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Saudi Arabia
Centre for the
Fourth Industrial
Revolution

6G Technology

Connecting the un-connected

White Paper

September 2023

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Research has been done with publicly accessible information, 6G reports, and white papers. It also utilized information collected from industry events.

Executive summary

Approximately every ten years, a distinctive chance emerges to mold the trajectory of mobile networks as we welcome the arrival of the next generation. On December 3, 1979, Nippon Telegraph and Telephone Public Corporation (NTT) made history by introducing the world's inaugural mobile communication service through a cellular system. Since that innovative moment, the radio access technology for mobile communications has undergone a systematic evolution, giving rise to a new generation system every decade.

As we witness the successful deployment of 5G systems, boasting over 200 operational networks globally, we recognize that the evolution of 5G is an ongoing journey. Over the next 7~8 years, we anticipate a series of evolutionary advancements falling under the view of "5G Advanced". These advancements are composed to encompass a wide range of solutions, aimed at boosting coverage, optimizing user experience, extending beyond connectivity, and achieving operational excellence.

Simultaneously, intensive efforts are underway to 6G research, supported by robust momentum from pre-competitive joint research initiatives. Setting itself apart from previous generations, 6G showcases its distinctiveness by prioritizing the definition of key foundation such as Native AI, NetZero, and sustainability. This strategic approach addresses critical research challenges while enabling diverse use case families expected to shape the landscape of the 2030s. In essence, the 6G research journey is driven by an interaction between "social pull" and "technology push," encompassing both the scope and essence of the research endeavour. Among the visionary use case families for 2030s communications lie immersive telepresence, massive twinning, collaborating robots, as well as the establishment of trusted and specialized 6G subnetworks, among other innovations.

Within the content of this white paper, our objective is to furnish readers with a comprehensive perspective on diverse aspects pertaining to 6G technology. These aspects encompass technical and social trends, services, requirements, and potential technologies. We wrap up this white paper with a thought-provoking conclusion that produces the key takeaways. Additionally, we provide a glimpse of the future roadmap for 6G. Our analysis in this white paper aims to empower readers with an informed understanding of 6G technology, equipping them to navigate the transformative landscape of the next-generation wireless communication. As we embark on this journey of discovery, we invite you to delve into the subsequent sections, where a wealth of knowledge awaits.

This whitepaper provides a comprehensive overview of 6G, the sixth generation of wireless communication technology. It highlights key components including technology evolution, Key Foundation, Spectrum under consideration, Terahertz (THz) band, Use Cases. It explores 6G's potential applications across various industries, including healthcare, transportation, entertainment etc. It emphasizes the transformative potential of 6G and enabling revolutionary applications like Native AI and augmented reality. Additionally, the whitepaper discusses spectrum allocation status, energy efficiency, security, and privacy concerns. The goal of the white paper is to equip stakeholders with a holistic understanding of 6G's potential, development efforts in research, development, and standardization for a seamless 6G future.

