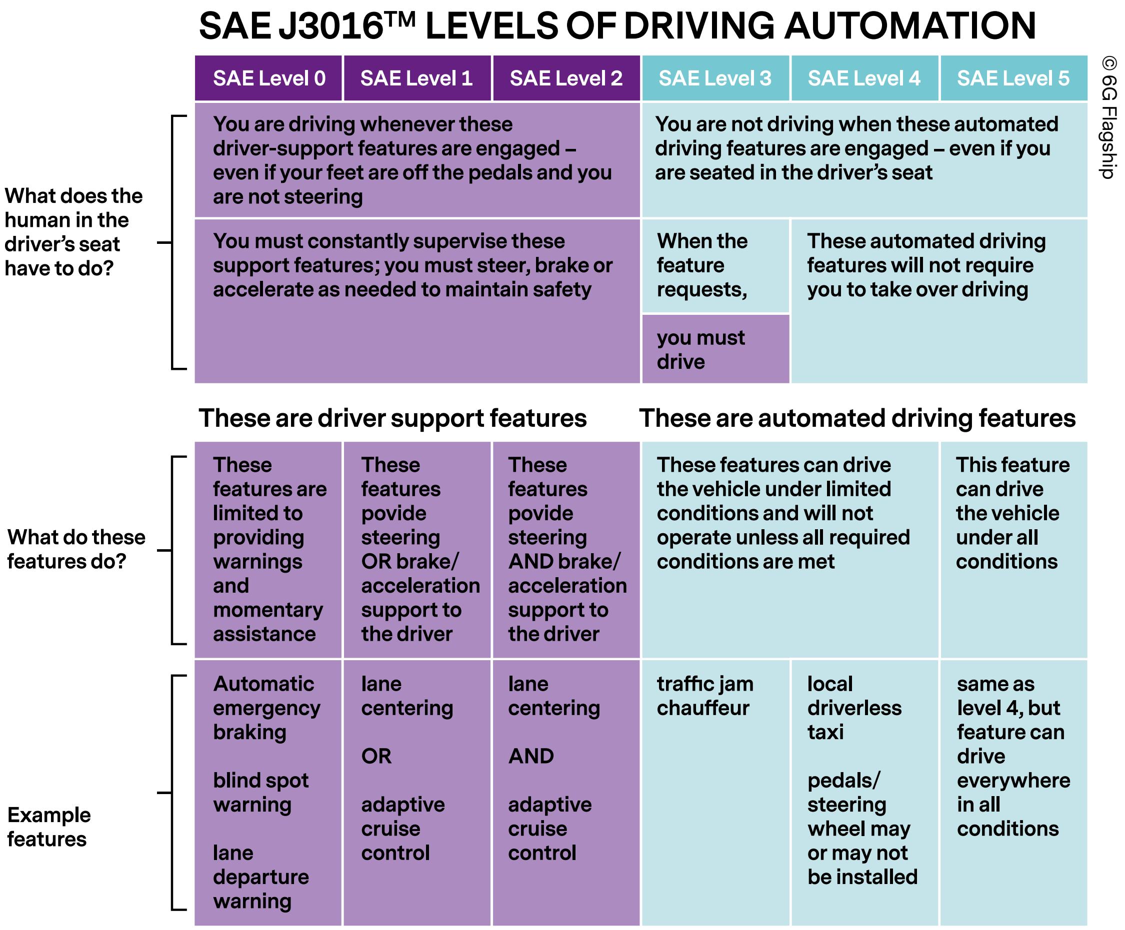
As individuals, we change over time, and the city around us grows and evolves. Traffic gets heavier, and entire neighborhoods and communities are being redesigned because of the economic forces. Yet the bus stop today is exactly where it was 30 years ago. Beyond-5G architectures should support the MaaS long-term vision in developing platforms for cities to optimize their public transportation, which will also entail a perfectly functional integration with other personal transportation solutions. Future MaaS platforms' AI-based algorithms will optimize bus routes and other means of public transportation so that practically anyone can hail a bus to take them from the corner and drop them off within 100 meters of their destination.

There have been several phases in which technology has helped to digitize and optimize urban mobility. Since 2010, the focus has been on optimizing existing resources, gathering data, and moving demand to consumer mobility apps. In the second phase, since 2017, technology has fueled the creation of new location-specific mobility solutions, using data gathered and users driven by consumer apps. Today, new MaaS providers are driving local transportation revolutions. The future of mobility is multimodal. The present is fragmented. We need to commoditize alternative transportation and make it dependable and 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.

A commonly used framework for levels of vehicle autonomy has been defined by the Society of Automotive Engineers (SAE) automation taxonomy, as depicted in Figure 5 a).

