6G: THE NETWORK OF TECHNOLOGY CONVERGENCE

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INTRODUCTION

Cellular technology evolution across multiple generations has consistently sustained the global economic growth. Each of these generations has uniquely contributed to boosting the world Gross Domestic Product (GDP) by addressing key industry pain-points and enabling new business opportunities not possible with previous generation networks. 6G will not be an exception here.

This paper will elaborate on some potential market opportunities 6G will enable, notably the build-up towards the metaverse. Most importantly, it will define the 6G vision and the three types of convergence this vision will encapsulate, namely:

- The communications and computing convergence referred to as 6G native intelligence in this paper.
- The telecommunications convergence whereby 6G becomes the network of networks bringing many access technologies together to enable ubiquitous coverage around the globe.
- The convergence between virtual and physical spaces as the industry cruises its way towards the metaverse. Not only could this enable new experiences and use-cases, but it could also help in reducing the risks attached to operating businesses, infrastructures, and the planning of new products and services.

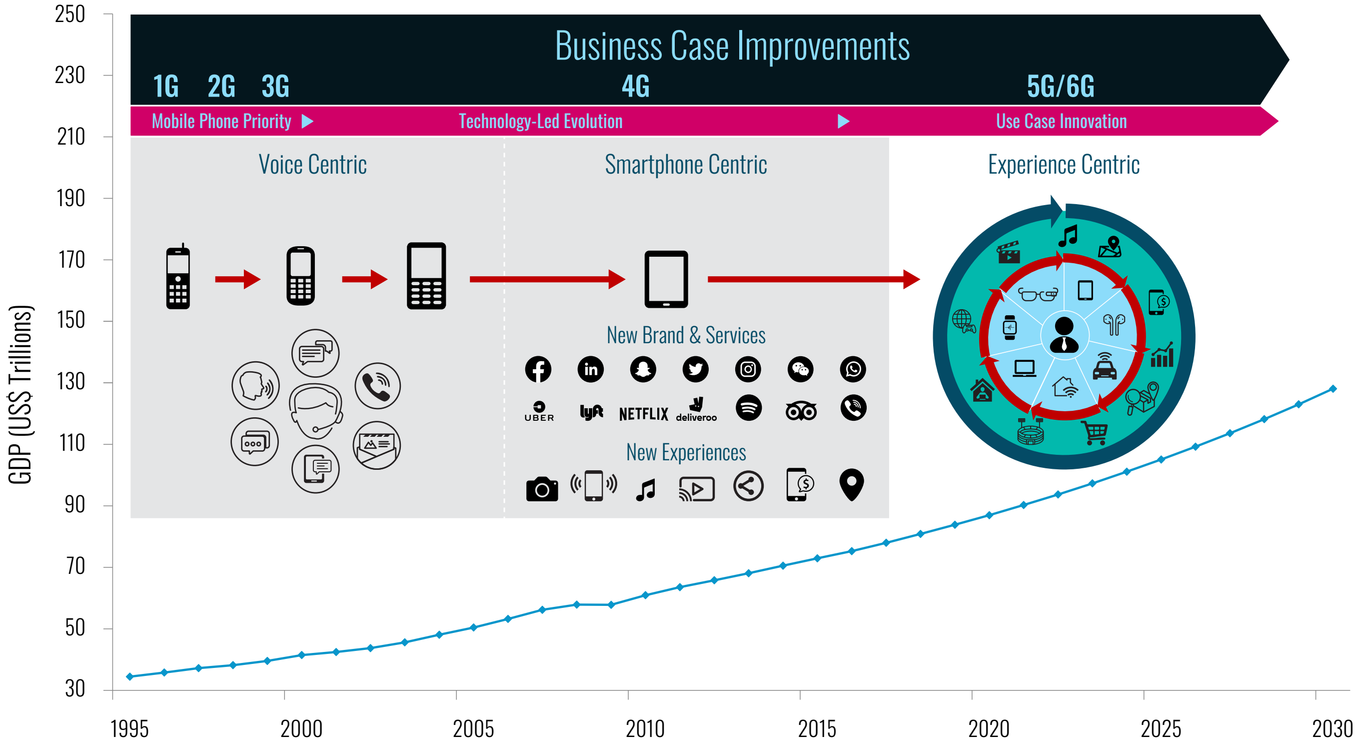
IMPACT OF CELLULAR INNOVATION ON ECONOMIC GROWTH

Cellular technology innovation has been instrumental in creating wealth in recent decades and has contributed significantly to global economic growth, both directly and indirectly. Since the commercial launch of 1G in 1979, a new mobile network generation has been introduced every decade to transform consumers' lifestyles and enable businesses to deploy new tools to enhance productivity and work efficiency. Cellular technology innovation has been always linked to enhancing the user experience and introducing new types of applications that would not have been possible with previous technologies. This innovation has been introduced in generation cycles, with each contributing massively to boosting demand for mobile services and creating business opportunities for new mobile services and new use-cases. For example, while 1G was the first generation to enable mobile telephony, the introduction of 2G made mobile calls more reliable,