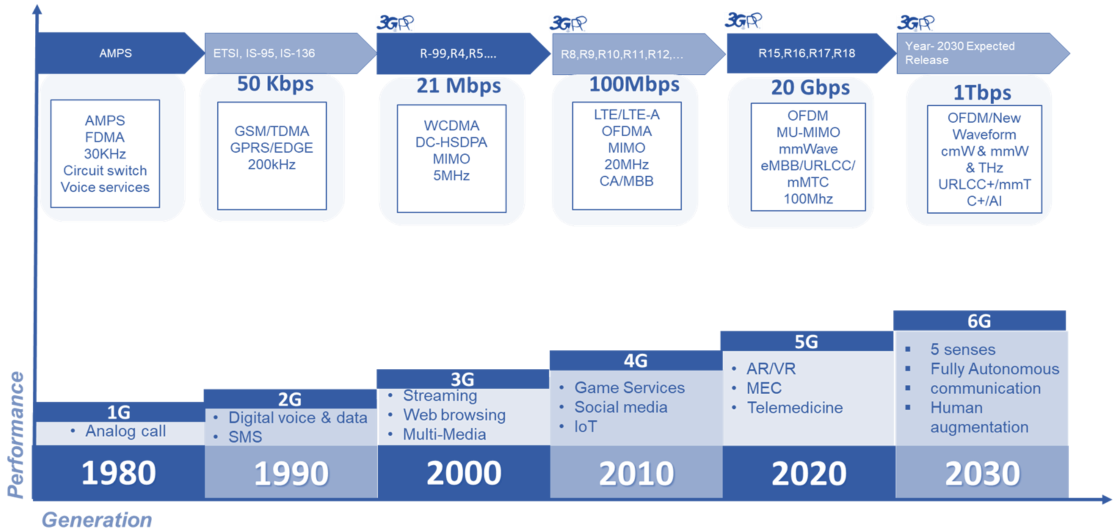
Introduction

Welcome to the Future: Unveiling the Potential of 6G Technology

Evolution of Mobile Communication: From 1G to 5G-Advance and Beyond

Drawing from historical precedent, it is foreseeable that technology will continue to advance, concluding in the emergence of another ITU-defined "IMT" within the timeframe of 2030.

Over the past few decades, the evolution of mobile communication technology has been nothing short of remarkable, driving us from the era of analog cellular networks to the 5G-Advance. Each generation has brought substantial improvements in devices, services, technology, and data rates, revolutionizing the way we connect and communicate.



2nd Generation (TDMA)

Digital Revolution

The 2G era emerged in the 1990s, with digital networks such as IS-54 (North American Digital Cellular) and IS-136 (Digital AMPS). These networks offered more efficient voice communication and data rates up 14.4 Kbps.

Famous 2G devices included the Nokia 3310 and Motorola StarTAC, which became iconic symbols of the mobile revolution.

3rd Generation (WCDMA)

Entering the 3G Era of High-Speed Data

The turn of the millennium brought 3G, which marked a significant leap in mobile technology. 3G networks like CDMA2000 and WCDMA (Wideband Code Division Multiple Access), based on 3GPP Release 99, enabled higher data rates up to 2Mbps, mobile internet capabilities, and multimedia services. The iPhone 3G, released by Apple in 2008, became a game-changer, popularizing mobile internet and ushering in the era of smartphone.

4th Generation (OFDMA)

The Era of Connectivity: Embracing 4G's Fast Data and Multimedia Experiences

In the late 2000s, 4G emerged as a game-changer, delivering faster data speeds, lower latency, and enhanced multimedia experiences. Networks like LTE (Long-Term Evolution), based on 3GPP Release 8, enabled data rates up to 100, enabling the era of mobile apps, video streaming, and mobile gaming, transforming the way people consumed content and services on their mobile devices.

5th Generation (OFDMA, mmWave, mMIMO)

Exploring the Transformative Power of 5G Networks

Stepping into the 2020s, 5G took center stage as the latest evolution in mobile communication. Building on the foundation of its predecessors, 5G networks, based on 3GPP Release 15, initially offered data rates up to 20 Gbps. This ushered in a transformational shift towards the Internet of Things (IoT), augmented reality (AR), virtual reality (VR), and autonomous systems. The rapid deployment of 5G-Advance, encompassing subsequent 3GPP releases, continues to push the boundaries of technology, opening doors to even more dynamic and innovative use cases.

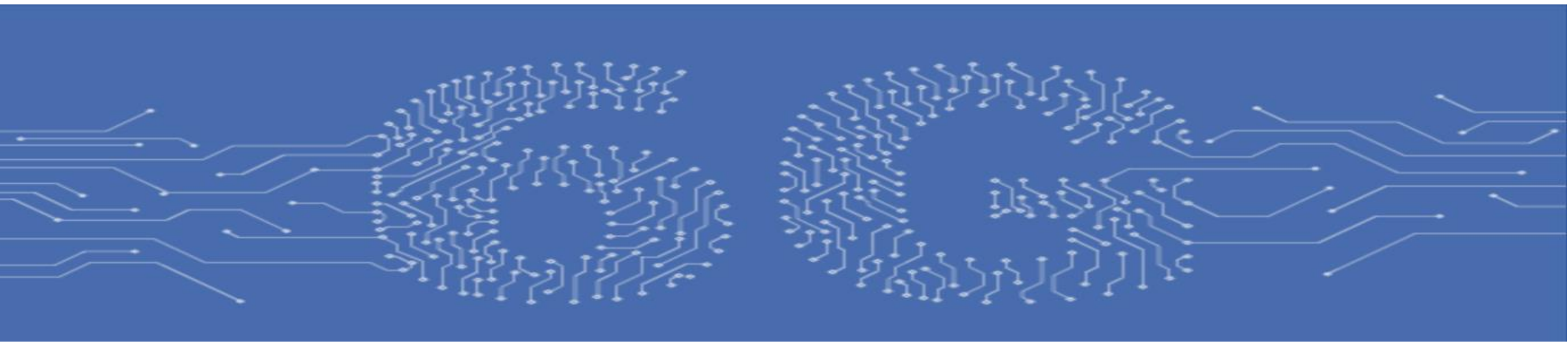
6th Generation (OFDMA, Tera hertz, extreme connectivity)

