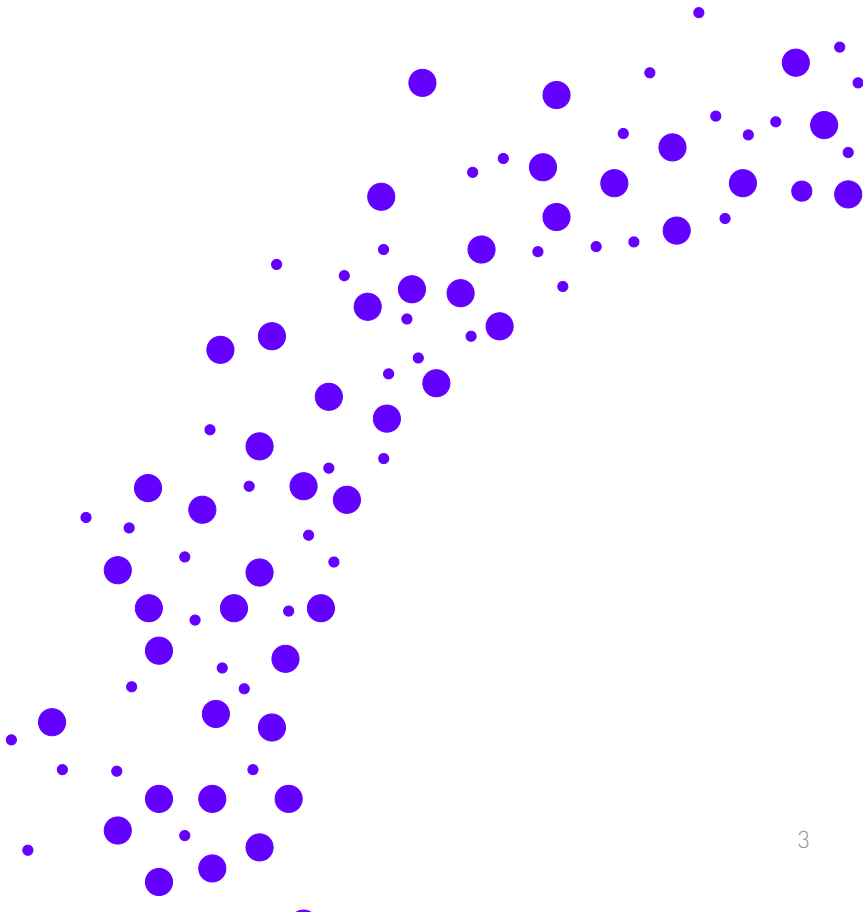
TDRA | هيئة تنظيم الاتصالات والحكومة الرقمية
TELECOMMUNICATIONS AND DIGITAL GOVERNMENT REGULATORY AUTHORITY

جامعة خليفة
Khalifa University

Next-Generation Connectivity In The UAE

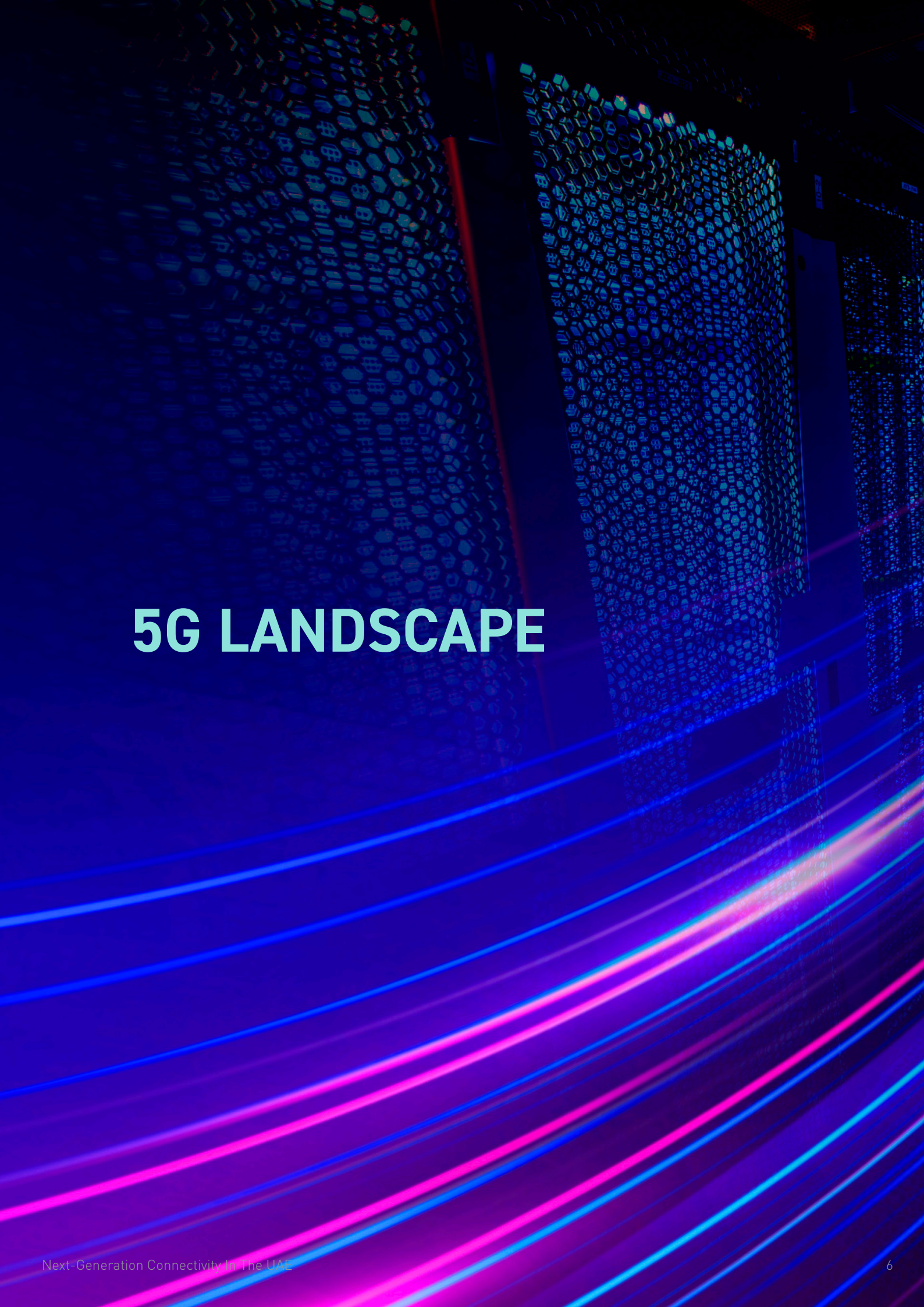
Table of Contents



Executive Summary

As the UAE is strategically positioning itself for the advent of 6G technology, this white paper aims to outline the imperative development of a 6G roadmap in the UAE. As the global telecommunications industry advances towards the sixth generation of mobile networks, it becomes essential for the UAE to strategically plan and invest in 6G technology to maintain its leading position in emerging technologies.

In 2016, the Telecommunications and Digital Government Regulatory Authority (TDRA) initiated its 5G project, establishing committees for spectrum, network, and verticals. The 5G roadmap aligned with the vision of making the UAE a global leader in information and communication technology (ICT). Early trials and demonstrations showcased 5G technology at various exhibitions, culminating in the successful launch of a commercial 5G network in 2018. The UAE became a pioneer in the Middle East and North Africa (MENA) region, and among the world leaders in 5G deployment. The existing telecommunications landscape in the UAE is robust, with 5G networks already making a signifi ant impact. However, as demands for higher data rates, lower latency, and increased connectivity grow, the need for 6G technology becomes evident. This white paper identifies the gaps and challenges that 6G aims o address in the context of the UAE's specific needs. his white paper serves as a foundational guide for the establishment of a comprehensive national strategy. As outlined in the paper, we recommend that the 6G roadmap should include forming a 6G task force, drawing insights from leading countries' studies, and focusing on key pillars such as Intellectual Property protection, R&D plans, startup support, excellence labs, standardization activities, and international collaborations. The World Radiocommunication Conference (WRC) 2023 has played a crucial role in setting spectrum foundations for 6G.. The Path to 6G Innovation program in the UAE outlines initiatives for research, live trials, consortiums, open interfaces, security solutions, localization of vendors, and the recommendation for the creation of a National Lab for O-RAN. This multifaceted approach aims to position the UAE as a global hub for 6G development, fostering economic growth and technological sovereignty. Within this context, the UAE is actively investing in the research and development of 6G technology, aiming to lead in technological advancements and become a hub for cutting-edge research in the region. The commitment to 6G research involves significant contributions from academia, which plays a crucial role in shaping the next generation of wireless communication technology. Academic institutions contribute to long-term research, innovation, and the creation of foundational knowledge essential for 6G development.



5G LANDSCAPE

The fifth generation of wireless networks (5G) marked a significant leap forward compared to its predecessors, introducing new milestones with respect to connectivity, latency, bandwidth, energy efficiency, and user data rates, including supporting emergent technologies such as edge computing and artificial intelligence (AI). Such advancements facilitated the emergence of new opportunities in a variety of market verticals, e.g., healthcare, education, manufacturing, transportation, and entertainment. As a keystone of 5G, service-based architecture has defined a fundamental architectural concept of how 5G networks are designed and operated, where different services are supported and are leveraged to enable the use-cases of interest. Compared to 4G, 5G brings up the following services:

Enhanced Mobile Broadband (eMBB):

Through advanced modulation schemes and the utilization of high frequency communication, 5G provides significantly faster data rates compared to 4G, with the potential for gigabit-per-second (Gbps) data rates. Following the continuous developments, especially those brought about by 5G Advanced, eMBB can o er more than 1 Gbps peak uplink rate and a downlink rate of more than 10 Gbps.

Ultra-Reliable Low Latency Communications (URLLC):

Among other aspects, the significance of 5G is demonstrated through extremely low latency communication, i.e., faster than human visual perception and processing, rendering it a promising technology for near real-time remote control of wireless devices. In reference to the 3rd Generation Partnership Project (3GPP) Release 17, 5G can achieve end-to-end (E2E) latency of 1 ms with up to 99.9999% reliability. This performance is supported by several technologies including blind retransmission and URLLC-eMBB coordination.

Massive Machine Type Communications (mMTC):

In the context of internet-of-things (IoT), 5G has introduced a radical shift from the narrowband IoT (NB-IoT) to mMTC, enabling millions of low-power IoT devices within a square meter to connect simultaneously, with 100 Mbps channel rate. Compared to 4G, 5G can support IoT devices with double rate at reduced energy consumption (up to 20% reduction), and reduced latency (5-10 ms) and cost. Furthermore, 5G Advanced technologies currently being explored at Etisalat by e& will introduce 5G Reduced Capacity (RedCap) devices in the near future. RedCap is a variation of 5G which enables less complex and less costly IoT devices to operate on the 5G Advanced network, while also being more power efficien

Network Slicing: Network slicing is a fundamental concept developed and introduced with the 5G technology, allowing operators to create multiple virtual networks on a shared physical infrastructure. This paradigm endows 5G networks with a level of customization, isolation, and optimization that were not o offered by earlier wireless generations. Using network slicing, network operators can create multiple slices to cater for the diverse requirements of di erent services, including URLLC, eMBB, and mMTC, where each slice can enjoy unique characteristics in terms of latency, bandwidth, rate, etc. Several live network configurations and trials of slicing solutions have already been deployed globally. The industry has implemented slicing

for 5G Virtual Private Networks, Fixed Wireless Access slicing, Edge Slicing, Slicing for Applications, and Sliced Private Wireless. In addition, they introduced an innovative new solution that enables Android smartphone users to purchase and activate network slices on-demand from their operator. This will allow end users to enhance their experience across a wide range of applications such as gaming, streaming, broadcasting, and social media.