ubiquitous, and cheaper. 3G was a key milestone in mobilizing workforces and offered users the flexibility to access their emails, the Internet, and work servers from anywhere and at any time. 4G introduced mobile broadband services on the move and enabled new businesses such as Uber, Didi, Deliveroo, Snapchat, Periscope, and Instagram to emerge and thrive.

Figure 1: Cellular Technologies Pillars to Global Economic Growth

(Source: ABI Research)



Today, the industry is on its way to experiencing the benefits of 5G. The enhanced performance of the technology, including faster speeds and lower latencies, are already opening new business opportunities beyond the consumer market. The technology promises to transform many industries, including automotive, transportation, supply chain, manufacturing, energy and utility services, retail, agriculture, health, education, enterprise, and many other industry sectors. Power efficiency, flexible deployment, cost effectiveness, and bandwidth availability across licensed and unlicensed spectrums are just a few of the many benefits 5G has over previous generation networks. Thanks to these benefits, 5G will be able to accelerate the Internet of Things (IoT) economies of scale through support of a multitude of mission critical, time sensitive, and massive IoT use-cases across various end-markets. Now that 5G commercial launches are rolling out in different parts of the world, targeting both consumer and enterprise applications, the industry is already preparing itself for 6G, the next generation of telecommunications networks.

This paper will focus on the 6G vision and roadmap, its foundation technologies, and its key attributes. The paper will also look at how 6G can be differentiated from previous technologies and what business potentials the technology could unlock across various industries and market verticals.

FRAMING OUT THE 6G VISION

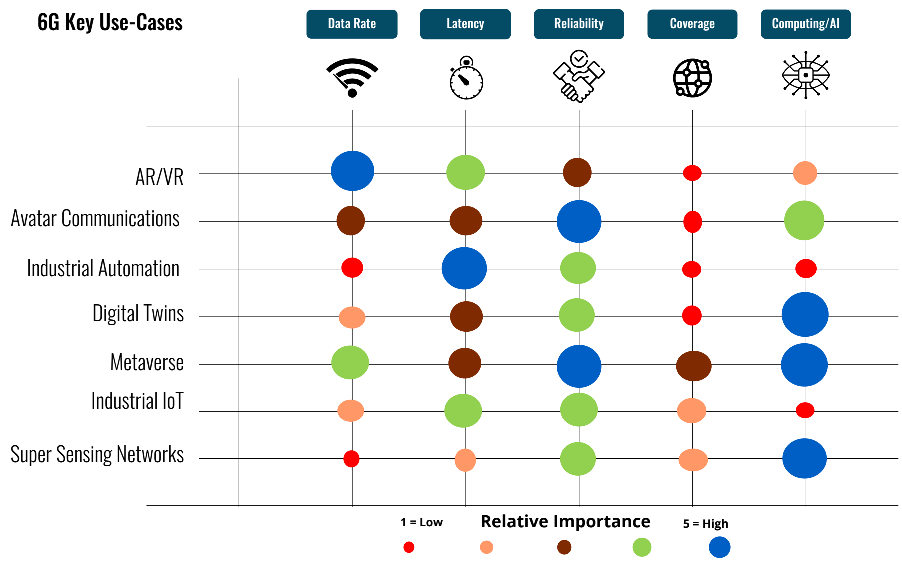
Now that 5G networks are making their way to commercial deployments and the industry is learning about key pain-points across multiple industry verticals, it becomes clear connectivity will no longer be the focal point for shaping the next generation networks. Technology developers, infrastructure suppliers, and implementers are envisioning 6G as a platform able to accommodate innovations coming from multiple disciplines, including connectivity, computing, artificial intelligence (AI), sensor networks, and virtualization. These innovations should be implemented natively within the core network and RAN infrastructure to be able to address many existing pain-points and facilitate the creation of new use-cases and business models not possible with the current network generations.

NEW APPLICATIONS AND USE-CASES ENABLED BY 6G

After virtual, augmented, and mixed reality technologies, the next wave of multimedia innovation is going to be more realistic, immersing the real world with the virtual world of things to enable a new type of applications, including the metaverse, avatar communications, digital twins of things, and sensor networks. These applications have even more demanding network requirements in terms of workloads, time sensitivity, intelligence, and quality of service, which could potentially challenge the way they are carried by current generation networks, including 5G and 5G Advanced.