Connecting Digital & Physical World with Intelligence

As we look ahead, the journey of technological evolution shows no signs of slowing down. With each passing generation, we witness an exponential acceleration in innovation, pushing the boundaries of what we thought was possible. The prospects of a future 6G technology on the promise to ignite a new era of connectivity, surpassing the capabilities of its predecessors.

Anticipated to roll out in the coming decade, 6G holds the potential to revolutionize our digital landscape, surpassing the limitations of current technology. Envision a world where data rates reach the terabits per second, enabled by advancements in spectral efficiency, waveforms, and access technologies developed through collaborative efforts by 3GPP (Third Generation Partnership Project) and other standardization bodies. Key technologies like Massive MIMO (Multiple-Input Multiple-Output), beamforming, and advanced antenna systems will play a key role in realizing these unprecedented data rates and enabling seamless connectivity.

With 6G, the vision of a highly connected, intelligent, and adaptive network takes shape. The concept of RIS emerges as a critical component, empowering networks to dynamically adapt and optimize their coverage based on real-time conditions. By leveraging AI and machine learning, 6G networks can intelligently allocate resources, anticipate user needs, and proactively address potential challenges, entering in a new era of user-centric communication.

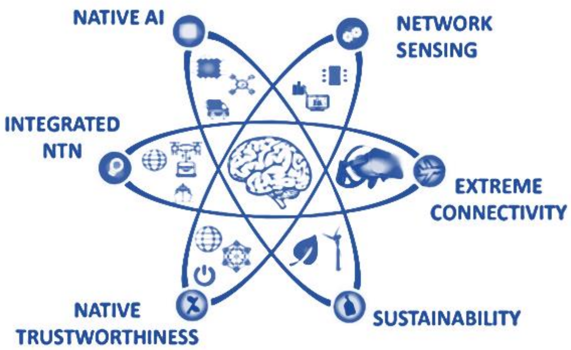


Aim of 6G Technology

The primary objective of 6G is to bring physical world & digital world closer to each other with a revolutionary transformation in wireless communication technology, opening possibilities in connectivity, services, and user interactions.

Pillars of 6G

Infinite Echoes of Interaction



eMBB+
6G sets its sights on achieving data rates in the terabits per second range, far exceeding the capabilities of 5G. This advancement will enable lightning-fast downloads, seamless high-resolution content streaming, and real-time interactive experiences.

URLLC+
The primary objective of 6G is to significantly reduce latency to sub-millisecond levels, guaranteeing instantaneous response times for critical applications. This advancement will prove essential for crucial tasks such as autonomous vehicles, remote surgeries, and real-time industrial automation.

mMTC+
6G aims to enable seamless connectivity for an extensive number of connected devices, supporting xMillion of devices effortlessly as the Internet of Things (IoT) experiences exponential growth.

AI
6G aims to embed AI-driven intelligence throughout the network, allowing for self-optimization, self-healing, and adaptive resource allocation. AI will play a central role in managing the complexity of the network and enhancing user experiences.

Sensing
The aim of sensing in 6G is to revolutionize the way we interact with and understand our environment, enabling transformative applications that benefit various industries and aspects of daily life.