New Frequency Bands:

With the advent of 5G technology, new frequency bands were introduced to serve for the increased data rate and capacity demands. In particular, two main new frequency ranges were identified or 5G, namely, the millimeter wave frequency band (with carrier bandwidth of 100 – 800 MHz), and the sub-6 GHz C-band (with maximum carrier bandwidth of 100 MHz). The mmWave band is aimed for high-speed, short-range applications in dense urban areas, while C-Band is suitable for urban and suburban areas. Furthermore, Etisalat by e& has initiated testing of the novel 6 GHz band for 5G and 5G Advanced in 2022, with additional testing in 2023 as led by TDRA and in coordination with Du. The 6 GHz band will provide even larger bandwidths than are available in C-Band while simultaneously providing significantly better coverage than mmWave.

5G Fixed Wireless Access (FWA):

Compared to 4G, 5G offers reliable internet connectivity to homes, businesses, and other fi ed locations with up to 1 Gbps speed. This supports multimedia applications, including high speed 4K and 8K video streaming and high-resolution online gaming. It is envisioned that by 2028, 300 Million FWA connections will be over 5G (this constitutes 80% of the overall FWA connections) [1].

Key Achievements & Milestones in 5G Development

As announced by Huawei at the Mobile World Congress 2023, during its first three years of deployment, 5G has surpassed what 4G did in its first five years. By the end of the first quarter of 2023, the number of 5G users have surpassed 1 billion, which is equivalent to more than 12% of the global number of mobile users. Furthermore, the ongoing commercial deployment of 5G networks has reached 240 networks worldwide. As a milestone, Ericsson announced having shipped 10 million 5G-ready radios worldwide by June 2023. According to the Nokia Middle East & Africa Broadband 2023 Index report, 5G data traffic ma et share will increase by 27% from 2022 to 2027 in the MEA region. In the GCC, 5G will grow rapidly from 2022 to 2027 at a CAGR of 41.9%.

The Development of 5G in the UAE

The World Radiocommunication Conference (WRC) in 2015 addressed over 40 topics related to frequency allocation. The most important of them was related to spectrum identification for International Mobile Telecommunications for 2020 (IMT-2020), which we now know as 5G. Also in 2015, the UAE preparations

to host Expo 2020 were at peak. The motto of Expo 2020 "Connecting Minds, Creating the Future" created an opportunity. The Telecommunications and Digital Government Regulatory Authority (TDRA) aspired to be the first country globally to launch 5G at Expo 2020. It was a challenging dream as no standards and no equipment roadmap was available.

TDRA launched its 5G initiative in 2016 through a high-level steering committee with three technical committees for spectrum, network and verticals. TDRA also published the 5G roadmap in 2016. The roadmap aligned with TDRA's vision, "Th academia, cybersecurity experts, consultants and members of the prospective verticals. As a result, the UAE conducted some of the earliest trials and demonstrated 5G technology at all GITEX exhibitions up to that point, with a live demonstration at the ITU Plenipotentiary Conference in 2018 hosted by the UAE. UAE also became the first country in the MENA region to launch a commercial 5G network providing ficed wireless service in May of 2018. The network rollout continued with adequate spectrum allocated for 5G. In May 2019, UAE started offering commercial 5G services to all users as 5G handsets were launched. This established UAE as among the leading countries globally to launch 5G. The collaborative e ort resulted in a successful launch of 5G, two years in advance of Expo 2020. WRC-19 then further identified millimeter wave bands for 5G. UAE was then again among the fi st countries to allocate 26 GHz frequency range for 5G. The UAE telcos demonstrated the fastest mobile networks globally through carrier aggregation.

UAE is one of the most '5G-ready' countries worldwide –along with Japan, South Korea, China and the USA. 5G will be a key platform for innovation. According to research, 5G-enabled solutions will present a 10-year cumulative USD 60 billion revenue opportunity for ICT providers in the UAE. The biggest vertical projected is the smart city. The research has also identified mo e than 20 different 5G services that could improve people's lifestyles and contribute to the UAE's economy.

Keeping in view the future shaping of the UAE ICT sector, TDRA has issued the "UAE Strategy 2020-2025 for 5G and Beyond". This strategy consists of three pillars, with each pillar having initiatives and activities. Pillar 1 focuses on achieving 5G network deployment and coverage. Pillar 2 relates to all initiatives for creating and further developing partnerships and collaboration in the UAE for a common goal of successful uptake and use of 5G. Pillar 3 relates to all initiatives for leading edge technology to support a diverse ecosystem, which means promoting and developing an environment in which an ecosystem for 5G can thrive.

TDRA gave an exceptional spectrum fees waiver for 5G frequencies of 3 GHz and above for five years, diverting the Telco investments into an ambitious 5G network rollout. The UAE telcos have so far invested more than AED 3 billion and rolled out more than 11,000 sites (based on 2024 Q1 results) for 5G covering more than 98% of the UAE population (outdoors). For 5G it is the beginning of a long journey. For UAE it is the journey of its commitment to its people for happiness, connectivity, and the world's best ICT.

The UAE continues with groundbreaking speed trials of 5G-Advanced networks. Phase II advanced 5G trials took place in major cities like Dubai and Abu Dhabi. These trials focused on testing the technology's capabilities and laying the groundwork for a wider rollout. As a signifi ant milestone, Telcos have successfully achieved 10 Gbps throughput on the 6 GHz band using 400 MHz bandwidth. Trials were conducted to test the coverage and capacity in the 6 GHz band.

5G Challenges & Implications for Future Wireless Communication Technologies

While 5G has brought up numerous opportunities and has already demonstrated a number of breakthroughs in terms of speed, network slicing, spectrum, etc., the rollouts of 5G have revealed several limitations and challenges that need to be addressed to realize the full potential of this technology. It should be highlighted that, while 5G technology o ers higher speeds compared to 4G, such an advancement is not truly perceived e UAE is a global leading country in ICT" and provided a unique collaborative platform for all its strategic partners to engage on all aspects of launching 5G. The 5G committee meetings brought together the industry, manufacturers, system integrators, telecom operators, by the average users, and hence, in terms of average user experience, 5G did not bring much in comparison with 4G. In more details, when using high-end handsets, both 4G and 5G can perform equivalently with respect to the resolution of 2K videos. In more immersive applications, the offered latency reduction achieved by 5G is diffiult to recognize in applications that are not related to XR/VR services or relevant to smart vehicles. Even in XR applications, the supported level of immersion by 5G is somewhat limited to video/audio support. The same applies to the massive connectivity feature of 5G, where it is rarely observed in regular scenarios, i.e., improvements often observed in mass gatherings like concerts and stadiums.

Main Challenges faced by the FWA use-case in the UAE:

The transition to 5G has brought challenges, particularly for indoor users. Although 5G uses advanced technology to target user devices, it uses high frequencies that struggle to penetrate indoor environments, unlike older technologies using lower frequencies. This makes it harder for 5G to reach users in high-rise buildings and dense urban environments, which requires an in-building solution (IBS). In the UAE, where there are many skyscrapers, only around 7% of total IBS sites have 5G.

Residential and suburban areas face another challenge with approximately 32% of telecom users having weak or no 5G coverage. To improve this, one technique is to increase the number of antenna elements, which helps to extend coverage. This method has proven to increase coverage by +3dB and improve user experience by +30% in both upload and download speeds. It also helps in reducing power consumption by almost 30% if the aim is to maintain the same coverage area.

Another strategy telecom companies are using is to combine low band frequency division duplex with time division duplex. This has resulted in a substantial increase in download and upload speeds.

THE TRANSITION TO 6G

The roll-out of IMT-2020 (5G) networks continues to expand successfully around the globe with currently hundreds of networks operational worldwide. The journey of IMT-2020 (5G) standards evolution will defini ely continue as evolutionary steps under the umbrella of "5G Advanced" leading to IMT-2030 (6G). The Radiocommunication Assembly 2023 (RA-23) has approved revisions to Resolution ITU-R 56, officially designating the next generation of IMT (commonly known as "6G") as "IMT-2030," and Resolution ITU-R 65, which outlines the principles of the IMT-process. In addition, RA-23 has endorsed the new Recommendation on the "IMT-2030 Framework," which will now be referred to as Recommendation ITU-R M.2160.

Alongside the existing Report on "Future Technology Trends" ITU-R M.2516, this accomplishment signifies the completion of the initial phase, laying the groundwork for the development of IMT-2030. The subsequent phase (2024-2027) will focus on defining relevant requirements and evaluation criteria for potential radio interface technologies (RIT) for IMT-2030 (refer to the "ITU-R timeline for IMT-2030" below).

As information and communications technologies evolve, IMT-2030 is anticipated to support enriched and potentially immersive experiences, enhanced ubiquitous coverage, and new forms of collaboration. Additionally, IMT-2030 aims to support expanded and new usage scenarios compared to IMT-2020, while offering enhanced and new capabilities.

IMT-2030 is also expected to address the need for greater environmental, social, and economic sustainability, supporting the objectives of the Paris Agreement under the United Nations Framework Convention on Climate Change.

The transition to 6G represents a remarkable leap forward in the realm of wireless communication and connectivity. Building upon the foundation laid by 4G and 5G, 6G promises to revolutionize the digital landscape by offering unprecedented speeds, ultra-low latency, and a host of groundbreaking applications. With data rates potentially exceeding 100 Gbps, 6G could enable real-time holographic communication, immersive augmented and virtual reality experiences, and support for seamless massive connectivity for an intricate network of IoT devices. Hence, the definition of 6G apabilities will go beyond high-speed communications, to novel advancements in architecture design, adaptivity, and coverage. Moreover, while being initially deployed in 5G, 6G is expected to signifi antly advance machine learning (ML) and AI capabilities, fostering the development of autonomous systems and smart cities. However, as with any technological transition, there will be challenges to overcome, including the need for a robust infrastructure, global standards, and addressing privacy and security concerns, to name a few. Nonetheless, 6G is anticipated to be an exciting frontier that holds the promise of transforming how we communicate and interact with the world around us.

What is 6G?

The IMT-2030 also known as 6G technology is the upcoming 6th generation of wireless networks, that is envisioned to deliver a truly intelligent wireless realm and is expected to be available in the 2030. 6G at its core is aimed to support the fourth industrial revolution through connecting humans, machines, and the environment. Different than the conventional revolutions of the earlier wireless generation concepts, the principle of 6G technology is built upon the notion of blending the digital and physical worlds, reshaping the way how humans interact with the cyber world. While 6G will be built on the strength of 5G, the advent of 6G is anticipated to bring a new level of intelligence, programmability and adaptivity, and sustainability, and to radically change the current concept of digital-physical divide into a seamless digital-physical continuum, towards sustainable connected world driven by sensing and human-machine interfacing. As a consequence, several opportunities pertinent to immersive smart cities will emerge, e.g., interactive real-time 4D maps, smart contact lenses and haptics, telepresence experiences, and breakthrough advancements in AR/VR technologies, impacting our everyday life. Accordingly, the 6G era will witness unprecedented advancements in embedded devices, computing fabric, cognitive networks, as well as breakthroughs in networks connectivity and coverage capabilities.