Figure 2: 6G Use Cases and Relative Network Requirements

(Source: ABI Research)

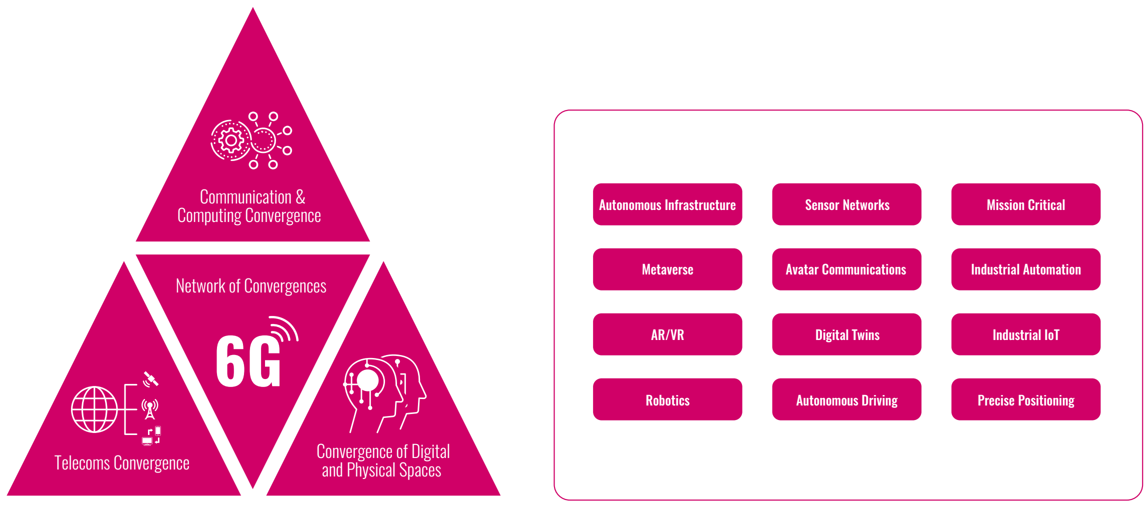


PARADIGM SHIFT FROM EXISTING NETWORK APPROACHES

Unlike previous cellular telecommunications technologies that have so far focused on extending the performance of the network towards higher bandwidth, lower latency, and better reliability, 6G will be designed to address additional requirements of existing and future applications as highlighted in the section above. These requirements include global coverage, spectral efficiency, lower carbon footprint, cost effectiveness, bullet proof security, and embedded intelligence through native AI implementation.

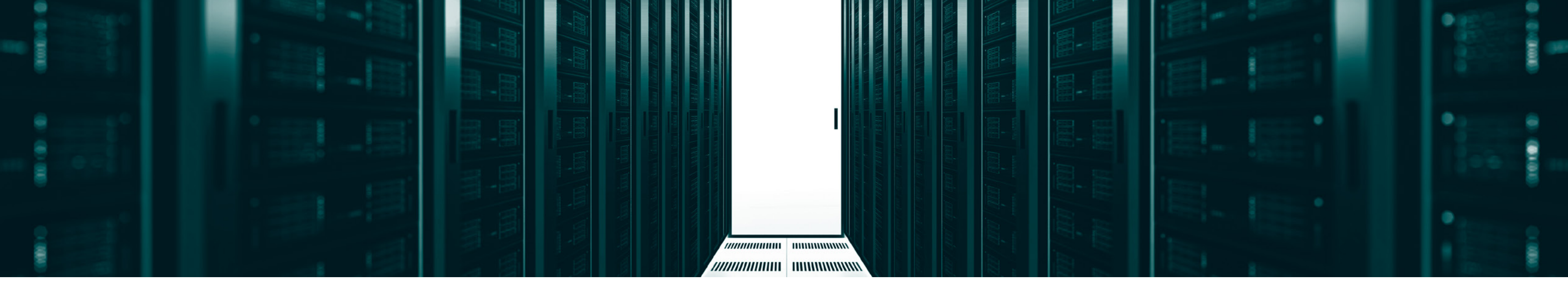
Figure 3: Three Pillars Behind the 6G Vision

(source: ABI Research)



To meet these requirements, 6G needs to be supported by additional technology pillars deemed unessential in previous generation networks. 6G should bring new paradigms to ensure end-to-end service delivery to address new use-cases without compromising requirements of existing applications and markets serviced with current generation networks. These paradigms will be based on three types of convergence, namely: computing-communications convergence, telecoms convergence for enabling ubiquitous coverage around the globe, and the convergence between digital and physical spaces for enabling metaverse applications.