Native AI (ai-everywhere)

6G will boast its native AI capability, enhancing the way we experience wireless communication. Its air interface and network designs will build E2E AI and machine learning to implement customized optimization and automated O&M, enhancing network efficiency and user experiences. This architectural shift opens the door to a many of innovative use cases, such as real-time autonomous vehicles that interact seamlessly with traffic systems, augmented reality experiences with instant object recognition, and smart healthcare applications that monitor patient health continuously.

Trustworthiness

Embedded at the core of 6G's design, Native Trustworthiness assumes the important role in safeguarding the security, privacy, and integrity of communication networks and services.

This encompassing trustworthiness have advanced encryption techniques, resilient authentication mechanisms, and secure data handling, effectively shielding against cyber threats and unauthorized breaches.

6G networks are purposefully equipped with inherent trust mechanisms to ascertain the authenticity of devices and users, thereby cultivating a dependable and secure communication environment. By prioritizing Native Trustworthiness, 6G sets robust foundation for critical applications like autonomous vehicles, healthcare, and financial services, ensuring the seamless protection of sensitive data and transactions.

Sustainability

Sustainability is a core value driving the development of 6G technology. Beyond just energy efficiency, 6G seeks to ensure sustainable growth by balancing social, economic, and environmental needs. It envisions green communication networks that minimize waste, reduce e-waste, and optimize the lifecycle of devices and infrastructure.

Energy efficiency expected this time as a key requirement in ITU-R IMT-2030.

6G technology trends with potential to drive higher efficiency and reduced power consumption.

✓ Use of AI/ML to drive smarter network, device and service behaviors

✓ Use of Sensing to support tuning of network and devices

✓ Use of passive nodes (e.g., RIS) to extend coverage and reduce power consumption

✓ Target zero energy transceivers through energy harvesting

Sustainability has been at the heart of Vision 2030 since its inception. Saudi Arabia is now ushering in a new era as the Kingdom aims to reach Net Zero by 2060. This announcement is in line with wider Vision 2030 ambitions to accelerate the energy transition, achieve sustainability goals, and drive a new wave of investment.

Extreme connectivity

Extreme Connectivity embodies 6G's ambitious goal to connect everything and everyone seamlessly, enabling hyper-connectivity across diverse devices and technologies. 6G will support massive machine-type communication, connecting xMillion of IoT devices, and achieving unparalleled device densities. Beyond this, 6G's extreme connectivity will provide robust communication in challenging environments, including underground, underwater, and remote areas. With pervasive connectivity and minimal latency, 6G opens the door to revolutionary applications, including smart infrastructure, precision agriculture, and ubiquitous AR/VR experiences.

Integrated ntn (non-terrestrial network)

A transformative integration is planned between terrestrial and non-terrestrial networks. By deploying a vast number of low- or very low-earth orbit (LEO/VLEO) satellites to form an "airborne wireless network," these non-terrestrial networks will complement terrestrial cellular infrastructure, expanding coverage and enabling low-latency solutions for ultra-long-haul transmission. Seamlessly providing continuous high-quality services worldwide requires deep integration, treating both network types' nodes as base stations to leverage their unique advantages in different service conditions. The integrated system opens doors to innovative use cases and bridging the digital divide in remote and underserved areas through improved connectivity.

Network as Sensor

Network Sensing represents a cutting-edge capability of 6G, where the network itself becomes a sophisticated sensing platform. 6G networks will integrate advanced sensors and machine learning algorithms to collect real-time data on network conditions, environmental parameters, and user behavior. This comprehensive network sensing enables dynamic resource allocation, seamless handovers, and predictive maintenance, optimizing network performance and ensuring superior user experiences. By continuously monitoring and analyzing network conditions, 6G will adapt to changing environments, maintain high-quality connections, and provide unparalleled connectivity.

Furthermore, the utilization of higher frequency ranges, like millimeter wave or terahertz, will amplify the ability to connect with the surroundings and gather contextual data. In the context of the 6G network, this help utilizing direct, reflected, and scattered radio wave signals to get information about target objects or the environment. This enables a range of functions, including positioning, distance estimation, speed assessment, imaging, detection, identification, and environmental modeling. As a result, the network achieves a sensory-based understanding of the physical world through comprehensive exploration.