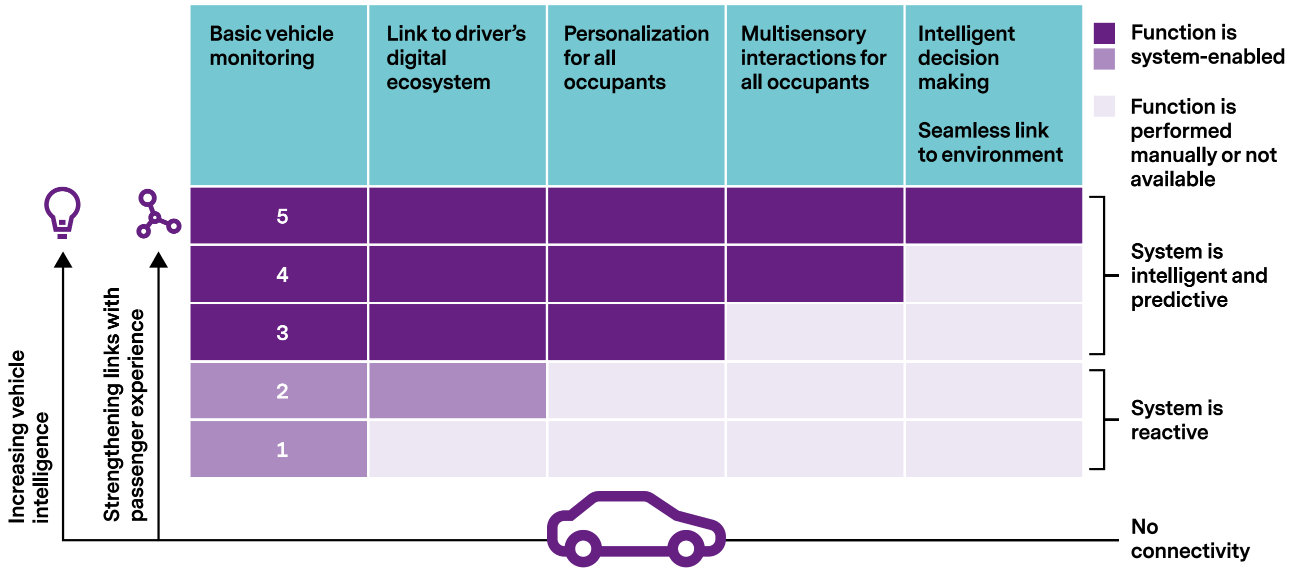
Today's cars use radar, sonar, and cameras to sense the environment and the normal tele-network to connect to the Internet. Internally, cars contain numerous sensors to control their internal functions. In the near future, the intelligence of cars will be dramatically advanced by adding sensors to sense the environment, software, and AI, and 5G and 6G connectivity to make their 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, the connected home, and the connected office. The McKinsey Center for Future Mobility has developed a framework to measure vehicle connectivity and the user's experience, the McKinsey Connected Car Customer Experience (C3X) framework, which describes five levels of user experience in connected cars, ranging from the most basic to the highly complex intelligence illustrated in Figure 5b.

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



SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE Level 0	SAE Level 1	SAE Level 2	SAE Level 3	SAE Level 4	SAE Level 5
What does the human in the driver's seat have to do?	You are driving whenever these driver-support features are engaged – even if your feet are off the pedals and you are not steering			You are not driving when these automated driving features are engaged – even if you are seated in the driver's seat		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features povide steering OR brake/ acceleration support to the driver	These features povide steering AND brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example features	Automatic emergency braking blind spot warning lane departure warning	lane centering OR adaptive cruise control	lane centering AND adaptive cruise control	traffic jam chauffeur	local driverless taxi pedals/ steering wheel may or may not be installed	same as level 4, but feature can drive everywhere in all conditions



	Basic vehicle monitoring	Link to driver's digital ecosystem	Personalization for all occupants	Multisensory interactions for all occupants	Intelligent decision making Seamless link to environment
5	■	■	■	■	■
4	■	■	■	■	□
3	■	■	■	□	□
2	▨	▨	□	□	□
1	▨	□	□	□	□

■ ▨ Function is system-enabled

□ Function is performed manually or not available

1. general hardware connectivity

Driver able to track basic vehicle usage and monitor technical status

2. Individual connectivity

Driver uses personal profile to access digital services via external digital ecosystems and platforms

3. Preference-based personalization

All occupants enjoy personalized controls, their own infotainment content, and targeted contextual advertising

4. Multimodal live dialogue

All occupants interact live with vehicle and receive proactive recommendations on services and functions

5. Virtual chauffeur

All occupants' explicit and unstated needs fulfilled by cognitive AI that predicts

Figure 5. a) The SAE taxonomy and b) McKinsey Connected Car Customer Experience (C3X) framework

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, the focus expands beyond the driver and to 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 enables them to receive proactive recommendations about 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 fulfill complicated unplanned tasks for the passengers.

Figure 6 describes the roadmap for automation development in the passenger vehicle path according to ERTRAC—European Road Transport Research Advisory Council [16]. Similar roadmaps are presented in the white paper for the automated freight vehicle path, as well as urban mobility vehicles. All the roadmaps indicate that full automation will be achieved in the early years of the 2030s. Cellular Vehicle-to-Everything (C-V2X) tech-