Previous network generations have focused on bringing voice (2G), data (3G), mobile broadband (4G), and high bandwidth, high-capacity data access (5G) to consumers and businesses. These generations were the first of their kinds, and the whole supply chain (from Research and Development to standards development to infrastructure supply to service roll-outs) rallied to introduce these services. As such, all of the aspects that 6G needs, including automation, end to end service delivery, and computing-communication convergence, could not have been implemented with previous generations as neither supply nor demand were ready for them. For example, network automation has initially



been implemented as a single vendor, proprietary solution in its early stages but is now evolving to open networks and multi-vendor automation. This technology, and many others, could not have been implemented in previous generations and in some cases, they were not even possible due to processors and even semiconductor technologies not being ready. On the other hand, several of these secondary areas are now maturing, allowing 6G foundations to be developed.

The following sections will focus on these three types of convergence as key building blocks for 6G vision.

THE THREE PILLARS OF 6G VISION

COMPUTING AND TELECOMMUNICATIONS CONVERGENCE

THE RATIONALE BEHIND TELECOMS NATIVE INTELLIGENCE

ABI Research refers to Telecoms Native Intelligence as telecommunications systems that consider artificial intelligence and computing as integral parts to its architecture not just add-on optional features. From this perspective, 6G will be designed for enabling native distributed intelligence across various nodes of the industry supply chain. To put this into a context, only 1% of data generated by connected humans, apps, and machines are processed, analyzed, and used to make better and informed decisions. There is a huge opportunity to refine and extract information from every single data point generated in the process in a trustworthy manner. This is where 6G will be useful. 6G will be the key enabler for massive data processing compared to 4G and 5G. This is why the industry needs to figure out how the computing infrastructure and the connectivity infrastructure, currently two separate domains, can be integrated to address key enterprise pain-points. It will take time to get there but that will be one of the most important missions of 6G.

While 5G is considering computing and intelligence functions as add-on functionalities that could be implemented incrementally on the top of connectivity, in the 6G era computing and intelligence will be implemented natively in the network and will be considered as integral parts of 6G standards, almost as important as connectivity. Under this approach, connectivity and computing will become intertwined to enable more distributed intelligence across the entire connectivity fabric. It is this distributed intelligence that will enable information to be delivered between machines, infrastructures, and virtual objects in real time, more reliably, and in a safer way. It is this “in-infrastructure” intelligence that will enable applications and services to interact with communications networks more intelligently and provide more accurate information.

TOWARDS NATIVELY INTELLIGENT TELECOM INFRASTRUCTURE

Software-hardware decoupling represents a fundamental catalyst of the convergence between communications and computing domains since these functions could potentially be executed on the same Commercial Off-The-Shelf (COTS) platforms. This decoupling is already supported in current generation networks including 5G, which will prepare the foundation for natively intelligent infrastructure

in 6G. This decoupling will enable many network and computing functions to be distributed across the entire infrastructure from the cloud to the end devices and sensors. 3GPP 5G standards, Service-Based-Architecture (SBA), and Control and User Plane (CUPS) decoupling in particular, together with ETSI's Multi-Access-Edge Computing (MEC) framework will increasingly address the interaction between computing and network functions to align with the software defined network paradigms. This alignment will enable the network to bring intelligence closer to end-applications and services at the edge of the network. The next step will be to immerse these two domains, i.e., connectivity and intelligence, under the same framework. 6G will consider computing, AI, and data processing as native parts of the network and will enable a smooth orchestration and synchronization of workloads across computing and connectivity domains.

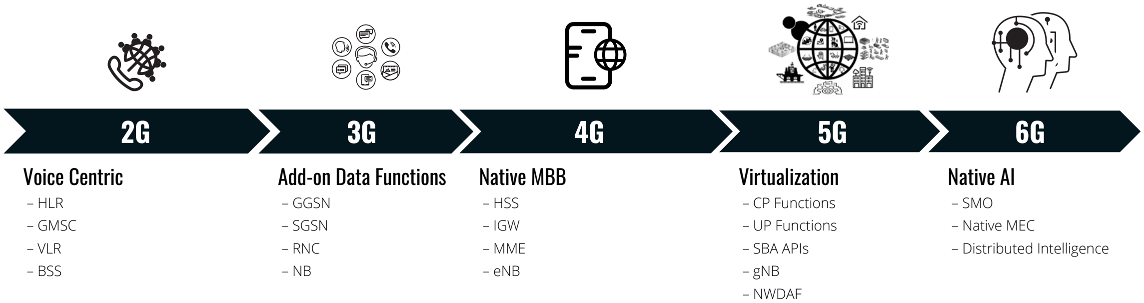
As mobile networks evolve towards 6G, AI will become an essential component of the network architecture to enable intelligence on demand, either for automated operations of the network, service management and orchestration, or for providing AI services on demand to a plethora of external applications anytime and anywhere.