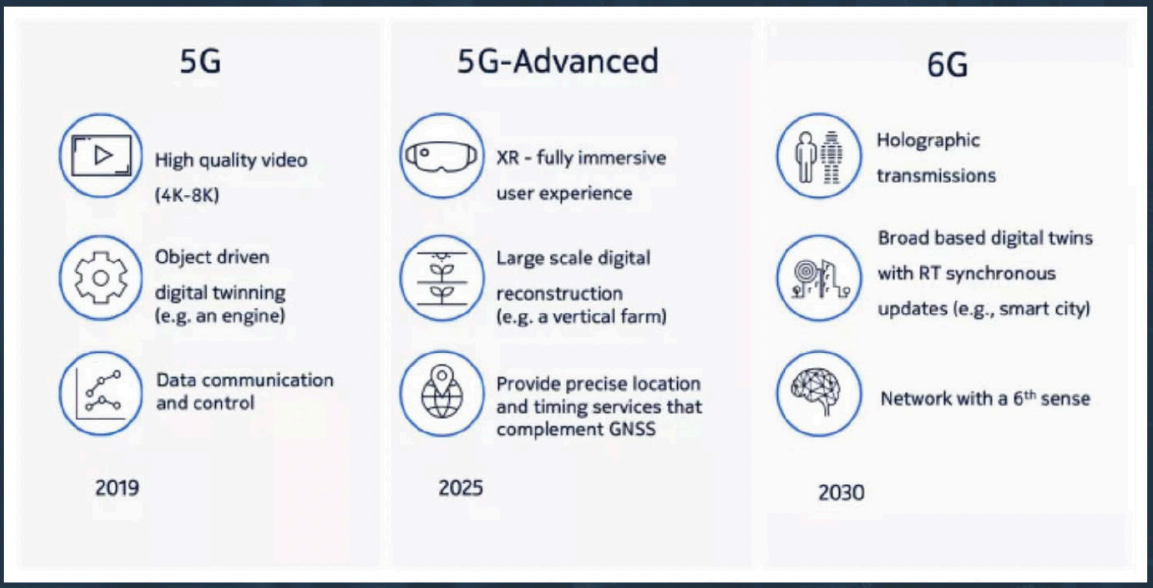


Figure 1 Use case for 6G (Source: Nokia)

6G Verticals / Applications

While 5G has already transformed industries and enabled a wide range of applications, 6G is set to elevate wireless communications to unprecedented heights. 6G verticals encompass a diverse array of applications, paradigms, and technological trends. 6G will not just build on existing technologies and systems, it will expand and transform what a network can do. Traditional metrics such as capacity, throughput, reliability, and latency will continue to be important. But unlike previous generations, 6G will go beyond. Sustainability and digital inclusion will become key value drivers for the 6G era (see table)

Table 1 Metrics and value drivers for 6G (Extreme attributes of performance may apply to specialized sub-networks only and all the requirements may not be achieved simultaneously.)

Capacity And Throughput	**Sustainability**
20X traffic growth Gbps peak data rates 100 Gpbs where needed 1	X10 capacity increasae with %50 power reduction, compared to 5G
Reliability and Latency	**Digital Inclusion**
0.1 ms1-ms Nine 9s (%99.99999999) Nanosecond synchronization level	Aim to address three key factors: accessibility, affordability and consumability
Scale and Felxibility	**Security and Privacy**
Global coverage 10 million devices/sq km Platform and services approach	Increase security and privacy risks require higher level of control

In the following, we emphasize on the key verticals that define the future of 6G:

Immersive Holographic Communication: 6G technology promises to transcend the boundaries of conventional communication methods by introducing holography as a means of interaction, overcoming the geographical limitations, and redefining the concept of remote communication. As a key to physical-digital integration, holographic communication will allow the transportation of the humans' 3D physical and emotional aspects with a remote site, in near real-time fashion. In addition to immersive online gaming, holographic communication will be the gateway to revolutionize teleconferencing, remote working, online shopping, etc. The deployment of holographic communication will require extraordinary data speeds to be provided by the 6G infrastructure, in addition to the need for commercially affordable devices for transporting and rendering 3D teleports, including 3D LiDAR cameras and advanced AR/VR headsets. In order to enable high-definition real-time holographic communication, 6G technology will also require the development of unique real-time compression and coding, as well as reconstruction

and visualization schemes that will facilitate the transmission of the holograms reliably with extreme low latency. Holographic communication will be driven by sensing, edge intelligence, and AI, which are key verticals of 6G. Integrated Digital-Physical Worlds: The blend of digital and physical realms was recently defined as the Metaverse, in which a high-fidelity virtual, fully immersive environment is created to duplicate an existing physical one, or to create an original virtual world. The advent of the Metaverse is expected to revolutionize how smart cities are defined, in which virtual offices, cinemas, shopping malls, industrial spaces and factories, healthcare centers, and education sector will be different in a decade or less, where virtual environments of these sectors will replace the physical one, allowing the users to enjoy an immersive experience from the comfort of their homes. The Metaverse paradigm will be fully supported by 6G, in which on-demand, reliable, high-speed communication need to be supported between the physical and digital worlds, to ensure seamless experiences and perfectly synchronized realms. Note that, in order to enable such a high quality of immersion, a huge amount of data need to be exchanged between the digital twin and its physical counterpart, with imperceptible time-lag, calling for massive connectivity and URLLC supported by edge computing.

Sustainable Networking: Sustainable networking in 6G is a critical consideration as the world moves toward the next generation of wireless communication technology. To address the growing demand for connectivity while minimizing environmental impact, 6G networks will need to incorporate sustainability principles in various aspects of their design and operation. This driven by the fact that energy cost accounts for 23% of the operational costs of Telecom operators. It is worthy to emphasize that the notion of sustainability is not confined y the implications of wireless networks on the environment, but also extends to cover economical and societal sustainability. Therefore, it aimed that 6G to be designed to achieve breakthroughs in terms of sustainability, contributing to reducing the carbon footprint and bringing several environmental benefits, as ell as achieving economical gains and advancing vertical societal sectors and sustainable quality of life, pushing the sustainability to the top priorities of the 6G technology development. Minimizing energy use is one dimension of achieving sustainability, thus every aspect of 6G design, implementation and operation will be scrutinized to maximize energy efficiency. We believe that the target for 6G should be cutting the average power consumption of 6G networks in half compared to 5G, while still supporting peak capacities 10 times higher than today's 5G networks. Not only will 6G enable lower costs per bit and faster connectivity, but it will also be able to turn off components more frequently with minimal end user impact and scale down capacity when the demand is low. To achieve these energy efficiency gains, 6G requires new underlying frameworks (e.g., physical layer, higher layer protocols, data exposure) and system-on-chip (SoC) technologies. Wider RF bandwidths, larger numbers of antenna elements and advanced radio processing are only feasible with the integration of powerful hardware design into the 6G system. Digital Inclusion: is an ambition associated with 6G as a platform. 6G networks will address three critical factors to enhance digital inclusion: accessibility, affordability and consumability. The delivery of cost-effective 6G solutions combined with non-terrestrial networks will help make global connectivity a reality.

Affordability will critically depend on economy of scale from global adoption and interoperability from global standards. Emerging markets, remote areas or even planes and ships, which currently enjoy limited connectivity services, will have access to broadband services, enabling a wide range of services beyond connectivity. With regards to consumability, 6G will offer the opportunity for enhanced and intuitive user interfaces.

Networked Sensing: Featuring higher frequency bands and massive antenna densification in 6G networks paves the way for integrated sensing and communication technologies. A key pillar of 6G is the emergence of sensing-assisted communication and vice versa. From the perspective of the first, sensing offers super-resolution localization and imaging, which can potentially contribute to improved communication schemes, including beamforming, channel state information acquisition, and handover, to name a few. Alternatively, radio waves, with their reflection and scattering properties, can be exploited for sensing purposes, offering improved understanding of the surrounding environments.

What further make 6G unique in terms of sensing capabilities, is that it will not solely rely on conventional sensing methods (RF sensing or images) but will rather be the base to realize multi-sensory communications, in which human-like fi e senses will be exploited for improved context-aware communication and to enable immersive experiences for the network users. In specific, as termed by Ericsson, internet-of-senses is a paradigm that allows data pertinent to human senses, i.e., visual, auditory, tactile, gustatory, and olfactory to be acquired and transmitted, with the aim to provide immersive physical-like experiences over the digital realm.

Generative AI/AI & ML: While traditional AI schemes, that focus on analyzing and interpreting data, will play a pivotal role in several applications in 6G networks, the newly emerged class of AI, generative AI (GenAI), is anticipated to profoundly impact what and how 6G applications and use-cases will be enabled. GenAI is a unique sub-class of AI that is designed to create new, original content, such as text, images, audio, or video, that appears as if it was produced by a human. One of the key features of GenAI is its ability to understand patterns, styles, and structures within the data it has been trained on, and then generate new data that follows similar patterns. Accordingly, GenAI holds immense potential, particularly with the emergence of the Metaverse paradigm, where GenAI models can be leveraged for dynamic content generation and moderation, avatar creation, natural language processing, conversational agents, immersive storytelling, realistic simulations, text-to-speech conversion, and information retrieval, among others. It is believed that GenAI will not kick-off be ore the advent of 6G networks, as 6G will provide the needed computing fabric for GenAI models training and operation. In addition, GenAI is anticipated to be deployed in a distributed manner, fulfilling the la ency, energy, privacy, and adaptivity requirements of network users, and hence, 6G is the key to enable edge computing and intelligence, that are essential for distributed GenAI. Furthermore, extremely ultra-reliable low latency wireless links, supported by 6G, are essential to enable multiple intelligent devices in the network, that are equipped with GenAI capabilities, to communicate. The goal is also to have AI native air interface for 6G where AI/ML will provide a new foundation for air interface design and optimization, enabling self-optimizing transmitters and receivers, cognitive spectrum use, and context awareness.

6G Spectrum Insights

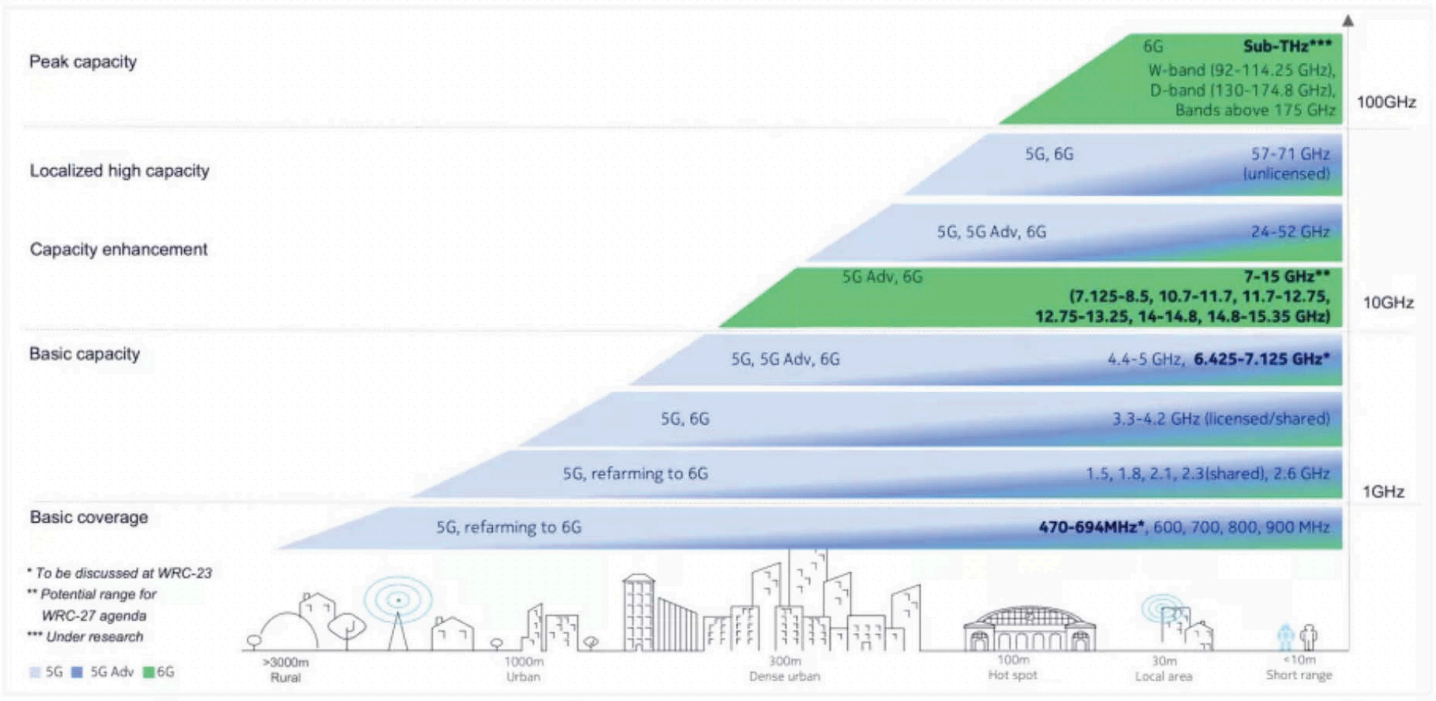
The new air interface has to be launched in parallel to the established air interfaces. For example, when 5G was launched, 2G/3G/4G were still operational. Each air interface requires a portion of the radio spectrum. Therefore, the industry requires each mobile generation to have its own dedicated "launch" spectrum e.g., GSM @ 900/1800 MHz, UMTS @2GHz, LTE @800/1800 MHz, 5G @700/2600/3500 MHz and millimeter wave bands. Historically, the ITU's World Radiocommunication Conferences (WRCs) identify the IMT spectrum in the Radio Regulations enabling the mobile industry to connect more than 5 billion people. The WRC-23, which took place from 20 November to 15 December in Dubai, gathered national administrations and telecom industry members to review and update the Radio Regulations, the international treaty governing the use of the radio-frequency spectrum. The conference addressed spectrum needs, including those for 5G Advanced and 6G. WRC-23 also discussed the agenda for WRC-27, thereby defining the likely roadmap for spectrum bands going into the 2030s and beyond.