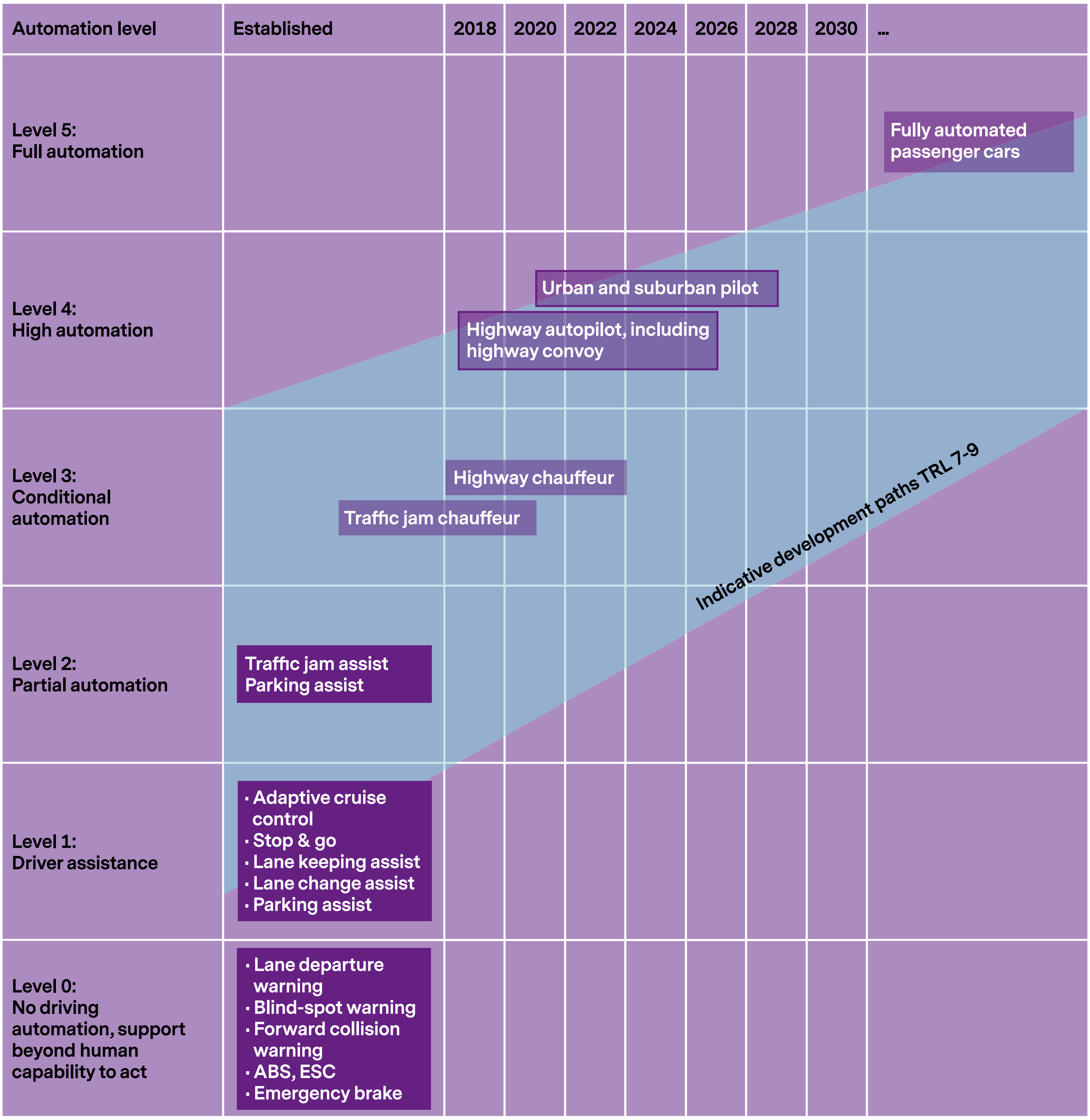


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Figure 6. Development of automation level in the passenger vehicle path according to ERTRAC—European Road Transport Research Advisory Council [16]

nology—currently based on 3GPP R14 LTE evolving into 5G R16—will provide 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 the 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 the 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. This is also called Cooperative Intelligent Transportation Systems (CITS). These systems use communication between vehicles, as well as between vehicles and infrastructure, other road users, and networks to exchange 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 toward road transportation automation. Vehicle connectivity and information exchange will be an important asset for future highly automated driving and smart traffic.

However, neither the latency nor positioning accuracy of these systems (3GPP Rel. 14 LTE-V2X or 5G Rel.16 V2X) is sufficient for self-driving fully automated vehicles. The better the positioning accuracy, the safer 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**. Yet vehicles can serve the network, because there is no energy limitation in practice to **introduce massive computing capability to the vehicles**, thus allowing the constant supervision of traffic and road conditions, the 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 an 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 to the casual observer, that despite the environmental concerns, the demand for passenger and commercial flights remains; for example, [6] states that "[d]emand for air travel is soaring." The BBC also states that whilst the technology exists for autonomous airplanes, many barriers, including trade unions, insurance, and legislation, now need to be addressed. Nevertheless, by the 2030s, 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 the 6G era may 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, etc. [50]. UAV technology is therefore 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, because they can facilitate wireless broadcasts and support high rate transmissions. In many cases, high-data-rate wireless connectivity will be provided using 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 it is sometimes impossible to provide any service in volatile environments. UAVs can easily handle these situations. In the 6G framework, 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 cellular networks, forming the "Internet of UAVs" as an airborne network [42]. In the airborne network (Internet of UAVs), 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.

To support this airborne network formed by UAVs as part of B5G and 6G networks, different types of communication are envisaged that can be labeled as UAV-to-Everything (U2X) communications. U2X communications will be used to realize the future 6G airborne network, enabling 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, toward cooperative transmission, or a single-hop transmission directly to the destination node/device [45].