To ensure automated operations, better performance, and sustainability of the network, AI will be an essential function used in many layers, from the optimization of beam forming in the radio layer to automated network resource management and scheduling at the cell site. In fact, 5G Advanced will already set the foundation for AI implementation within the network. AI will enable the network to optimize its resources in line with traffic demand. It will also ensure better management and optimization of radio resources across disaggregated networks. However, implementing AI as a native function of the network will enable 6G to become the first-generation network to promote large scale deployment of self-optimized and automated network.

Native AI implementation will also bring intelligence closer to the end user. The goal here is to allow applications and services to tap into connected computing resources available at the edge of network and the data they need to make better use of these resources. Under this vision, computing and communications resources need to converge with the aim of enabling end-to-end quality of service to applications carried over 6G networks. From this perspective, 6G will no longer be a communications centric network but one where connected intelligence is a cornerstone.

The convergence between computing and communications infrastructures, enabled by 6G, will provide far richer experiences to the end-user. Here again, 5G Advanced is setting the foundation for this trend through the addition of Network Data Analytics Function (NWDAF) to 5G new core. The aim of this addition is to enable AI-optimized network and mobility management. However, 5G only focuses on the use of AI to optimize the network itself but it is not designed to provide native AI features to end-users, applications, and services.

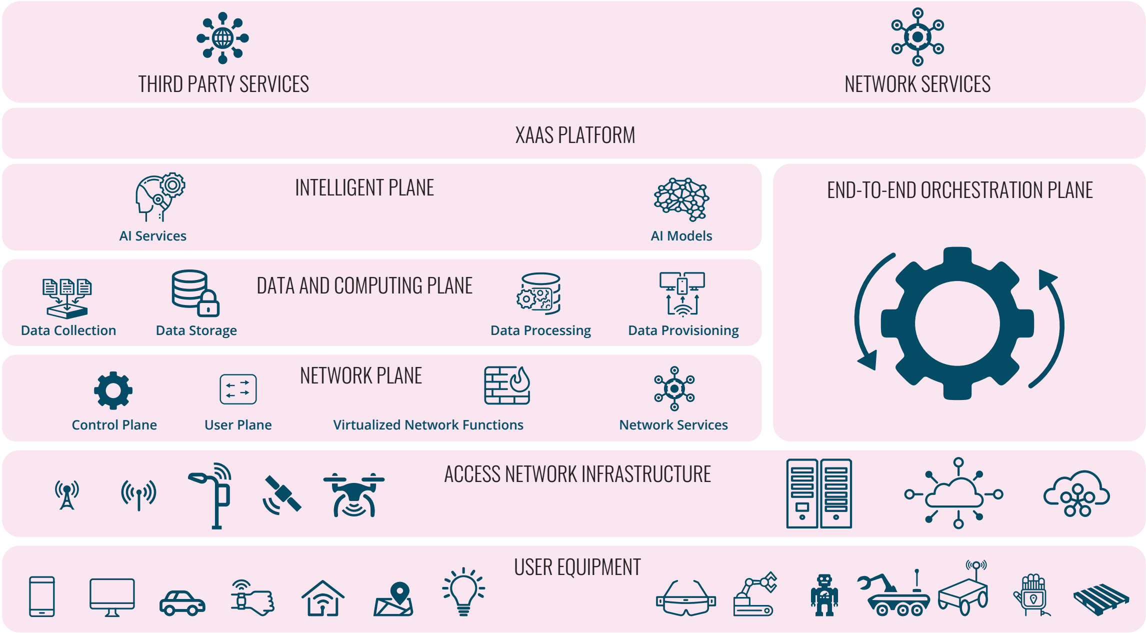
Figure 4: Mobile Network Evolution towards Native Distributed Intelligence
(source: ABI Research)



In contrast, edge computing and AI should be treated as native components of 6G. They will be essential for moving intelligence from the central cloud to the edge of the network and ensure end-to-end orchestration of workloads across both the communication and computing domains.

To realize this vision, a fundamental architectural redesign of the network is required to bring computing and communications resources together without end-to-end latency. For this to happen, there is a common consensus among industry players that 6G specifications should consider a native implementation of computing and AI functions as illustrated in the figure below.