Following WRC-23, the questions that arose when discussing 6G candidate bands were: why more spectrum, how much, and from which frequency bands?

From Which Bands?

Spectrum in different frequency ranges – low, medium, and high – is critical for the commercial success of 6G. One key learning from the introduction of 5G is that reusing the existing network site infrastructure with new spectrum is vital for network planning and cost efficiency. As old air interfaces are phased out the spectrum is re-purposed for newer air interfaces. For example, as GSM is phased out the 900 and 1800 MHz range will become available for UMTS (3G) and LTE (4G). Many countries are planning to phase out even 3G and the spectrum will be re-purposed to 4G and 5G. The activation of 2G network (GSM) in the UAE dates back to 1994 and now the TDRA is working with Telcos to shut down the 2G.

The 5G spectrum requirements are also growing as the network gains footprint and more 5G devices are available with users. The mobile networks require a combination of frequency bands below 1 GHz for coverage, 1-7 GHz for coverage and capacity while the bands above 24 GHz (millimeter wave) are for capacity in dense environment. The mobile industry considers that, to balance capacity and coverage, new mid-band spectrum from within the 7-15 GHz frequency range is needed. Focus on this range in the next ITU-R study cycle (2024-2027) would enable spectrum availability in time for the introduction of 6G before 2030.



6G era Nokia spectrum vision in the 2 Figure

From a regulatory perspective, IMT identification of new spectrum in the extended mid-band will be vital for the industry, as it can enable global or regional harmonization, provide regulatory certainty for technological investments in the ecosystem, and create economies of scale for faster development and broader adoption. However, spectrum in this range is already intensively used by incumbent services including satellite, commercial radar, fixed links services and other services; therefore, opening the band for 6G would not be simple. It will require technical studies looking into the co-existence and compatibility with the well-established services. If bands are not cleared for 6G operations specifically, advanced spectrum sharing solutions should be explored to ensure that 6G deployments do not cause harmful interference to incumbent services while they achieve the desired 6G QoS. Co-existence with other services will have to be studied and evaluated, depending on the services discussed and their technical and operational requirements and parameters.

Additional 6G research is ongoing on sub-THz spectrum that can be useful for applications like high accuracy sensing and positioning. As the propagation characteristics of sub-THz frequencies do not allow for efficient delivery of capacity and coverage in wide area networks, such spectrum can only complement the mid-bands, not replace them.

How much?

Initial 6G spectrum need calculations for XR and holographic communications have been developed by GSA. To address the needs of some of the 6G data-hungry use-cases, the minimum wide-area spectrum required is estimated to be roughly 1 GHz per network.

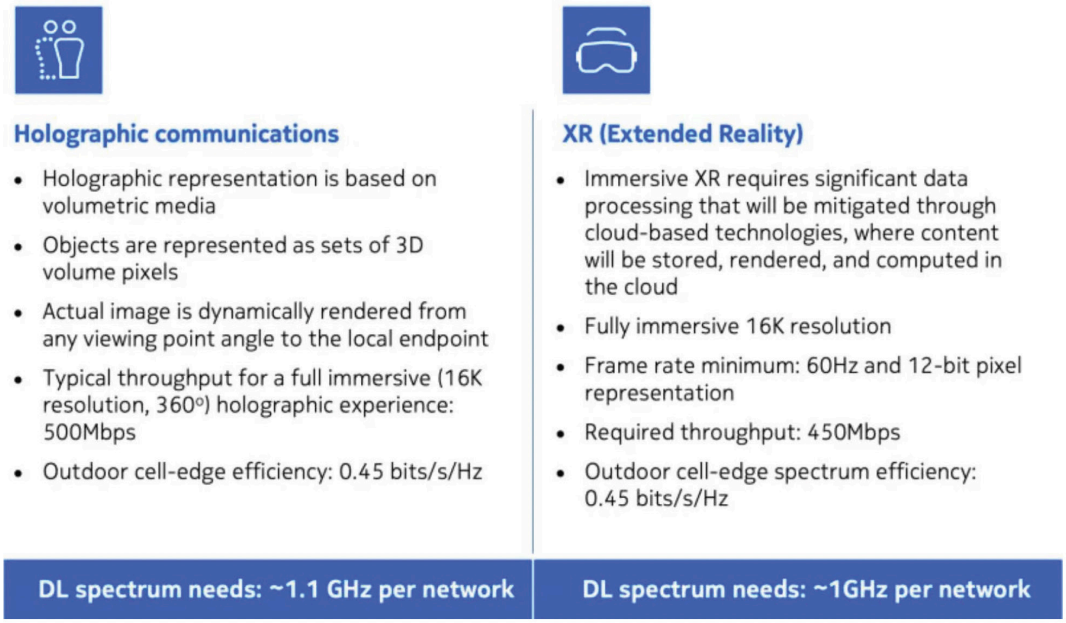


Figure 3 Holographic Communications vs. XR

Considering three to four operators per country and assuming that in the long-term the existing mid-band spectrum available for IMT (roughly ~1GHz) will solely be reused to address the wide-area use cases, then approximately 500-750 MHz of additional new wide-area spectrum per network will be needed in the 7-15 GHz range.

The decisions of previous WRCs that identified spectrum for IMT were proven to be prudent. The existing global spectrum map has been vital for the development of new technologies, vertical industries, enhanced ecosystems, societal benefits, and economic growth, but the question remains: will this spectrum be adequate for 6G?

Following WRC-23, it is important to demystify the myths. The next four questions address these myths and bring more clarity on the need for new spectrum for 6G

Why is more spectrum needed when there is already so much spectrum available for IMT?

While refarming existing frequency bands to deploy 6G is possible, it poses regulatory and compatibility challenges. The sunset of previous mobile generations is not a straightforward process, and we are still learning from the phase out of 2G and 3G. Even though current technology advancements allow the parallel use of different mobile generations in a single frequency band where needed, they can only be considered as temporary solutions, as they do not achieve efficient utilization of spectrum. Nevertheless, even if regulatory, compatibility and efficiency challenges were to be overcome, existing available spectrum will still not be enough to meet the expected data traffic demand or 6G by the end of the decade.

Why is more spectrum needed when deployment of mobile networks can be densified o achieve higher throughputs?

Network densification is not always an economically viable or sustainable solution. Small cells need to maintain distinct separation distances to avoid inter-cell interference, while deployment density needs to

maintain the same levels of experience during cell handovers. Identifying locations for numerous small cells makes network planning and deployment significantly more challenging, while the acquisition and running cost to achieve extreme densification will significantly increase the deployment and operational cost. Extreme densification to deliver high user experience will also adversely impact the carbon footprint. Recent studies have indicated that in the absence of additional mid-band spectrum, the total cost of network ownership will be 3-5 times higher over a ten-year period, and the carbon footprint will be 1.8-2.9 times greater to deliver the target performance levels. Therefore, densification on its own cannot be considered the sole solution to additional capacity.

Why is more mid-band spectrum needed when there is high potential for a broader IMT identification in the upper 6GHz band?

Different frequency ranges satisfy different spectrum needs and support different use-cases. Early reports suggest various amounts of spectrum needed to provide full 6G experience in a macro-cellular environment. The upper 6 GHz band (6425-7125 MHz) will be vital for enabling growth and will mostly be used in further 5G-Advanced evolution, and eventually, in some countries, as basis for 6G introduction. However, this band alone, with its total of 700 MHz available, will not be sufficient to satisfy the individual national spectrum demands for 6G.

Why is more spectrum needed when existing mmWave spectrum is currently under-utilized?

The mmWave spectrum is a promising range for high-capacity enhancements mainly in dense urban environments. Nevertheless, the nature of signals in these frequencies cannot offer a viable solution for macro cellular coverage. Available spectrum in the mmWave bands can achieve Gigabit speeds but only in small ranges. Considering the propagation challenges, as well as the economic and sustainability challenges posed by extreme densification, it is clear that mmWave spectrum is optimal for local capacity enhancements, not for macro-cellular coverage.

In addition to the currently designated spectrum, 6G will require new spectrum to meet the data demands by 2030. New spectrum will act as the enabler for the industry to meet its targets in the areas of efficiency, performance, and sustainability, while still maintaining a viable economic environment to attract investments. From a regulatory perspective, IMT identification of new spectrum in the extended mid-band 7-15 GHz will be vital for the industry.

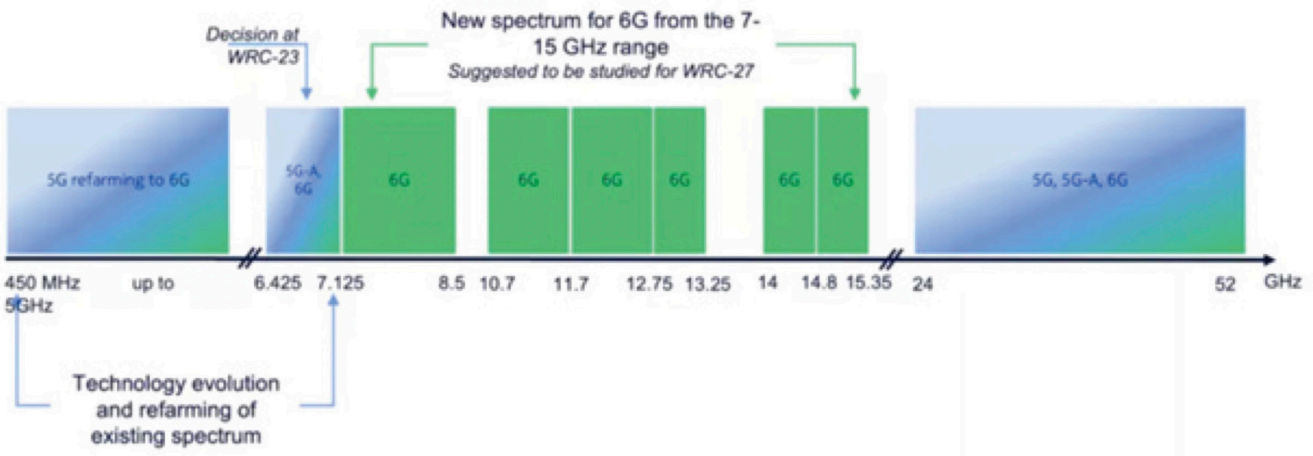


Figure 4 Summary overview on spectrum for 6G

Global Trends and Initiatives

The country case studies of 6G vision

As the world anticipates the arrival of 6G technology, global trends and initiatives have started to take shape. In the following, we highlight the main 6G developments at the global scale:

China: Since the initial stage of the research and development on 6G, China has marked its significant contributions to push the development and testing of several technologies that contribute to shaping the future of 6G. On the one hand, China has successfully filled mo e than 8000 patents on topics related to 6G, which accounts for 40.3% of the total number of patents worldwide. Furthermore, At the end of 2020, China has launched the world's first 6G satellite for testing future potential solutions for 6G satellite communications. Moreover, Huawei has developed a testing prototype for integrated sensing and communication (ISAC) to conduct thorough testing on the 6G THz band.