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

2.3 Vision of eHealth services toward 2030

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

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

Future connectivity solutions will enable the implementation of infrastructures for ubiquitous human-centered healthcare services. The development of technology such as medical sensing and imaging, as well as the digitalization of healthcare records, has created a reality in which the amount of clinical data is growing rapidly [31]. The shift from curing diseases to the proactive prevention of health problems [28, 29] will also change healthcare delivery models, meaning clinical data alone will be insufficient. The healthcare models of the future will combine clinical and medical data with data about people's mundane lives to assist them in managing their health and well-being. What will characterize health data is that as it accumulates over a person's lifetime, the amount of data will be enormous—it has been estimated that the clinical data accumulated during a person's life will be 0.4 terabytes, while other health-relevant data will exceed 1,100 terabytes [31]. Health-related data such as genomics or chemical processes related to medication will also be very detailed and rich in nature. Intelligent real-time processing of anomaly detection and personalization will therefore require distributed processing in different parts of the network, because data cannot be stored solely in the mobile device, and it cannot be moved back and forth from the cloud for real-time decision making. Entirely new ways of storing and processing data will need to be available.

The move to open ecosystems and data-driven interoperable service concepts may challenge the prevailing healthcare information system paradigm based on proprietary information systems. Open standards may 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 may be used to create care models that include the data-driven personalization of the care pathway. Open standardized approaches to storing and processing sensor and context data in the cloud will be required.

To create an immersive VR/AR healthcare environment for treating diseases accordingly and achieving 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 the technology limitations of 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) will facilitate a vivid immersive virtual and augmented reality experience in e-healthcare services. Compared with traditional video streaming, VR/AR involving the streaming of ***360-degree video scenes*** will require a much higher network bandwidth and a much lower packet delivery latency, and the user's quality of experience will be highly sensitive to the dynamics in both the network environment and user viewing behaviors. VR/AR applications will be required in developing **novel *360-degree video* 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 will bring frequently accessed content and computing resources close to 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 the network edge for high resolution VR/AR frame rendering, will be important. As edge caching breaks the network down into a **distributed cloud structure in which training data resides at the network edges**, the network will exacerbate the trend to move toward **even smaller cells for more capacity and less latency in 6G**.

With the rapidly approaching aging era, populations with cognitive impairment will grow rapidly. Cognitive function has multiple dimensions such as memory, attention, visual space ability, computing power, execution function, etc. In addition to treatment with medication, it has been shown that intensive cognitive training may delay the development of disease for patients at the stage of mild-cognitive impairment (MCI). In this respect, it is proposed that VR/AR will simulate a variety of everyday scenarios as task modules for cognitive training 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. will be integrated with VR/AR systems to gather a variety of neuro-behavior and task-performance data, including reaction time, the correct rate, completion time, and number of completions (see Figure 7). Based on the rich data collected via VR systems, AI methods may be applied in developing models for automatic assessment, which may assist with the diagnosis of Alzheimer's disease or the screening of MCI populations. Combined with the Internet of Things (IoT), VR/AR system neuro-behavioral data and task performance will be able to be transferred to the cloud database, and AI computing on the data may be performed remotely in the cloud or edge. As a result, innovative healthcare services for cognitive training and automatic assessment may be provided. While healthy aging is promoted by the WHO, and cognitive reserve is recommended by the Harvard Medical School, the service mentioned above will not only be for patients but 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.

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 unlocking the potential of VR/AR [37]. The progress in VR/AR based on holographic communication will generate a binocular vision display. **These services will require a 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 the massive amount of real-time data transfer over the air, 6G will be needed to meet the end-to-end latency requirements.

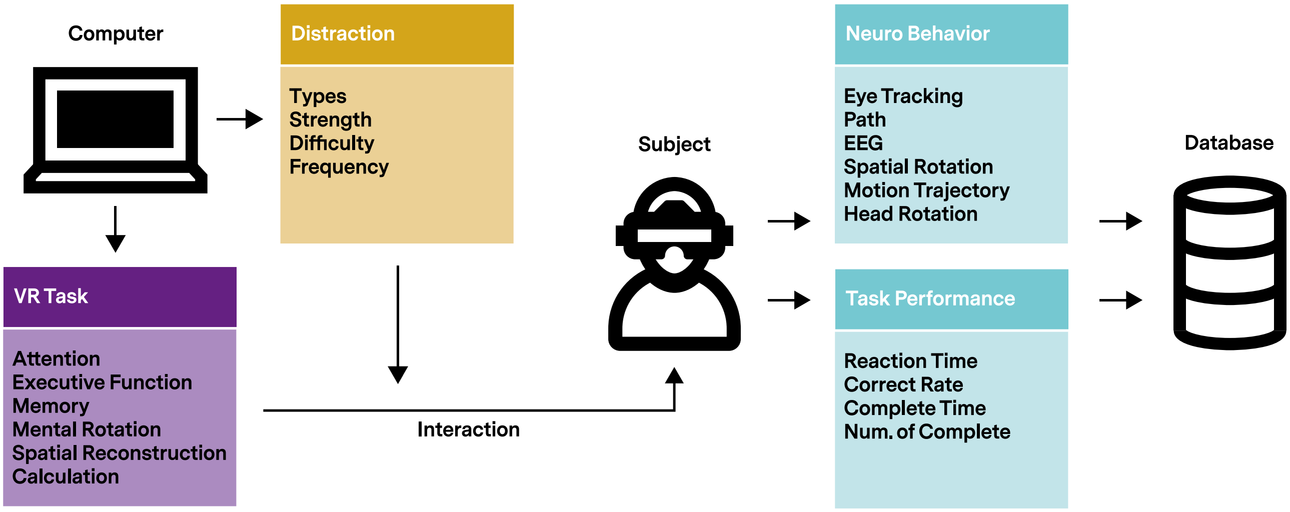

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Figure 7. Using XR to assess neuro-behavior through task performance