Theoretical structure for sensing burst

- ✓ Brain User Interface (Typing text by thinking about the words without physically moving fingers)
- ✓ Digital smell
- ✓ Virtual view embedded with reality
- ✓ Digitized taste buds
- ✓ Digital body touch

Theoretical str Network will become the sensor; using cellular signals to vastly expands the sensing capabilities.

6G Specification & Spectrum

Journey to 6G Specification

3GPP has established itself as the premier global standard for telecommunication, from GSM (2G), WCDMA (3G), LTE (4G) to recent NR (5G). The current focus of standards body 3GPP is on finalizing Release 18, the first standard for 5G Advanced. From there, 5G Advanced refinements will continue in releases 19 and 20. The first 6G standard is expected around 2029, although formal study items are expected as early as next year 2024.

Upcoming Event wrc-23

Identifying and securing the right spectrum for 6G is essential if it is to successfully and cost-efficiently rollout during the 2030s with both expanded coverage and capacity. Taking note of the above learning from 5G. As frequency bands within this range are not yet identified to be used by mobile technologies, we consider that they should be studied during the 2023-2027 study cycle, with a final decision to be taken at WRC-27. That would enable the availability of such spectrum in time for the 6G introduction. Further developments of mobile technologies promise to efficiently make the most use of 7-15 or 7~20 GHz range, taking advantage of their wider bandwidth to address services requirements while better addressing the coverage challenge. There is a long journey towards 6G that starts now, and our efforts need to focus on getting the right spectrum that will assure its full success. Upcoming WRC-23 is expected to add the spectrum consideration for 6G.

ITU Position

In June 2023, the 44th meeting of the International Telecommunication Union (ITU) was held in Geneva, Switzerland, and the Proposal on Framework and Overall Objectives for 2030 and Future Development was completed as scheduled.

The successful completion of the global 6G Vision marks the official start of the journey toward 6G standardization. It is a fundamental milestone in the development of 6G, which will be implemented through global cooperation in accordance with the timeline set by ITU-R. In the next three years starting from 2024, ITU-R will focus on the study of detailed technical performance requirements and the evaluation criteria and methodologies, flagging the way for the technology proposal evaluation in the last phase of the IMT-2030 cycle, i.e., from 2027 to 2030. Meanwhile, 3GPP will continue the evolution of 5G into 5G Advanced, also known as 5.5G, and is expected to start 6G technology standardization with the aim of completing the specifications of IMT-2030 in 2030.

Tera Hertz

The potential of the THz band, an electromagnetic spectrum boasting frequencies higher than those in the mmWave range THz becomes an essential. Within THz band, mobile communications can control bandwidths exceeding 50 GHz. Under consistent conditions, higher bandwidth directly corresponds to elevated data transmission rates. Furthermore, the elevated frequencies within the THz spectrum facilitate centimeter-level precision in positioning that is beneficial with 6G deployment.

Frequencies ranging from 0.1 to 10 THz, the THz band holds significant promise. The foundation of the IEEE 802–100 Gbps project, specifically marked by IEEE 802.15d in March 2014, highlights the potential of this spectrum. However, the THz band's typical attributes, including notable path loss, scattering, and reflection, introduce an excess of new challenges. Resolving these obstacles is vital to realizing Tbps connections.