South Korea (SK): SK has allocated US$481.0 million as funding for the research & development on 6G, with focus on AI-native cloud-based core networks. Also, it targets to launch the first LEO satellite by SK in 2027. To set the plan for the 6G development and deployment, SK Telecom has recently released a white paper on the roadmap to 6G within its commitment to lead 6G standardization globally with collaborations with several alliances and companies, including NGMN Alliance, IOWN, and NTT DOCOMO. Furthermore, it was announced that Samsung, LG, and ETRI are actively working on research plans for 6G and open RAN.

Finland: 6G Flagship in Finland promotes high-quality 6G research to create future know-how and sustainable solutions for society's needs in the 2030s. It operates under the University of Oulu, which funds it together with the Research Council of Finland. Finland has also a 6G national program (6Genesis) funded through the Academy of Finland, an also launched 6G Finland, a national coalition to promote 6G competitiveness.

Singapore: Singapore University of Technology and Design (SUTD), one of the leading scientific research institutions in telecommunications, has established the fi st 6G R&D lab in Southeast Asia (Future Communications Connectivity (FCC) Lab), to advance in Singapore's 6G future connectivity vision. In collaboration with SUTD's AI Mega Centre, the FCC Lab is aimed to develop new schemes for emerging technologies related to holographic communications, intelligent sensing, and next generation mobility.

Japan: Japan has taken a collaborative approach to next generations networks and established the Beyond 5G Promotion Consortium in collaboration with industry, academia, and government as a 6G-related initiative. The consortium is also engaged in activities to promote collaboration and cooperation with like-minded entities around the world. In Japan for instance, Nokia is partnering with DOCOMO and NTT to

jointly define and develop key technologies towards 6G. The collaboration will focus on proof-of-concepts for emerging 6G technologies such an AI native air interface. These aim to demonstrate a performance gain with an AI based 6G air interface compared to a conventional air interface.

US: The United States owns 35% of the total patent applications that are dedicated to the 6G development. US is dedicating considerable R&D forces for the development of innovative technologies that are related to sensing, imaging, and wireless cognition in particular. Furthermore, US has initiated the Next G Alliance as a private-sector-led initiative to advance and lead the North American wireless technology in 6G.

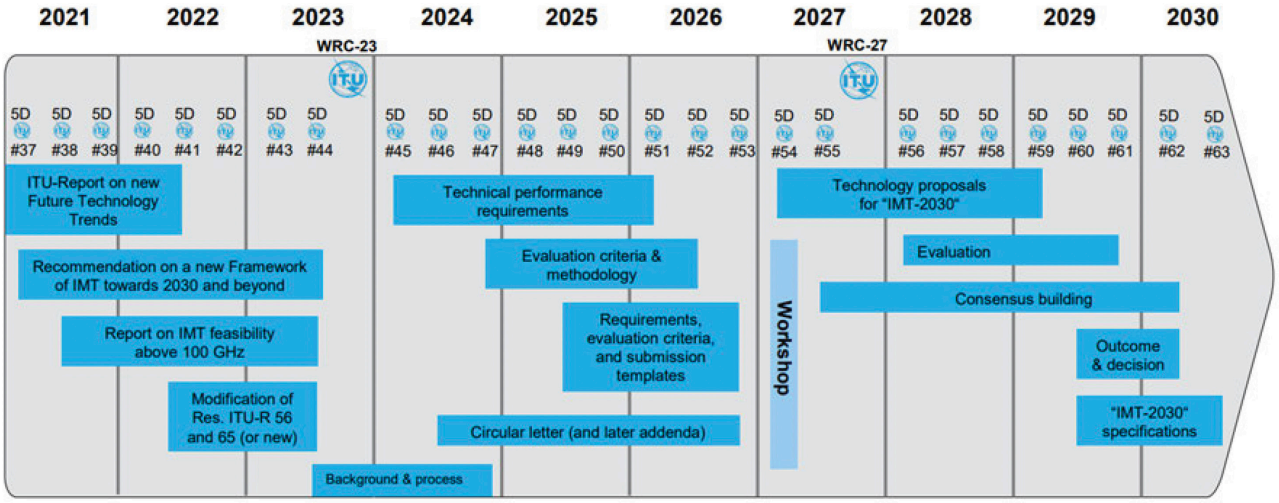
Europe: Hexa-X is the first official research initiative across the industry ecosystem to accelerate and foster 6G research and drive European leadership in the 6G era. The Hexa-X project has been awarded funding from the European Commission under the European Union's Horizon 2020 research and innovation program, a significant step toward bringing together key industry stakeholders in Europe to take the lead in advancing 6G. The stakeholders represent the full value-chain of future connectivity solutions ranging from network vendors, communication service providers, verticals, and technology providers, as well as the most prominent European communications research institutes.

India: In an effort to cope up with the global efforts in 6G technology, Bharat 6G Alliance of India has released a White Paper on "Meeting IMT-2030 Performance Targets: The Potential of OTFDM Waveform and Structural MIMO Technologies". The white paper has addressed several topics within the 6G, including, integrated access and backhaul in 6G, integrating satellite and terrestrial communications, and machine learning in the physical, MAC and higher layers. Also, Nokia launched the first-of-its-kind 6G Lab in India aiming to be a platform for future collaboration for industry and academic stakeholders on 6G and facilitate the testing of new solutions while establishing their potential for commercialization. Research areas will include foundational 6G technologies like Network as a Sensor, Network Exposure and Automation.

ITU-R (WP5D) roadmap for IMT-2030

IMT-2030/6G is expected to become the primary mobile technology in the 2030s and will offer an enhanced user experience compared to previous generations. 6G promises ultra-fast data rates with lower latency, significant energy efficiency, and greater reliability besides sensing connectivity, immersive communications and communications empowered by artificial intelligence.

ITU-R Working Party 5D has developed a work plan, timeline, process and all the required deliverables for the future development of IMT that are necessary to be provided by the 2030 time-frame. The process and related deliverables were agreed as shown in Figure 5 as an overview.



Note 1: WP 5D #59 will additionally organize a workshop involving the Proponents and registered Independent Evaluation Groups (IEGs) to support the evaluation process

Note 2: While not expected to change, details may be adjusted if warranted. Content of deliverables to be defined by responsible WP 5D groups

***Note by the ITU-R Radiocommunication Bureaux:** This document is taken from Attachment 2.12 to Chapter 2 of Document 5D/1361 (Meeting report WP 5D #41, June 2022) and adjustments could be made in the future. ITU holds copyright in the information – when used, reference to the source shall be done.*

Figure 5 ITU-R Timeline for IMT-2030

It is envisaged that IMT-2030/6G, similar to the previous IMT systems, would be used in a variety of deployments such as wide area, hot spots, campuses, indoor, etc. with different frequency ranges typically used to enable various deployments. Demand for spectrum is anticipated to continue to increase for a variety of uses.

It is noted that no single frequency range satisfies all the criteria required to deploy IMT systems. Hence, to meet the capacity and coverage demands of 6G/IMT-2030 and to serve the emerging services and applications, multiple frequency ranges from the low to the very high frequency bands would be needed. For future IMT-2030/6G, availability of spectrum resources that could support broad and contiguous channel bandwidths need to be explored.

In addition to re-using the existing spectrum, the IMT industry considers additional spectrum from within the 7.125-24 GHz range to be essential to enable the 2030 capacity-demanding use cases, the lower the frequency bands are, the better the coverage will be. This should be complemented by spectrum from within the sub-THz range (92-300 GHz), enabling Tbit/s data rates and extremely low latency capabilities that would be needed for some specific IMT-2030 use-cases. Such use cases would include direct device to device communications, sensing and recognition, and virtual reality, among other local area mobile use cases where such extreme performance is required.

3GPP roadmap for Release 21 3GPP is the global standards body in which each generation of mobile technology is established. In 2022, the third 5G standard — 3GPP Release 17 — successfully completed bringing many 5G innovations, and the work on 5G Advanced has also officially begun. Qua omm and a worldwide ecosystem of 3GPP companies are actively working on 5G NR Release 18, the inaugural standard release that will establish the technology roadmap for 5G Advanced, a second wave of technology innovations, including advanced technologies that will fuel future wireless enhancement and further

expansion.

5G Advanced will improve existing use cases as well as extend 5G into new devices, services, and industries. Through the rest of this decade, 5G Advanced will drive further evolution of mobile broadband and expansion into new verticals, with improvements and new features. More importantly, 5G Advanced is establishing the technical foundation for 6G — the next-generation mobile platform coming in 2030 and beyond.

As shown in Figure 6, the completion of Release 18 is expected in early 2024. The Release 19 timeline started at the end of 2023, and Study/Work Items began in 2024. For 6G, current expectations are that 1) 3GPP RAN Workshop will be early 2025, followed by the start of 2) Release 20 6G Study Item in 2025, and 3) Release 21 will be the first release of 6G Work Item considering all system design requirements and design targets.

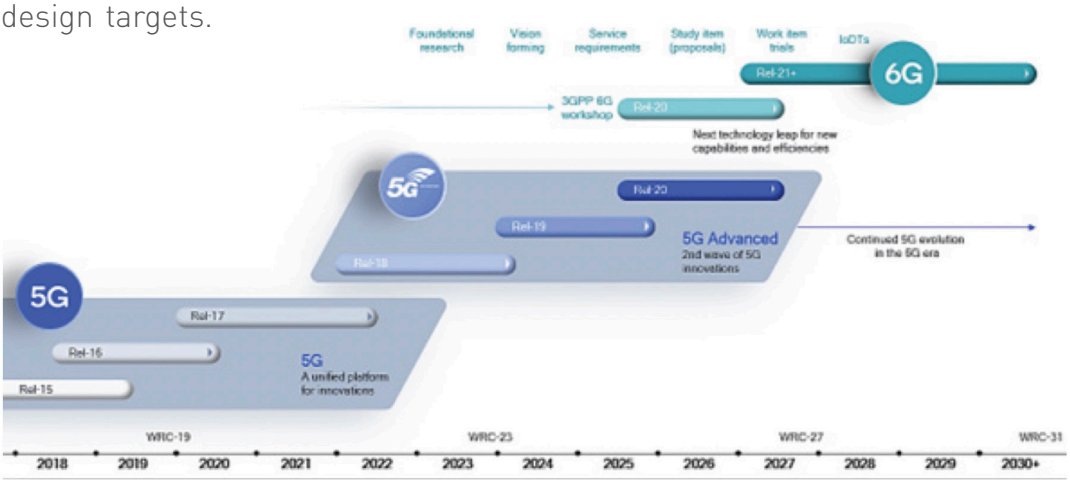


Figure 6 Standardization timeline (Source Qualcomm)

Industry Roadmaps

In terms of the timeline, requirements studies on 6G standardization are likely start to from 2H24, followed by the first 6G specification in 3GPP Release 21, assumed to be completed around 2H 2028. We expect to see the first commercial 6G deployments before 2030. Meanwhile 5G will be enhanced by 5G-Advanced, which will be a key focus for 3GPP in Release 18 &19 and will power commercial public & private networks starting in 2025.