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), ultra-low 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 energy services toward 2030

The global energy system is undergoing a slow but massive change initiated by environmental concerns, but it is also increasingly driven by the zero-marginal cost of renewable energy. This change will include an increase in the effort to make the electric power system the principal future transportation path for energy. A massive research and development effort will be made to modernize the electricity grid toward a "Smart Grid" by combining the power grid with communication networks and automation, as well as modernized market systems and structures. Increasing renewable production will necessitate demand-side management, in which the traditional practice of power production being adjusted to demand will at least partially be dropped, and flexibility in demand will be used to match supply, because such technologies will be deemed crucial for integrating the unsteady supply from renewable resources like wind and solar power [18].

These developments are leading to increasingly complex supply-and-demand power flows, pressurizing 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 end user and their predictable load profiles. Today, 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 the amplitude of these bidirectional power flows is making the historic passive and over-dimensioned distribution network planning and operation approach economically unfeasible. Furthermore, a significant loss of efficiency is evident in the electricity markets, because largely inelastic demand must meet supply in different periods with only limited storage capacity. Negative electricity prices have recently been observed in different European electricity markets, as well as on the day-ahead, intra-day, and balancing markets [19].

With the increase in the available compute power of 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 applications are moved from the cloud closer to the data at the edge to overcome the latency and control requirements of critical systems, while delivering the benefits of cloud computing. The capacity to run applications at the edge will allow a new degree of virtualization to occur, in which a collection of virtual software-based "devices" can all run within a single piece of hardware. Just as virtualization has revolutionized how cloud-scale servers operate, edge software-based platforms will combine many functions in a single device that will contain multiple personalities/functionalities that are executed in parallel. Virtualization solutions are mainly available for cellular communication functions. In the smart grid era, control functions will face many challenges. They will need to adapt to the reconfiguration of distribution feeders (or the installation of new ones), and the growth of prosumers and renewable energy sources. They will also need to support a fast recovery in the event of controller failure, and they must be resilient to the threat of cyberattacks on communication networks. To cope with these challenges, control, trading, and forecasting functions will need to be virtualized as software instances in cloud servers, enabling the necessary dynamic placement of virtualized control functions (VCFs). A general overview of the virtualized smart grid functions of a typical micro-grid of the future is depicted in Figure 8.

Many of the aforementioned services can be provided by existing wireless solutions, including 5G. However, the transformation of the transmission and distribution grids is an enormous undertaking, and it is expected that the 2030s will be the decade in which the revolution in micro-generation electric vehicles and demand response will herald the 6G era. Some specific notions of control solutions today can also already be devised, pointing to advanced wireless operation **substation automation throughout the grid, requiring time-sensitive networking** with jitter control in the microsecond domain. Some actions to introduce TSN functions to 5G/B5G standards are ongoing, but whether this level of jitter control can be achieved remains to be seen. A second aspect of distributed control is that the **number of sensing/actuation devices in the grid** will increase tremendously if the aforementioned distributed control and energy trading is to be realized. Due to the number of such devices, costs must be kept low. Hence, transmit-/receive-only devices may be needed. A third feature causing significant 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 congestion and short circuits, but this technology may require **control latencies in the sub-ms. range**, which again points to the specific need for air interface latencies in the wireless solution.

2.5 Vision of finance and banking services toward 2030

Increasingly, banking and financial services (BFS) are blurring their boundaries with other services and prod-