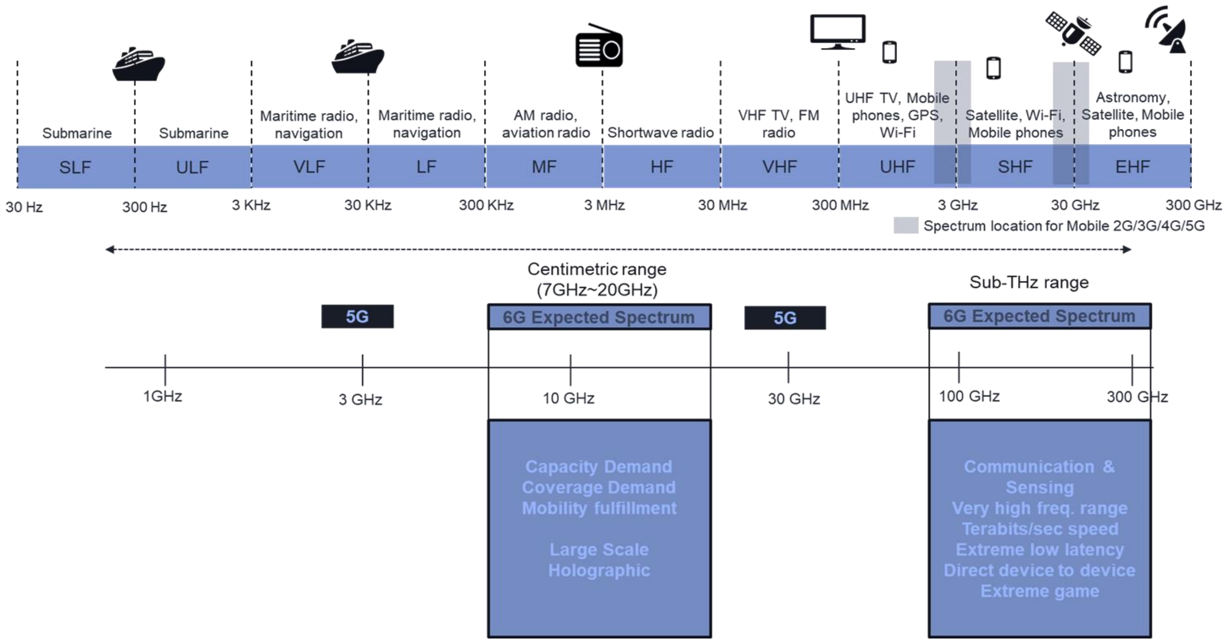
Radio & light technology combination

6G foresee a future where light and radio technologies work harmoniously, offering users the flexibility to choose between radio and light-based communication methods.

Light offers a multitude of benefits, including access to extensive unlicensed and freely available spectrum. Control light, we can achieve remarkably high data rates, potentially reaching hundreds of gigabits per second.

Additionally, communication through light is inherently secure, as the light signals are contained within the confines of the room where the communication is taking place. This inherent physical limitation ensures that external entities cannot intercept our communication, establishing a strong foundation of security and privacy.

An examination is required to explore the utilization of emerging spectral bands, including optical communications frequencies.



Reshaping Technology

The integration of biological interfaces, precise positioning, and hyper-realistic virtual worlds, high connectivity required combination of technology and our physical reality. The subsequent chapter will highlight some key aspect of technology enhancement.

Reconfigurable Intelligent Super surface (RIS)

One of the distinguishing characteristics of 6G compared to its predecessors (4G and 5G) is the potential use of higher frequency bands for communication. High-frequency bands, including millimeter-wave and terahertz frequencies, offer significant advantages in terms of data capacity and speed due to their wider available bandwidth. However, they also come with challenges, particularly related to propagation and coverage due to their lower penetration capabilities.

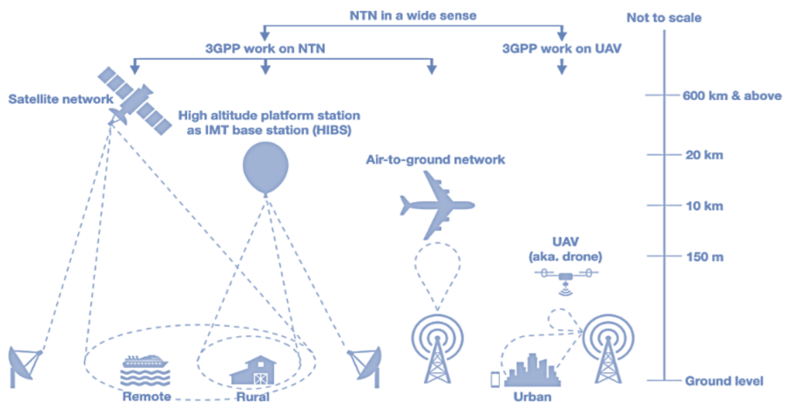
High-frequency signals are more susceptible to attenuation, reflection, and absorption by various objects and materials in the environment. This is where Reconfigurable Intelligent Surfaces (RIS) come into play. RIS technology offers a promising solution to address the propagation challenges associated with higher frequency bands in 6G.