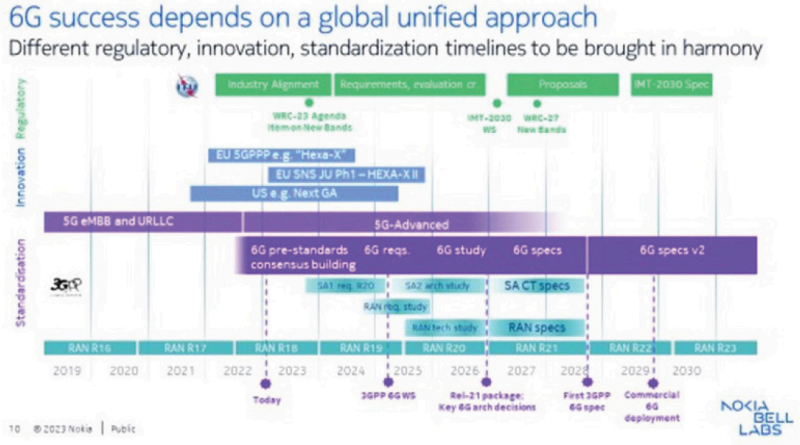


Figure 7 Industry Roadmap for IMT-2030

UAE 6G VISION

Being at the forefront of emerging technologies and its commitment to innovation, UAE has started already to put the efforts to push for the development and advancing the 6G technology from research and development (R&D) and industrial perspectives. Through visionary initiatives and strategic partnerships with leading technology organizations, the UAE has advanced in the research and development efforts in 6G, aiming to harness its potential for transforming industries such as healthcare, transportation, and smart cities. In particular, recently, Du has signed a memorandum of understanding (MoU) with Huawei for strategic cooperation on 5.5G and 6G innovations, where the partnership is aimed to advance in key technologies that serves needs of 6G technology, including but are not limited to extremely large antenna array massive MIMO (ELAA-MM), passive IoT, virtual large carrier. The UAE's telecom giant, Etisalat by e&, is working on enhancing its existing 5G network and rolling out 5G-Advanced, which will bring about numerous performance benefits as ell as enabling network slicing, RedCap IoT, and other revolutionary technologies and use-cases. Etisalat by e& is also planning to explore 6G-enabling technologies such as Reconfigurable Intelligent Surfaces (RIS) for higher frequency bands in coordination with its partners in the near future. Alongside these efforts, Dubai government has recently announced the Dubai Metaverse strategy, that aims to foster innovation, establish international collaborations for research and development on Metaverse-related topics, invest in enhancing the Metaverse technology, and establish a Metaverse eco-system that host Metaverse developers and incubators. This initiative is focusing on core technologies that including XR/ AR/VR/MR services, digital twin, real-time data analysis, AI/ML and IoT, and blockchain.

To Enhance the Quality of Life & the Competitiveness of the Country

The 6G UAE vision is a bold and forward-looking commitment aimed at not only advancing cutting-edge telecommunications technology but also at improving the overall quality of life for its citizens and ensuring that the country remains a key player in the rapidly evolving digital world. Advancing the research and development in the internet-of-senses technologies, with their associated reliable ultra-low latency connectivity enabled by 6G, has a direct impact on the healthcare sector and the revolution of smart homes concept. It is anticipated that 6G will enable improved tele-health, including remote health monitoring and automated video consultation, with the massive support of IoT-based wearable devices. In addition to the convenience and improved security, smart home concept is a key element in realizing sustainability, in which efficient optimization of the resource's consumption can be achieved at the individual and society levels. Furthermore, smart home technology can enable older adults to continue living independently and safely in their own homes, reducing the need for assisted living facilities.

At the entertainment level, with the emergence of holographic communication and XR/VR technologies, 6G can enhance the live streaming experiences for events like concerts and sports. Viewers can enjoy 360-degree video, high-resolution live streams, and multi-angle perspectives, providing a more engaging and interactive experience. In addition, in such events, 6G can enable holographic displays and telepresence, and real-time, 3D holographic interactions, bringing a new level of immersion to the entertainment sector. Furthermore, with extremely low latency and high bandwidth, users can enjoy more immersive XR applications for gaming, interactive storytelling, and virtual tourism.

Moreover, advancements in AI and big data analytics allow personalized experiences for the individuals. In particular, 6G networks will provide the needed infrastructure and connectivity to enable AI-based applications to analyze user preferences and behavior in real-time, allowing for highly personalized recommendations, in terms of online content delivery, shopping experiences, health & fitness- elated recommendations, etc.

To Promote the Research & Development

UAE aspires to become a global hub for the research and development on 6G technology. This vision not only emphasizes the importance of staying at the forefront of technological progress but also signifies the UAE's dedication to building an ecosystem that drives innovation and positions the country as a pioneer in the evolution of telecommunications and connectivity. Such vision is pursued through heavily investing in latest technologies and equipment that constitute the cornerstone to several technologies that are yet at the research level. Furthermore, UAE is currently focusing on encouraging collaborations between academia, industry, and government, and establishing a number of multi-disciplinary research institutes and labs, that aim to develop innovative technologies which pave the way to 6G.

To Continue the UAE Role in Global Standardization Through ITU

As a main pillar in advancing the development of the 6G technology, UAE aims at maintaining its prominent role in 6G global standardization through the International Telecommunication Union (ITU). This vision can be achieved through the active participation of the UAE in ITU working groups and study groups focused on 6G technology, as well as working within the ITU to establish policies and regulations that support the deployment of 6G technology, including spectrum allocation, licensing frameworks, and regulatory best practices. This is critical for ensuring the successful deployment of 6G networks in the UAE and globally.

Among several initiative, du UAE is targeting to establish an ITU Focus Group on Artificial In elligence in 6G. This initiative by Du is aiming to create a focus group to study the integration of AI in 6G, building upon the previous work of ITU such as FG ML5G and FG AN. This has come amid the ITU CxO meeting [2], 6 December 2022, Dubai, in which CxOs called to support creating a global Meta Data Framework standard and to create a Data Frame work standard, to create and standardize the MENA AL ML sandbox, and To support the growing demand in areas such as AI/ML; immersive multimedia; Internet of Things; digital twin; environmental sustainability; 5G and beyond-5G network infrastructure, capabilities, performance and integration. The objective of the Focus Group is to provide an open platform to study and identify relevant gaps and issues in standardization activities related to adoption of AI in 6G networks. The Focus Group will identify the current landscape of relevant concerns, technologies, and stakeholders in integrating AI techniques to future networks including 6G. From this, the Focus Group will propose relevant existing and future novel use cases that exemplify appropriate concerns and motivations for AI in networks. The network impacts on integrating AI-native techniques in future networks would be studied. Furthermore, this Focus Group will propose possible requirements, architectures, tooling, and relevant data sets to be implemented in proof of concepts, identifying relevant technology enablers. It will also lay emphasis on providing a common platform for exchange of idea between relevant SDOs.

To Lead the Middle East Countries in 6G

By recognizing the critical role of being a leading country in the telecommunication technology market and driven by the fact that UAE was the first in the Arab region to deploy the 5G technology, the UAE is committed to not only adopting 6G technology but also driving its development, implementation, and standardization within the Arab region. In particular, the UAE seeks to set a high benchmark for technological innovation, economic growth, and digital transformation in the region, and to solidify its position as a leader in the evolution of wireless communications.

6G RESEARCH AND DEVELOPMENT IN THE UAE

The UAE is demonstrating a remarkable commitment to the research and development of 6G technology, with the aim to drive technological advancements and to position itself as a hub for cutting-edge research in the region. In the following, we demonstrate the UAE's devotion to advance the R&D on 6G.

The Role of Academia in 6G Research Academia plays a critical role in advancing and shaping the development of the next generation of wireless communication technology. Academic institutions, with their focus on long-term research, are hubs of research and innovation, where fundamental research is conducted, new technologies are developed, and foundational knowledge necessary for the development of 6G is created. Furthermore, academic institutions provide testbeds and facilities for testing and validating 6G technologies. This includes creating real-world simulation environments, conducting experiments, and analyzing data to ensure the viability and performance of 6G concepts. From another perspective, academic institutions in general promote open access to research findings, which an help disseminate knowledge and encourage collaboration in the 6G research community.

6G Centers of Excellence As a cornerstone in the 6G journey, UAE has devoted particular efforts to pioneer the innovation and research through the establishment of a number of research centers, dedicated for pushing the research on various technologies that are identified as pillars in 6G networks and beyond. By housing state-of-the-art facilities and fostering partnerships with leading international institutions, the UAE's 6G Centers of Excellence aim to establish the nation as a global leader in 6G technology, attracting talents and investments from around the world. The primary mission of these strategic centers is to drive advanced research in 6G technology, facilitating experimentation, testing, and innovation, and hence, ensuring the UAE remains at the forefront of technological evolution. These centers serve as focal points for collaborative efforts between government, academia, industry, and other stakeholders, each contributing their expertise and resources to advance the development and deployment of 6G technology, locally and globally.

The 6G centers of excellence at the UAE are:

- The newly established Khalifa University 6G Research Center, with three main themes, that are fully dedicated for cutting-edge research on 6G. The three themes are: Native AI, Sensing and Localization, and Broadband Connectivity.
- Khalifa University Center of Cyber-Physical Systems (C2PS), with a theme dedicated for Networks and Communication Technology.
- Emirates ICT Innovation Center (EBTIC) as an international center of excellence, established by Etisalat by e&, BT, and Khalifa University, with the aim to advance intelligent systems technologies for the Next Generation Networks (NGNs) and NGN-enabled ICT applications and services.
- Digital Science Research Center (Technology Innovation Institute) that is aimed for developing novel technologies in the areas of AI, intelligent environment, next generation mobility, and intelligent platforms.
- Big Data Analytics Center by UAEU, that contributes to the preparation of qualified scientists an researchers well-versed with big data analytics to meet the nation's interests and benefits

- The National Space Science and Technology Center has been established jointly by UAEU, the UAE Space Agency and the Telecommunications Regulatory and Digital Government Authority (TDRA), with a theme focused on the research on radio waves and data transmission for satellite communication, fostering the research on integrated satellite networks.
- Center for Artificial Intelligence and Robotics at NYU-Abu Dhabi, that aims to conduct fundamental research and develop applications in AI. Its research areas include, but are not limited to, the data processing and fusion, path planning and navigation, multi-agent systems, brain-machine interfaces, and autonomous decision making.
- In 2022 Intel has launched first AI software R&D center in the GCC based in Dubai Internet City [3].

6G Use-Case Development & Trials in the UAE

1. Du LiFi Du is honored to be the only MENA LCA (Light Communication Alliance) founding member. The alliance was founded in 2019 targeting the regulation, development, and standardization of Light communication with focus on LiFi communication. The LCA is the authority on light communication, being the most extensive light communications alliance in the world, and a recognized leader. The target of the LCA is building demand for light communication through collaboration. As an alliance we leverage partnerships between industry leaders to validate use cases and build functioning ecosystems, with the aim to ultimately inspire global investment in light communication [4]. Furthermore, Du has co-authored a white paper on the Terabit Indoor Laser-Based Wireless Communications: LiFi 2.0 for 6G White paper [5], which explores the available technologies required for implementing indoor laser-based wireless networks capable of achieving aggregate data-rates of terabits per second as widely accepted as a 6G key performance indicator. The main focus of this paper is on the technologies supporting the near infrared region of the optical spectrum.

2. Real-time point cloud adaptive streaming and interaction with 3D objects in VR Environments by Technology Innovation Institute (TII)
   The emergence of immersive media applications has given a rise to volumetric video streaming as typical use-case for 6G wireless communications. Inspired by this, the Telecom Unit at the TII has developed a demo to efficiently stream volumetric videos, while ensuring a fully interactive user experience, yet maintaining the low-power constraints of commercial VR headsets. The demo showcases an end-to-end adaptive point cloud video streaming, including encoding, transmission, decoding, and rendering processes. The demo has successfully achieved an immersive experience with six Degrees of Freedom (6DoF).

3. VR-based Fleet Control System: UAV and Ground Robot Use Case by Technology Innovation Institute (TII)
   The Telecom unit at the TII has further developed a demonstration to quantify the level of immersion in VR-based Fleet Control system, through incorporating a UAV to provide multi-source immersive streams from both aerial and ground vehicles. The demo is based on a combination of advanced equipment that provides an additional level of immersion. In specific, an innovative VR treadmill is used to provide

enhanced movement control, a feature usually missing from traditional VR setups. Furthermore, a haptic vest is used to provide tactile feedback to users, embodying user engagement in the virtual environment.