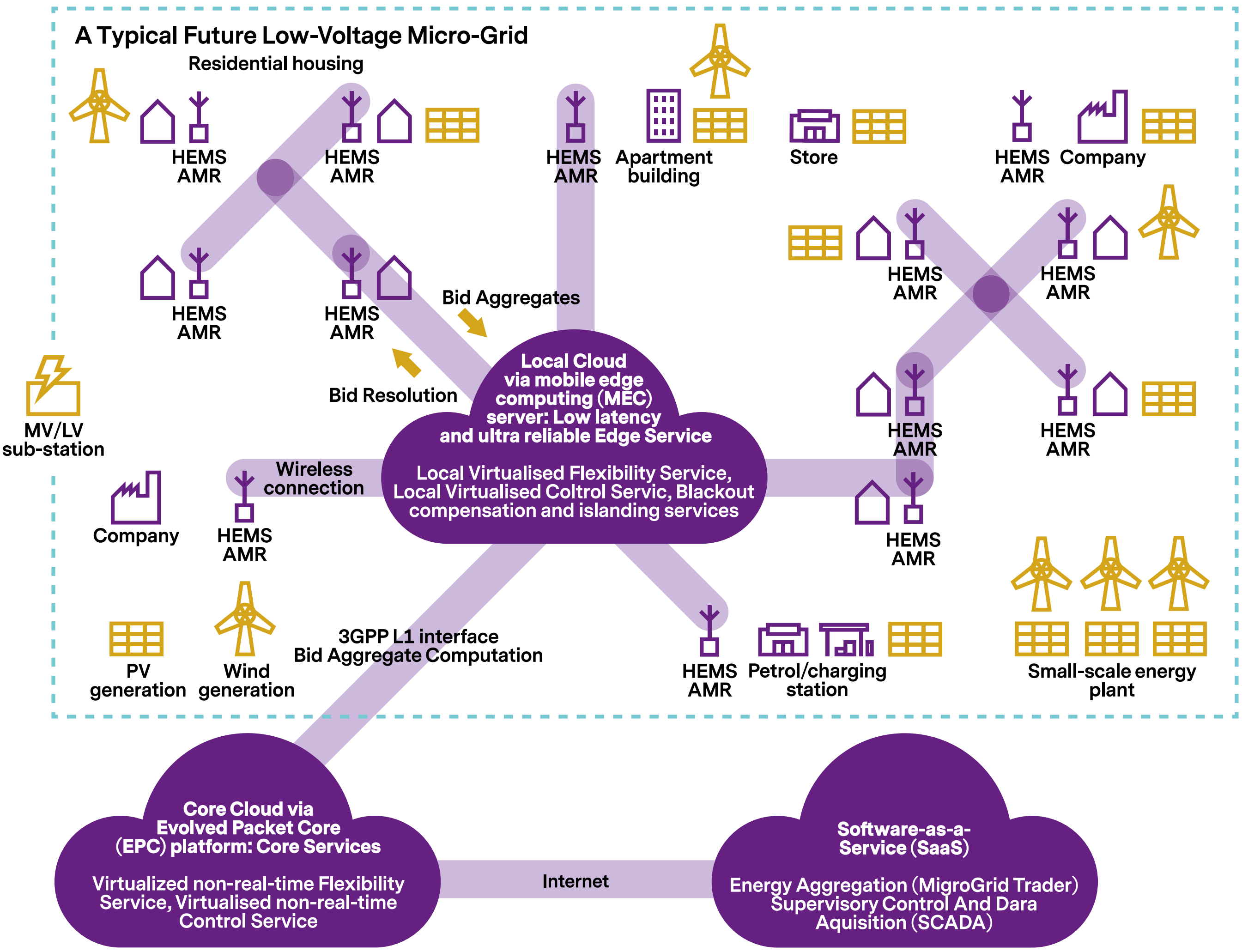

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Figure 8. A model of future micro-grid with virtualized services

ucts such as energy, retail, and transportation. Many of the business paradigms we know today will change drastically in the shared economy. This will also impact audits, regulations, compliance, and governance models over the next decade. Both insurance and banking domains will require one-way communication, primarily in asset tracking. Extremely **low latency requirements** will be important for some **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 assist 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 metropolitan areas, the approximately four billion people at the bottom will not be first class citizens in the realm of digital connectivity. This may cause their exclusion in the financial realm unless we create novel solutions to accommodate them and simplify the technology for them. For example, in India, the use of Aadhaar (a primarily finger-based biometric) has helped reach out to hundreds of millions of people in a trustworthy manner [20]. Such solutions still need to be extended for better network reach, better user education to improve trust, alternate forms of biometric and non-biometric identity, and a natural user experience in mixed reality, etc. This will also require interoperability to increase with other connectivity solutions like satellite communications for sparsely populated areas. Self-healing networks and multiple/heterogeneous connectivity, coupled with edge compute and mixed-reality, may deliver significantly better user experiences beyond today's traditional brick-and-mortar branches.

Shared, metered, and green economy. Another trend relates to a shared economy in which people prefer to pay for what they use. Newer incentive models will emerge that will subsidize the shared use of products and services in an eco-friendly manner. Besides monetary transactions, green incentives and related transactions will increase. This will lead to **micro and nano transactions**. In

contrast with the coarse granularity of today's prevalent products and services, 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 norm. Today, humans and instruments carried by them are the predominant origin of payments (e.g. mobile phones, smartcards, wearables etc.). However, over the next ten years, machines will make most payments (on behalf of entities [humans, machines, or organizations]). Today, examples of such payments are around vehicles automatically paying tolls on roads or in parking lots, or transactions related to electric power supply. In future, the diversity of such devices will increase. In addition to the number of transactions, the security and audits of such transactions will present a major challenge to 6G networks.

Privacy and data monetization. As technologies like distributed ledgers and crypto-currencies transition through the trough of this decade's disillusionment, novel financial scenarios will emerge. Many of these systems will provide a negotiated trade-off between opportunity and discovery, end-point identity, transaction auditability, and privacy. As entities (including machines) increase in the network, identity management will present a major challenge. Both people and devices will require **privacy that protects the management of their identities**. A single entity may have multiple personas, and multiple entities may combine to create a new persona. Contextual transactions and encounters will need to be captured and archived for audit in a manner that protects privacy. 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. Use of distributed ledgers will also introduce extreme reliability and latency demands to the network.

The ethical sourcing of personal data for transaction, including insurance claims and loan sanctions, will be important in processing, and subsequently for compliance. Although multiple approaches exist today, most operate 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. Currently, only governments are involved in financial matters with respect to 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 adapt to challenges because of the volatile nature of such communication systems.

Infra sharing across industries. Increasingly, service providers are under financial stress and are not in a position to provide services in some challenging geographical areas. 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. For example, cameras near banks can be utilized for smart city applications. Instead of the 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 the people who operate it (similar to today's car drivers). 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. It will allow on-demand sustainable delivery of services to sparse remote communities, while limiting concerns about radiation.