RIS can be used to create constructive or destructive interference patterns in the wireless propagation environment.

By adjusting the phase shifts and reflections of the RIS elements, the signal that reaches the receiver can be enhanced or weakened based on the desired outcome.

RIS technology can be used to improve signal strength, increase coverage, reduce interference, and enhance the overall efficiency of wireless communication systems. Application of RIS includes, Coverage Enhancement, Interference Management, Energy Efficiency etc.

Non terrestrial network (ntn)



"Extensive coverage expansion" envisions scenarios encompassing all locations, encompassing not only terrestrial areas but also the sky, sea, and space. Accomplishing this, requires broadening the reach of network coverage to cater to mobile communication demands in settings involving drones, aerial vehicles, maritime vessels, and even space stations—situations that conventional networks have not adequately addressed. Consequently, it becomes vital to thoroughly investigate the above-mentioned New Radio Network Topology from a three-dimensional view, accounting for vertical dimensions as well. Furthermore, establishing communication in airborne, marine, and space domains will necessitate a technology

capable of facilitating efficient, long-range radio transmission, ideally spanning several kilometers with high efficiency.

Current satellite communication systems are based on proprietary protocols, such as Starlink and Oneweb. Starting from Rel17, 3GPP has defined a unified NTN protocol standard, it includes two types: Transparent satellites and regenerative satellites. Transparent satellites are only used by RF units, while regenerative satellites send DUs or the entire gNodeB to the sky. R17 involves only transparent satellite.

OneWeb's satellite communications network features 648 satellites (1,200km above) in low Earth orbit (LEO, orbit > 350km) & Starlink consists of over 5,000 mass-produced small satellite in LEO.

Net Zero

"In the evolution towards 6G, several transformative trends are composed to reshape the landscape of wireless communication systems, centering around enhanced efficiency and minimized power consumption. These trends not only address the escalating demand for data and connectivity but also aim to create a sustainable and eco-friendly communication ecosystem.

The Integration of AI and Machine Learning

One key trajectory involves harnessing the capabilities of Artificial Intelligence (AI) and Machine Learning (ML) to imbue networks, devices, and services with greater intelligence. By providing AI-driven insights, networks can dynamically optimize their operations, predict user behaviors, and allocate resources more efficiently, ultimately resulting in reduced power consumption and an overall enhanced user experience.

Sensor-Driven Optimization

Another significant direction focuses on employing sensory mechanisms to fine-tune both network infrastructure and connected devices. These sensors facilitate real-time monitoring of environmental conditions, enabling networks to adapt dynamically to changes and adjust their parameters accordingly. This approach not only improves network performance but also minimizes unnecessary power expenditure by ensuring that resources are utilized optimally.

Passive Node Adoption

The introduction of passive elements like Reconfigurable Intelligent Surfaces (RIS) introduces a novel approach to coverage extension and power conservation. By strategically deploying RIS, signal propagation can be manipulated, enhancing coverage in challenging areas and reducing the need for energy-intensive transmitter systems.

Energy Optimizing for Transceivers

In direction of energy efficiency, 6G envisions transceivers that are capable of achieving energy neutrality through energy harvesting (Solar, Wind, Hydro etc.). This includes both dedicated energy sources and binding ambient energy from the environment. This not only reduces reliance on conventional power sources but also contributes to a more sustainable wireless ecosystem.

AI Native

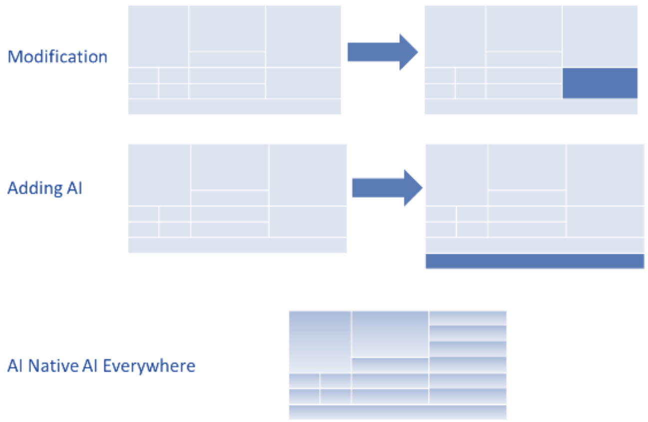
Artificial Intelligence and Machine Learning are catalysts for the emergence of innovative air interfaces