4. Large Generative AI for Telecom by Technology Innovation Institute (TII)
   Aligning with the UAE vision to lead the digital transformation in the region, the Telecom unit at the TII has led the very fi st position articles on the interplay of generative AI and Telecommunications [6] [7] with the aim to put the foundation for leveraging large generative AI models, with multi-modal data, to pre-train a single foundation model that can subsequently be employed across a range of di erent downstream tasks in the Telecom domain. This approach has several signifi ant advantages, including improved efficie y, reduced training requirements, and enhanced adaptability to varying network conditions. Furthermore, within this context, initial results were obtained by the team, where it was shown that LLMs can be fine tuned to fit in o the Telecom domain. In particular, it was demonstrated that a pretrained LLM, fine-tuned on 3GPP documents, can be used to identify di erent 3GPP working groups. Such results pave the way for the realization of intent-driven network automation.

5. Abu Dhabi Digital Twin for Improved Network Planning and Optimization by Technology Innovation Institute (TII)
   With the emergence of virtualization technologies and their implementation in the Telecom domain, the TII is currently developing Abu Dhabi digital twin, in which an exact virtual replica of Abu Dhabi city is created and then leveraged for optimizing the network planning, optimization, and configuration. The digital replica is utilized as well as a rich multi-modal platform to acquire close-to-real datasets that can be fed to various AI models, including large GenAI models, in order to optimize the models to fit within Abu Dhabi use-cases and scenarios.

6. UAE trial of 5.5G technology is paving the way for future 6G technology experimentation UAE was the first country in the MENA region to trial 5.5 G technology demonstrating 10Gbps speed experience combined with wide area coverage. This is a significant step forward in telecommunications and a necessary bridge paving the way for the future evolutions of UAE networks toward 6G. This trial was conducted in the 6GHz spectrum range showing the importance of mid-bands in accommodating the need for higher speeds and higher capacity while ensuring seamless and reliable connectivity. This is enabling emerging applications such as the metaverse, ushering in a new era of high-quality streaming, seamless cloud services and enhanced IoT experience.

7. Reconfigurable Intelligent Surface Trials by Technology Innovation Institute (TII)
   For the FR1 band, specifically focusing on the 3.5GHz frequency band, a private 5G network was set up indoors, supplemented with a 3.5GHz RIS. This was to assess its influence on coverage extension and blockage mitigation. The findings demonstrated that the RIS could enhance coverage extension sevenfold and blockage mitigation almost fourfold, without needing to modify or reconfigure the private 5G base station. In the FR2 band experiment, a 28GHz transmitter was used, equipped with a phased array antenna containing 64 elements, despite having no direct line of sight to the receiver. A 28GHz RIS was integrated, programmed with an optimized codebook, to establish a virtual line of sight link. The

results were equally impressive, with the team demonstrating that the RIS could establish a link with nearly 1Gbps of data rate, matching the data rate achieved in the LOS condition. It›s also important to point out that in both experiments, the RIS utilized minimal power, varying between 4 to 10W. This is significantly less than the power required for an additional base station.

Furthermore, in the following we highlight some examples of potential live trials that will help in the path to 6G:

- Implementation of Intent Driven Orchestration. Using artificial intelligence to orchestrate network and compute resources to optimize the usage of the assets and improve energy efficiency.

- Cloudification in every network domain and element, including virtualization of radio access network, edge cloud and core on hybrid-cloud. Disaggregation of the Radio Access Network is a must for certain scenarios and will facilitate the deployment of different versions and vendors of radio in a common radio access node infrastructure. It will be desirable to adopt in certain scenarios of deployment radio vendors that can decouple completely the software from the hardware.
- Small cells deployments for higher bands that complement current radio access network, adopting a new philosophy of defining the radio access, from Cell-Centric to Subscriber-Centric.
- In order to facilitate this vision of "Network of Networks", it is highly recommended to adopt any technology solution that facilitate the interoperability between different telecom vendors, as an example, open interfaces and open APIs like eCPRI fronthaul interface, openRAN and ORAN; and participate actively in any industry forum that promote these new standard interfaces, so they receive the feedback from the UAE market specific needs.
- Convergence of Network Cloud and general-purpose Cloud, and integration of capabilities of virtual network functions catalogue and generic cloud compute services catalogue.
- Edge computing cloud architectures to support network workloads, generic purpose compute workloads, highly demanding new workloads like VR, gaming, metaverse, AI LLM; industry 4.0 and enterprise workloads, private (dedicated) wireless networks, etc.
- Fix and mobile backhaul convergence, to support more efficiently the explosive growth of data in the next years. Adoption of virtual AGF defined in 3GPP to aggregate the function of BNG and UPF.
- Network APIs based on open standards. Adding any capacity to the network that allow to the carrier to "program" services according to the business requirements and to provide a way to third party business partners to access the network capacities and develop new services combined with their own capacities.
- Adoption of Smart Network Interface Cards, Smart NICs. Considering the ultra-low latency requirements and the need to embed AI everywhere, it is recommended to have a strategy about using Smart NICs that will reduce the latency processing certain workloads. Smart NICs avoid processing a workload in the main Central Processing Unit, CPU, thanks to Remote Direct Memory Access, RDMA. These Smart NICs could be used to accelerate security protocols and guarantee the level of trustworthiness that will be needed in 6G. Reducing the latency will help for the deterministic characteristic that will be intrinsic in 6G new digital services.
- Promote the adoption of silicon vendors that counts with a strategic roadmap to integrate in the same chipset different kind of compute accelerators, as an example, AI accelerators, security accelerators, graphics accelerators, etc. By this way, we can guarantee an energy efficient and sustainable ICT

infrastructure. It would be desirable, but not essential, to count with a silicon vendor that integrates in their products multiple architectures and have the ability to produce chipsets with this heterogeneous approach. By this way, the ICT infrastructure will be more flexible and efficient.

- Standardize underlying ICT infrastructure using the most energy efficient solutions, use advanced telemetry capabilities to manage the power state of the individual components in a chipset. Integrate this advanced telemetry capabilities in the main orchestration and management tools of the network, data center and cloud. Integrate artificial intelligence capabilities to take smart decisions in real time about the activation and de-activation of network and IT assets, at server level and CPU and individual components level.

All of these technology use cases could be applied to the vertical industries that will create a higher impact in the UAE economy like oil and gas, transportation and logistics, tourism, education, etc.


6G

6G RESEARCH TOPICS

Standards Development

ITU-R WP5D has finalized and agreed a Draft New Recommendation, "Framework and overall objectives of the future development of IMT for 2030 and beyond" in its June meeting of 2023. ITU-R Study Group 5 has adopted the new Recommendation on the "IMT-2030 Framework" since its meeting on 26 September 2023. It is expected that ITU Member States will approve the Recommendation by end of 2023. The publication of the Framework Recommendation is expected to communicate the overall objectives of IMT-2030/6G to research organizations and standardization bodies around the world, thus helping them to focus their activities towards common goals. In addition, WP 5D has also completed a new ITU-R Report on "Future Technology Trends", which has been published as ITU-R Report M.2516 in December 2022. This Report has provided an overview of future technical aspects of terrestrial IMT systems considering the time-frame up to 2030 and beyond. All these relevant information can be found from the ITU-R IMT-2030 website (https:// www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2030/Pages/default.aspx).

6G will comprise both evolutionary and revolutionary advances. Technology areas being studied and included for 5G Advanced will become the evolutionary foundation for 6G. Research and studies are underway, in industry, standardization bodies, academia, and regulatory bodies.

The technology trends of 6G/IMT2030 that are applicable to radio interfaces, mobile terminals and radio access networks are described in the ITU Report on "Future technology trends of terrestrial International Mobile Telecommunications systems towards 2030 and beyond". Figure 8 summarizes these trends, which include emerging technologies and the technologies to enhance the radio interface as well as the radio network.

Emerging Technology Trends	• Technologies for AI-native communications • Technologies for integrated sensing and communication • Technologies to support convergence of communication and computing architecture • Technologies to support convergence of communication and computing architecture • Technologies for device-to-device communications • Technologies to efficiently util e spectrum • Technologies to enhance energy efficie y and low power consumption • Technologies to natively support real-time services and communications • Technologies to enhance trustworthiness
Technologies To Enhance The Radio Interface	• Advanced modulation, coding and multiple access schemes • Advanced antenna technologies • In-band full duplex communications • Multiple physical dimension transmission • THz communications • Technologies to support ultra-high accuracy positioning
Technology Enablers To Enhance The Radio Network	• RAN slicing • Technologies to support resilient and soft networks for guaranteed QoS • New RAN architecture • Technologies to support digital twin network • Technologies for interconnection with non-terrestrial networks • Support for ultra-dense radio network deployments • Technologies to enhance RAN infrastructure sharing

Figure 8 Technology Trends of 6G/IMT2030 (ITU-R Report M.2516)

At Mobile World Congress Barcelona 2023, Qualcomm [8] showcased advanced research demos across multiple technology themes to highlight its latest innovations. The following are some potential technology building blocks for the new 6G platform.

AI-enabled, End-to-End Communication [9]

While being initially deployed in 5G to improve performance, efficiency, user experience and operation of wireless systems, 6G is expected to significantly advance machine learning (ML) and AI capabilities. 6G is expected to be AI-native, incorporating AI by design, with AI being integrated across all protocols and layers to operate autonomously between the device and the network as shown in Figure 9. That opens up the opportunity to bring more intelligence and coordination to radio access networks (RANs), device and to the end-to-end system. One anticipated benefit of AI native design is that the end-to-end system can be dynamically optimized for the specific deployment site, radio environment and user context.

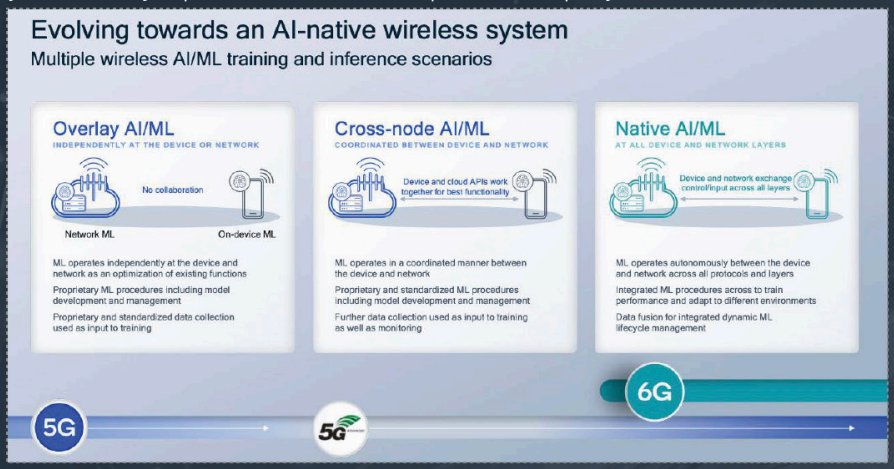


Figure 9 Evolving towards native wireless ML (Source: Qualcomm)

Next-Gen Air-Interface Innovations [10]

Every new mobile generation brings with it a new air interface that can support the full capabilities needed for the different targeted use cases. New duplexing schemes (e.g., full duplex) and advanced MIMO technologies can play role in facilitating these use cases and improving user experience in 6G across existing bands with the full potential of new 6G bands.

In conventional cellular system, a band has a fixed duplex scheme, i.e. either FDD or TDD. DL and UL transmissions occur mutually exclusively either in TDD or in FDD. Dynamic TDD was introduced in 5G to enhance the duplex flexibility, thus facilitating adjustment of the ratio between DL and UL time slots depending on traffic demand. Advanced duplexing schemes in 6G are expected to be more flexible and to adapt efficiently o specific needs. full-duplex communication has been successfully prototyped and demonstrated in over-the-air environments. Continued development of techniques for self-interference and crosslink- interference estimation, cancellation and avoidance will mitigate the impact of transceiver nonlinearities.

RAN Development

In the pursuit of 6G advancement, one of the central objectives is to enable advanced features like distributed computational tasks at the edge, and supporting applications such XR, V2X, and sensing.