2.6 Vision of public safety (critical communications) services toward 2030

The security of European citizens at large-scale events has been a major concern for governments, especially in the last ten years, because of 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 working in emergency and disaster situations, for example, policemen, first responders, firemen, and border guards. To ensure a successful emergency response and support operational management, PPDR authorities have high requirements of communication. Essentially, secure communication services need to be available everywhere, in all situations, at all times.

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

PPDR authorities currently 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 B5G [35]. Broadband technologies will allow new services such as wearable sensors and mMTC, which will 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].

Furthermore, such services will work toward the future goal of utilizing 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 will gather data from public places like railway stations or city squares. Such systems will include video surveillance cameras or specialized sensors deployed by private companies and individuals. PPDR officers themselves will also increasingly use wearable sensors and integrated cameras to generate data from the emergency scene. PPDR authorities may also permanently install sensors in critical locations.

Sensors and cameras may also be integrated with **mobile robots** such as unmanned aerial systems (UAS). Such robots will offer a safe and efficient way of gathering data during dangerous operations and may be used to reduce the immediate risk to human life. Mobile robots will also be suitable for the 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 will enable the delivery of the immersive experiences of an emergency scene, fusing virtual environments and ubiquitous sensor/actuator networks. Virtual and XR reality may be utilized for **pre-incident planning and training for emergency situations**. XR technologies may be a new way to communicate and share information with crowds. Future XR technologies and holograms, as well as advanced AI methods, will make it possible to transfer rich information to and from field operations.

Advanced situational awareness solutions will require efficient identity and object recognition. New personal identity management technologies such as face or fingerprint recognition or iris scanning will identify, authenticate, and authorize individuals or groups in crises. Real-time object recognition (vehicle license plates, firearms) and location information will also be essential to PPRD operational management.

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

2.7 Vision of agribusiness services toward 2030

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

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

Besides the relevant social impact, future mobile networks will play an important role in the development of agrobusiness. Food demand is constantly increasing, pressurizing farms to increase production. In developing countries, where agrobusiness is a prominent element of gross domestic product, the increase in agricultural production is commonly associated with major exploitation of forests and other protected areas. A reliable mobile wireless network that provides coverage in remote and rural areas may support the informatization of fields and farms, triggering new services and applications, and opening new markets for mobile operators. With the appropriate coverage, IoT devices may be used to measure soil properties and 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 may detect early-stage plagues or insect swarms. Drones for pulverization may be automatically sent to precisely pulverize fertilizers or pesticides in affected areas, reducing chemical waste and environmental contamination. Cattle may also be constantly monitored, and the biological data of each animal may be collected and sent to the cloud. Unconventional behavior, fevers, or other symptoms of diseases may be detected before they spread extensively, avoiding embargoes of the entire production of a given region. Finally, the remote and rural area network may be an important tool for compensating the lack of manpower in rural areas. Today, more people live in urban areas than in the countryside [23], and migration is reducing the available human resources on farms. A rural mobile network is essential to implement farm automation, because it is necessary to provide connectivity for autonomous machinery and communication for the control loop in automatized processes. All these technological improvements will increase efficiency and reduce costs in agricultural production. Reliable Internet availability in remote and rural areas may help reduce migration, because new job and education opportunities will emerge in the countryside.

Rural and remote area networks must cover a huge set of requirements, some of them contradictory. **Cell coverage must guarantee** a sustainable number of subscribers per base station, while throughput must support broadband applications with the Quality of Experience (QoE) found in urban areas. The use of frequencies below 1 GHz is an interesting feature of this goal, because the propagation properties in VHF and UHF bands allow the signal to reach long distances. The exploitation of vacant TV white spaces (TVWS) as a secondary network, using a cognitive radio approach, is also very attractive, because MNOs operating in remote areas will avoid paying high prices to use the spectrum in regions where the average revenue per user (ARPU) may be lower than in urban areas. In this case, a narrow band control channel in conventional 3GPP bands, i.e. a 28 1.4 MHz band channel, may be used to organize the network, informing new devices about the channels currently occupied by the mobile network. Spectrum sensing performed by mobile nodes on the request of the base station may 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 on automated farms and autonomous tractors may require **low latency communication over the rural 6G network**. Since the future remote area network may 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 that covers all these applications must be flexible and self-configurable, and able to dynamically share its resources among users with competing requirements.

Since 6G networks are more than just communication, agribusiness may exploit the new foreseen use cases to improve productivity on 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 crops, applying pesticides and fertilizer only to the plants that need these chemicals. Sensing based on THz signals may be used to detect volatile insect pheromones, allowing the deployment of non-toxic substances that jam the insects' chemical communication. The new 6G features may boost agrobusiness productivity to an unprecedented level.

The remote and rural area scenario is very challenging, requiring **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, field trials and performance evaluations will provide data for 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, will researchers and engineers have reliable data to guarantee that future networks will definitely close the connectivity gap between urban and rural areas.

2.8 Vision of software vertical testing and monitoring toward 2030

Self-driving cars, farm automation, robots, and other non-human actors will become increasingly common in the 6G environment. This will increase the required quality of such systems, because malfunctions can lead to life-threatening situations. History has shown that shortcutting software testing and monitoring can lead to devastating consequences. A well-known example is the Arianne 5 rocket, which crashed because of a software malfunction. The same software worked in Arianne 4, but it malfunctioned in Arianne 5 because of its more powerful engines and software shortcuts. Ensuring that non-human actors in 6G cause no harm increases the need for software test automation. Furthermore, if malfunctions do occur, continuous monitoring should terminate non-human actors before any harm can occur.