Figure 5: High Level 6G Architecture for Computing and Telecoms Convergence
(source: ABI Research)



TELECOMMUNICATIONS CONVERGENCE

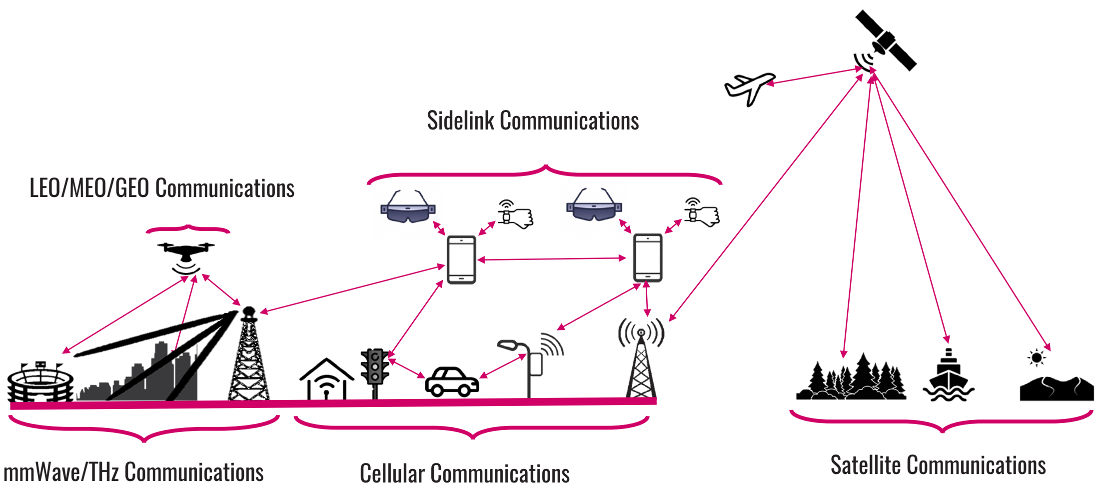
Another facet of 6G consists of bringing multiple network technologies, including fixed, mobile, nomadic, and satellite communications under a single framework. The convergence between these networks will enable seamless information flows across multiple devices, infrastructures, and assets.

To provide global coverage, and seamless and cost-effective telecommunications services, 6G network infrastructure should be ubiquitous and not limited by the coverage of radio communication networks, as is the case with 5G and previous generations of cellular networks. Data traffic should use all access technologies available according to their strengths, whether that be fixed networks, cellular networks, or satellite networks. This is to ensure cost effective, agile, robust, resilient, and adaptable delivery of communications and computing services anywhere, anytime in line with the end-user demand.

To materialize this global and ubiquitous experience, 6G specifications should offer great architectural flexibility to accommodate heterogeneous spectrum capabilities beyond the current terrestrial systems of today. Non-Terrestrial Network (NTN) systems, including remote satellite communications, low orbit satellites, or unmanned aerial systems should be an integral part of the 6G network deployment.

6G should also enable user-equipment to communicate directly in short range, using device to device (D2D) communications protocols. With its intelligent mobility management technology, 6G should enable data traffic to be offloaded to the best access technology. For instance traffic could be carried over D2D or Wi-Fi in the case of short-range use-cases when convenient, over satellite communications in the case of airspace, sea, and lands not covered by terrestrial communications, or the traditional terrestrial communications in the case of wide area networks coverage.

Figure 6: 6G For Global and Ubiquitous Coverage and Data Offload



Here again, future generation 5G networks are already laying the foundation for this vision by including satellite communications and D2D communications as critical components in future 5G 3GPP standards. Indeed, 5G Release 17, expected to be Frozen in 1H22, is the first 3GPP specification to factor Non-Terrestrial Network (NTN) requirements and the satellite communications' role in the 5G infrastructure. However, 6G will enable a smooth traffic handover between terrestrial and non-terrestrial networks to enable a better and intelligent utilization of the network resources while offering ubiquitous service coverage across the globe.

Similarly, the first generation of D2D communications, commonly called sidelink, were introduced for the first time under LTE Release 12 mainly to service vehicular communications (Vehicle-to-Everything (V2X)). Further enhancements are expected in future 5G releases. For example, sidelink enhancements have been introduced under Release 17 to enable smartphones and wearables to communicate with vehicles, enhancing public and pedestrians' safety. 5G Advanced, specified under Release 18 and above, will bring further enhancements including sidelink positioning for improved accuracy, power efficiency, and integrity of positioning measurement used for Simultaneous Location and Mapping (SLAM) applications. Sidelink specifications will continue to evolve under 6G to enable devices to establish their own ad hoc network and communicate with devices belonging to that network without using public radio access resources as an intermediary. Under 6G, the full D2D communications capabilities will enable a massive amount of traffic to be offloaded as devices can communicate directly and share data with other devices in their proximity without the need for public network intermediation. Not only this, but D2D will enable proximity services to be offered with premium quality in line with their expected ultra-reliability and low latency requirements.