The communication stack, especially the protocol stack, requires re-engineering to meet application Quality of Service (QoS) requirements dynamically. This includes optimizing both network (NW) and UE layers, aiming to enhance end-user experience while minimizing UE complexity. The 6G protocol stack redesign should tailor to specific applications, avoiding excessive flexibility that increases signaling, implementation complexity, memory, and power consumption. Redundant functionalities across different layers need mitigation to streamline operations. In order to simplify the implementation of the 6G stack and improve power consumption and energy efficiency, reduction of unnecessary NW-UE interactions and minimization of signaling and data processing overhead are primordial. Mobility enhancements at L1/L3 levels are vital for cell-less deployment, minimizing signaling, data processing overhead, and enhancing control/data plane architectures.

In addition to revisiting and optimizing control-plane and data-plane procedures, integrating an AI/ML-native network architecture is crucial to streamline Radio Access Network (RAN) functionality and minimize complexity in both network infrastructure and UE. Moreover, the emergence of heterogeneous networks and distributed data applications in 6G necessitates distributed data-driven decision-making approaches like distributed ML and federated learning. Leveraging these techniques also requires data and model exchange between the cellular network and UEs. For instance, UEs can utilize network information and on-device contextual information to assist in connectivity decisions, enhancing connectivity Quality of Experience (QoE). Also, private federated learning can be used through sharing NW models with the UEs and train the model on contextual UE.

In order to protect UE data privacy, privacy-preserving measures (such as secure aggregation, data anonymization, and federated learning with differential privacy) should be incorporated into the deployment of AI/ML functionality in the cellular network fabric. Data and model exchange between network nodes calls for new requirements related to data collection, training, and inference, including privacy preservation and coordination of data and learning among cellular nodes. Therefore, research should focus on the privacy aspects of data and privacy-preserving sharing mechanisms, emphasizing architectural and signaling adaptations of the cellular network. Finally, learning coordination is needed to keep data and models up to date, requiring new signaling and life-cycle management processes.

Core Network Development

Core network development is a critical research area within the 6G landscape, focusing on the fundamental architecture and infrastructure that will underpin the future 6G network. It is foreseen that current core infrastructure will be replaced with a newly designed digital infrastructure that will support the envisioned digital transformation and the 4th industrial revolution. Telecom operators and service providers should explore the capabilities of the digital infrastructure and actively contribute to the evolution of future networks. Within the area of core networks, the following topics should be tackled: i) developing AI-based solutions for intelligent core network management, including predictive maintenance, self-optimization, and resource allocation, ii) developing advanced network virtualization techniques within the core network, enabling greater flexibility, and iii) developing standards and protocols that allow seamless interoperability in 6G core networks, ensuring consistency and compatibility worldwide.

Reconfigurable Intelligent Surface

Reconfiguable Intelligent Surfaces (RIS), comprising a number of metamaterial-based elements, represent a cutting-edge technology in the field of wireless communication and signal propagation. RIS has a unique capability in dynamically manipulating electromagnetic waves, enabling various functionalities, including beam steering, splitting, blocking, and focusing, rendering them optimum solution for adapting to changing wireless environments and for optimizing signals transmission. The RIS technology has the potential to revolutionize future wireless networks, by offering improved connectivity, reduced interference, and increased energy efficiency. As a promising research direction, further explorations if the field of RIS open up new possibilities for RIS-enabled seamless, high-speed wireless connectivity.

Securing the 6G

Securing 6G is of paramount importance as we prepare for the next generation of wireless connectivity and communication advancements. Building a secure 6G network involves addressing various key considerations, including securing AI, authentication and access control, strong data protection measures, secure network slicing, blockchain technology, as well as zero-trust networks.

Massive MIMO & Beamforming [12]

MIMO (Multiple Input Multiple Output) technology has been used in wireless communications for a long time. It requires a combination of antenna expansion and complex algorithms. Now, with the design of new 5G NR networks, massive MIMO expands beyond the legacy systems by adding a much higher number of antennas on the base station. Massive MIMO is a key enabler of 5G's extremely fast data rates and helps focus energy, which brings drastic improvements in throughput and efficiency.

6G MIMO technologies will evolve with other fundamental PHY building blocks to improve user experience across existing bands in addition to new 6G bands. As described in "6G Spectrum Insights", 6G is expected to expand into upper-mid band spectrum to achieve higher data rates. GIGA MIMO, an advanced form of 5G massive MIMO, which utilize a large number of antennas on both the base station and device, has been showcased by Qualcomm at MWC 23 in Barcelona. Studies show that the coverage in the upper mid-band is comparable to what can be achieved with 5G massive MIMO today in the lower mid-band frequency bands.

Satellite Integration

The integration of satellites in wireless networks constitutes a main pilar in future 6G wireless communication, and envisioned to be a key in realizing speed, latency, and connectivity. Satellites can provide ubiquitous global coverage, bridging the digital divide in remote and underserved areas, while offering low-latency connections that can revolutionize industries like telemedicine, autonomous vehicles, and the Internet of Things (IoT). With high-throughput, low Earth orbit (LEO) satellite constellations and advanced antenna technologies, 6G networks will benefit from enhanced connectivity options, ensuring that users can stay connected anywhere in the world. The seamless integration of satellite technology into 6G networks promises to unlock a new era of connectivity and innovation, pushing the boundaries of what is possible in the digital age.

WAY FORWARD

Similar to UAE's 5G strategy (https://tdra.gov.ae/en/uae-5g) it will be very useful to establish a national 6G task force including working groups on di erent aspects of 6G. UAE may also follow the 6G studies of governments especially leading countries like USA, South Korea. Shaping the path toward 6G excellence in the UAE requires the development of a multi-dimensional strategy, with Intellectual Property (IP) strategy, R&D and start-ups plans, 6G labs of excellence, standardization activities, and international collaborations being main pillars in this strategy. From the one hand, there is a need to establish a robust Intellectual IP plan, strategically designed to protect the locally developed innovations and hence, to push for an ecosystem of continuous creativity and growth. Furthermore, recognizing the imperative role of startups in driving innovation, the UAE 6G strategy should put a particular focus on nurturing and propelling emerging enterprises into the forefront of the 6G ecosystem. The goal is to create a thriving innovation ecosystem that not only fosters entrepreneurship but also positions the UAE as a global hub for 6G technological development. Additionally, to set the scene for the development of 6G technologies in the UAE, it is imperative to build a dynamic 6G Lab to provide a real-world environment for testing and refining 6G use cases, thereby accelerating the pace of technological evolution. This lab will not only showcase the potential applications of 6G but also provide a collaborative space for industry players, researchers, and policymakers to jointly explore the technology's capabilities. Moreover, the emphasis on cybersecurity and sustainability aligns with the global agenda, with the UAE actively participating in COP28 and integrating these crucial considerations into the fabric of its 6G vision. From a standardization perspective, the UAE is aiming to build a solid and clear strategy on how the UAE, with its R&D centers and industry force, will contribute to the establishment of 6G standards through international standardization bodies, and to develop a plan to adhere to international standards, ensuring interoperability and seamless integration within the global 6G landscape. As part of UAE 6G vision, the di erent R&D institutions are focusing on building a strategic approach towards knowledge dissemination, through reinforcing the publication of a series of influential scientific pape s on various technologies of 6G.

On the other hand, the World Radiocommunication Conference 2023 (WRC-23) in November set the spectrum foundations for 6G and discussed the agenda for WRC-27. Accordingly, as a way forward, we recommend defining the oadmap for spectrum bands supporting future networks. The consideration of the use of THz spectrum for 6G, and the use of 7-15 GHz for future networks is essential. The study cycle towards WRC-27 is crucial to evaluate and identify the right spectrum bands in which 6G can be deployed from the early roll-out stage. Decisions on spectrum for IMT-2030/6G at WRC-27 will allow for the spectrum conditions to be defined in due time or the initial deployments. Furthermore, we recommend collaborating in forming the guidelines on the spectrum needs, as well as research on the potential socioeconomic and climate benefits rom this technology, as 6G spectrum work in 2023 will be driven by industry research and collaboration.

The Path to 6G Innovation program will stimulate:

- Research and development of key technologies that are expected to contribute for a successful implementation of the 6G networks.
- Live trials targeting the key economic sectors that are the engine of growth of the UAE economy.

- Public to private consortiums with international industry vendors to acquire the skills and the essential know-how to guarantee the sovereignty and control over this technological asset, that is expected to be the backbone of the digital economy.
- The adoption of open interfaces to have more flexibility and to have a proper supply chain diversification that guarantee the supply of critical components in case of a new pandemic or any other global supply chain issues.

- The implementation of the latest security solutions that will cover the potential risks that may arise, promoting the development of zero trust layers.
- Localization (landing) of international leading technology vendors to promote high quality of employment and achieve the desired spillover effect over other Emiratis companies and public entities.
- Scholarships and post degree awards for the best paper, patent fillings, etc.
- Creation of a master's degree for Path to 6G in collaboration with leading industry vendors to gain skills in all the fundamental technologies involved.
- Foundation of a National Lab for open-RAN/O-RAN as a way to increase flexibility, experiment new digital services and gain hands-on experience in open standards and emerging technologies in the Path to 6G. This lab should be hosted ideally in a university/research institute and will count with a steering committee that will include the government, the carriers (e& and du) plus academia and international industry vendors.

CONTRIBUTORS

Telecommunications and Digital Government Regulatory Authority
Hasan Sharif
Sultan Al Blooshi
Fawzeya Alali

Khalifa University
Merouane Debbah
Ernesto Damiani
Nawaf I. Almoosa

Technology Innovation Institute
Lina Bariah
Faouzi Bader
Thierry Lestable

Emirates Integrated Telecommunications Company (Du)
Najla Alkaabi
Fathi Abdeldayem
Hicham Hifdi
Abdulrahman Aljasmi

Etisalat by e&
Hareth Alshehhi
Wisaam Farhat

Nokia
Brahim Ghribi
Noman Waheed

Intel
Ignacio Astilleros
Turhan Muluk
Michael Kraemer

Qualcomm
Jinane Karam
Lola Awoniyi-Oteri
Danny Tseng

Huawei
Fatima Karim
Shu Kodo

Apple
Tarik Tabet
Sree Vallath

Ministry of Foreign Affairs
Nouf Alhameli
Office of Assistant Foreign Minister of Advanced Science and Technology

Ministry of Industry and Advanced Technology

BIBLIOGRAPHY

[1] Ericsson, "Fixed wireless access outlook," [Online].
Available: https://www.ericsson.com/en/reports-and-papers/mobility-report/dataforecasts /fwa-outlook.
[2] I. C. MEETING, Dec. 2022. [Online]. Available: https://www.itu.int/en/ITU-T/tsbdir/cto/Documents/ Communique_ITU_CxO_2022_06.12_Final.pdf.
[3] Intel. [Online]. Available: • https://www.mediaoffice.ae/en/news/2022/October/11-10/ Dubai-Internet-City-to-welcome.

[4] [Online]. Available: http://lightcommunications.org/.
[5] [Online]. Available: https://strathprints.strath.ac.uk/83827/1/Soltani_etal_arXiv_2022_Terabit_indoor_ laser_based_wireless_communications.pdf.
[6] Q. Z. H. Z. Y. T. F. B. M. D. Lina Bariah, "Large Language Models for Telecom: The Next Big Thing?," arXiv preprint arXiv:2306.10249, 2023.
[7] Q. Z. L. B. M. B. M. D. Hang Zou, "Wireless multi-agent generative AI: From connected intelligence to collective intelligence," arXiv preprint arXiv:2307.02757, 2023.
[8] Qualcomm, "How is Qualcomm driving 5G Advanced into new verticals and toward 6G?". [9] Qualcomm, "MWC2023: How Qualcomm uses AI to enhance 5G E2E communication - YouTube". [10] Qualcomm, "MWC 2023: How Qualcomm is bringing next-gen air interface innovations - YouTube". [11] Intel, «6G Cloud-Native System: Vision, Challenges, Architecture Framework and Enabling Technologies» Intel https://ieeexplore.ieee.org/abstract/document/9882121.

[12] Qualcomm, MWC2023: Showcasing Qualcomm's Giga-MIMO & sub-THz innovations – YouTube.

@TDRAUAE, www.tdra.gov.ae