The software testing advances required in 6G come from fields such as search-based testing, fuzzing, concolic testing, metamorphic testing, combinatorial testing, and model-based testing. For reviews, see [24]. The application of these techniques has been limited in the industry because of their complexity and cost. Yet their application does lead to superior test coverage. Thus, there is not only a need for scientific advances in them but also for practical testing tools that can help software developers ensure the required quality level.

Monitoring non-human actors is a new challenge in the 6G environment. Monitoring shares the Oracle problem with software testing, i.e. how 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 the increasing use of AI in modern systems. Where once there was documentation that under certain conditions a system would behave in a certain way, AI systems have changed all this. Systems are no longer pre-programmed. Instead, 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 such an AI monitoring vs. AI-system can be validated through the self-play-like scenarios that have recently achieved 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 offerings. Any vertical can and will benefit from mobile broadband offering data rates of up to 1 Tbps. If we examine the other needs of verticals, 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. A set of KPIs is provided in Tables 1 and 2 for situations in which broadband services for verticals and assessments of more vertical-specific use cases are omitted. Please note that the KPI values proposed are the most stringent estimated KPI values per category. Hence, not all KPIs per vertical use case are valid at the same time within a use case. This suggests that in KPI assessment within the vertical community, more use-case-oriented studies need to be performed to produce final values for vertical-specific KPIs. For categories where values are not given, nominal means at par with 5G, while high and low mean higher and lower performance need than in 5G respectively.

However, we should 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 at the global level. In the coming years, associations in the commercial domain such as NGMN, GSMA, 5GAA,

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

Table 1. Some Key Performance Indicators for verticals

5GACIA, as well as regional associations, e.g. 5G IA, and international counterparts will contribute to this discussion to achieve a global consensus.

Numerical values are not given for key value indicators. Instead, how a category is related to 5G as we start to develop 6G technologies is indicated. This also indicates whether legislative, regulative, or standardization activities are required. For more discussion o these topics, the reader is referred to [55] and [56].

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
Agri-business	High	< 10 cm	High (Precision agriculture)	Low	High	> 50 km

Table 2. Some Key Performance Indicators for verticals

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
Agri-business	Nominal	High	Nominal	Nominal	High

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

Need for trials

4

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

As a solution to ever-increasing and diverging requirements, the softwarization of networks and open source platforms and cloud native solutions have been proposed. Whether this offers sufficient flexibility 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 latency and especially jitter in such networks? How do you ensure the compatibility of a multitude of vendors’ devices and software?

The development of a new technology is typically simulated first. When a theory has been proven sufficiently accurately, the technology is brought to the real world through implementation in hardware as a proof of concept, optimized, and then productized. These steps yield one major topic: implementation loss. This means that even if a system seems to work perfectly in the simulation, there are various reasons for it not to do so in the real world. A very simple example is that simulation may utilize floating-point data formats, while only integer data formats are used in the hardware, which basically causes differences in calculation accuracy. This leads to the conclusion that in the emergence of a new technology, one must be aware that the system will and must be trialed in depth in hardware.

Such trials are of course only significant if they rely on well-defined and relevant test cases, and can be repeated by anyone willing to invest the effort. Otherwise, no fair and neutral comparison and evaluation will be possible, and it will come down to trusting a producer’s self-evaluation benchmarks. This may be acceptable considering streaming services or voice calls, but it is unacceptable in the case of mission-critical communication. It can be concluded from this that for each KPI defined for the system, conditions for which this value must be achieved need to be defined at the same time.

Nevertheless, this is not as straightforward as it may seem, because, as stated above, “relevant test cases” are a wide field and may depend on individual industry types. Of course, this has already been addressed in many use cases and statistical approaches, but when mission-critical communication is considered, it again boils down to challenging corner test cases that need to be fulfilled—for example, in considering a radio-controlled device that is moved inside an obstructing object like a metal box. This will not be covered by statistical approaches, as it is clearly one of the scenarios in which a wireless communication system typically fails. However, this is indeed an interesting area in which genuine trust in a wireless system needs to be created.

In addition to the environments blocking and reflecting properties, the interference and coexistence situation also needs to be addressed to include realistic disturbances, thus providing an estimate of actual best-case performance as well. This also indicates that a typical traffic load needs to be present.

When the above test cases have been defined, it will be necessary to define a trial methodology, 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 perspective of the vertical industries and end users who will use them.
- Technical requirements: The business requirements will be converted into technical requirements at the 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 on GSMA Generic Slice Template (GST) and Network Slice Type (NEST) concepts intended to consolidate a common method to which the industry can refer in describing 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 will include a standard deployment, as well as 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 differ considerably in their working environments, it may be worthwhile to **define testing environments which are individual to a certain industry type**. Thus, the goal should be to create a flexible and portable testing solution. With this, it will become possible to evaluate new testing ranges regarding their compliance with the reference testing system, and the compliance with given performance criteria can thus be evaluated by various neutral bodies. **Only by taking this approach, will the industry-required certification of 6G industrial components become 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/m3 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?
Agri-business	· 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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6G White Paper on Validation and Trials for Verticals towards 2030's

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