CONVERGENCE OF DIGITAL AND PHYSICAL SPACES

Current generation networks are designed to carry different types of services independently. For example, 2G and 3G are designed to carry voice and basic data services, 4G and 5G non-standalone are designed for enhanced mobile broadband (eMBB), and IoT services are carried over specialized networks including long range (LoRa), narrowband (NB)-IoT, SigFOX, or RedCAP in the future. 6G should be designed to carry all types of services and information using the same infrastructure. 6G will come with a huge capacity, up to one TBps per base-station, ultra-low latency below one millisecond, reliability up to ten times for certain mission critical services and dynamic slicing. The network should be able to accommodate the requirements of different device types, from simple sensors to smart devices, and different application types belonging to either the physical or the virtual domains.

In addition, a new wave of digital innovation is cruising its way towards building the metaverse, a confluence of interconnected open platforms bringing the virtual world and the physical space together under a single technology ecosystem. This concept has the ability to help multiple industries to reduce the risk in planning

their products and services, optimize operating expenditures (OPEX), and increase the productivity of their businesses. 6G promises to blur the boundaries between the virtual and real spaces. The technology will enable the extension of the end-user experience beyond physical reality. Under this vision, users will be able to visualize, monitor, operate, or even simulate the reality of physical objects in a digital world without any physical constraints. Not only will this enable remote control of physical objects in real-time, but it could also enable the network to identify and predict potential problems otherwise not detectable in a real space. Simulating real-world solutions in a digital domain will lead to more accurate results and lower hardware repair costs by predicting maintenance needs and scheduling. Simulations could also lower the cost of new projects by eliminating the need for unwanted physical trials and proof-of-concept designs.

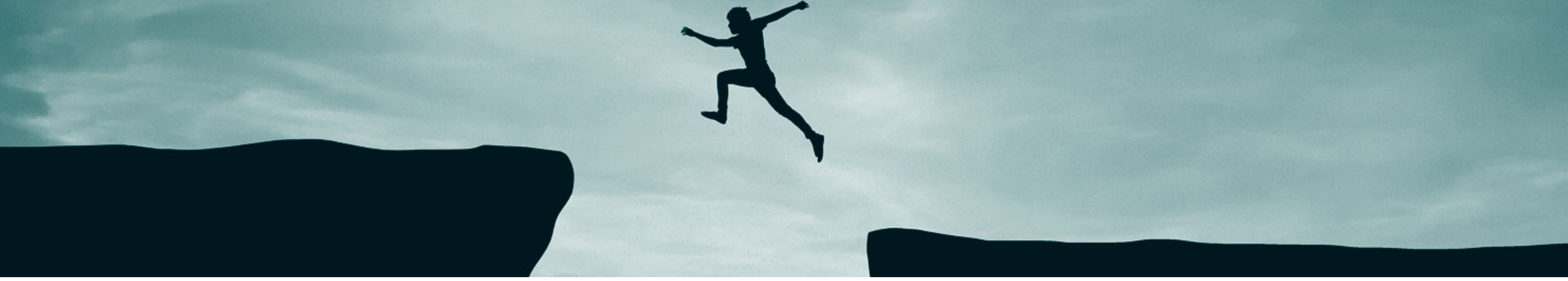
The realization of the metaverse will rely on a widespread deployment of interconnected sensory networks, including cameras, photodiodes, inertial sensors, time-of-flight sensors, ambient sensors, and biometric sensors. Sensory Networks will play a fundamental role in the digitization of physical assets and the creation of the digital twin world.

In fact, many Research and Development initiatives are currently investigating the build of such networks, with China leading this trend. For example, China Unicom and Huawei are working on a new concept known as "smart super sensing networks", whereby new sensing capabilities are introduced into traditional cellular networks to enable the creation of digital twins of various network infrastructure assets. The two companies claim they are already working with ecosystem partners to define requirements and develop an application platform around their smart super sensing networks concept. They also said they are working with 3GPP and the China Communications Standards Association CCSA to bring this concept to 5G Advanced specifications.

Here again, the industry will not wait for 6G to introduce sensory networks. Early proof of concept and pilot commercial implementations will start with 5G Advanced. 6G will likely improve and democratize this approach and, most importantly, widen its potential to more application scenarios, which will drive the development of many lucrative use-cases in smart cities, smart transportation, manufacturing, healthcare, smart enterprises, entertainment, consumer services, and many other verticals.

CONCLUSIONS AND KEY TAKEAWAYS:

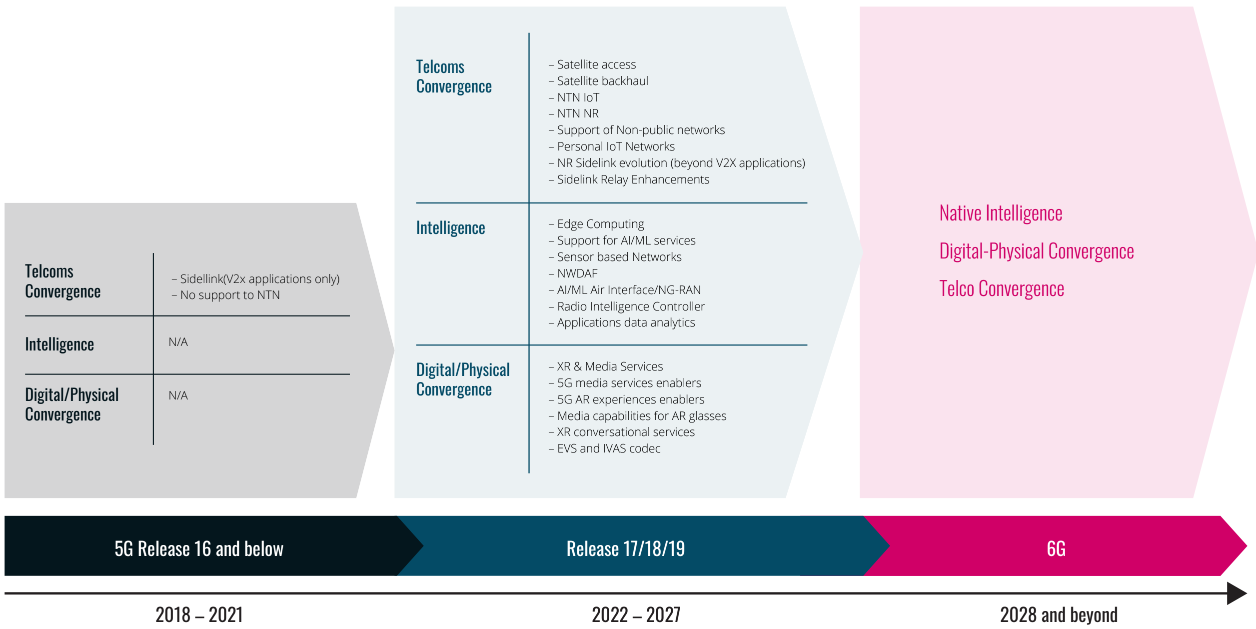
No doubt 6G will have a significant impact on global economic growth and will enable new business opportunities not otherwise possible with 5G and previous generation networks. The technology will be a fundamental building block towards the metaverse. It promises to bring intelligence close to the end-user while building bridges between physical and virtual spaces to create new use-cases while enabling the industry to better optimize their operations and the business planning of future products and services.



To materialize this vision, 6G should lay out the foundation for many technologies, including computing, AI, and telecommunications networks to come together and drive structural changes to the way the mobile infrastructure is designed. 6G should bring new architectural paradigms different from how previous generation cellular technologies were designed and conceived. These network generations, 5G included, have so far focused on cellular telecommunications functions as core building blocks while other access technologies, such as NTN, computing technologies, or artificial intelligence, are treated as add-on features that are unnecessary in the construct of the infrastructure. In contrast, 6G infrastructure should inherently provide holistic and end-to-end solutions to the key pain-points facing the industry and realize the full promise of industry digital transformation and build-up towards the metaverse. These solutions should be based on the three convergence pillars discussed in this paper, without which the 6G vision could be compromised.

However, for this vision to materialize, a significant number of new innovations need to take place in the domains of security, end to end orchestration, automation and many other technical areas, as discussed in previous 6GWorld white papers. Moreover, the 6G supply chain needs to retain its global status and remain free of geopolitical influences to allow 6G to accelerate and create a critical mass of enterprise use cases. On the technical side, the industry is gearing up to address these requirements, with hyperscalers, infrastructure vendors, telecom operators and content providers aligning towards 5G and 6G network capabilities. This alignment will further illustrate the capabilities of 6G, and by the time the 6G standard is ready, the market will have matured for several use cases to be commercialized.

Figure 7: 5G evolution laying out the foundation for 6G technology convergence



Signs of such an alignment is already reflected in the evolution of 5G standards which will increasingly characterise 6G as the network of networks and the foundation for conevergence of many technologies. For example, many communications access networks, including satellite and other non-terrestrial technologies as well as sidelink, Wi-Fi, and other non public access networks will increasingly be supported in future 5G releases. Also, next generation 5G specifications will be able to accommodate many AI and computing features to enable the network resources to be automated and more optimized. Future 5G releases will also be able to provide more support to augmented and extended reality services and experiences, which will bring us one step closer the metaverse vision.

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