ML is not something completely new to wireless. For example, self-optimizing networks (SON) make extensive use of it. The SON approach to network management has always been based on applying traditional machine-learning techniques to large volumes of changing operational data to derive the most optimal network parameter settings over time. Meanwhile, deep learning is being applied to solve SON and radio resource management (RRM) problems, such as load balancing, carrier aggregation, handover optimization and anomaly detection.

The AI native concept can be defined as follows: "AI native is the concept of having inherent trustworthy AI capabilities, where AI is a natural part of the functionality, in terms of design, deployment, operation, and maintenance. An AI native implementation leverages a data-driven and knowledge-based ecosystem, where data/knowledge is consumed and produced to realize new AI-based functionality.

6G will boast its native AI capability. Its air interface and network designs will leverage E2E AI and machine learning to implement customized optimization and automated O&M.

Not only this, each 6G network element will natively integrate communication, computing, and sensing capabilities, facilitating the evolution from centralized intelligence in the cloud to ubiquitous intelligence on deep edges. A distributed machine learning architecture built on deep edge intelligence will be key to meeting the large-scale intelligence requirements of future society and manufacturing.



Key benefits of AI

- AI can help to improve the speed and efficiency of 6G networks,
- AI can be used to analyze data from the network and identify areas where improvements can be made to reduce latency and improve the overall performance of the network,
- AI can help to ensure that users get the best possible experience when using 6G technology.
- AI can also be used to provide personalized services to users, such as custom-made content or recommendations.

KSA 6G Potential View

Similar like 5G, it is expected that Saudia Arabia will continue its early involvement role in investment in 6G by actively participating in the global 6G standardization, development, and collaboration, Saudi Arabia can position itself as a leader in the next generation of wireless communication technology, contributing to economic growth, innovation, and technological advancement. In life cycle of any technology to introduce below are two main building blocks.

Global Standardization and Regulatory Alignment

- **Technical Standards Formation**

Establish international technical standards through organizations like ITU and 3GPP.

- **Spectrum Planning and Allocation**

Collaborate with regulatory authorities to allocate suitable spectrum for 6G operations.

- **Leadership in Standardization Bodies**

Actively participate in global discussions to shape 6G standards according to local requirements.

- **Regulatory Framework Alignment**

Ensure domestic regulatory frameworks are aligned with global standards for seamless 6G deployment.

Technology Development and Ecosystem Building

- **Prototyping and Testing**

Engineers develop prototypes to validate the feasibility of 6G technology, addressing technical challenges.

- **Pilot Deployments and Trials**

Small-scale deployments test 6G's real-world performance, providing insights for refinement.

- **Ecosystem Development**

Collaborate with industry partners to create necessary hardware, software, and infrastructure components.

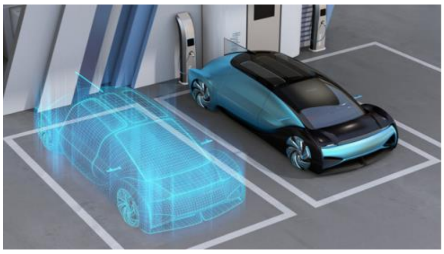
- **AI and Edge Computing Integration**

Explore the integration of artificial intelligence and edge computing, critical for 6G's advanced capabilities.

Saudia Arabia is active participating in role of standardization (WRC) & expectedly will take significant role as technology Adopter in the future.

Useful Use Cases for the Kingdom

Digital Twin



A digital twin refers to a virtual counterpart of a physical object or system, exactly replicating its behavior, attributes, and interactions in a digital environment. This dynamic simulation utilizes real-time data from sensors and IoT devices to offer continuous monitoring, predictive analysis, and scenario testing. In the context of 6G, digital twins can revolutionize telecommunications by enabling real-time network optimization, personalized services, and efficient resource allocation. For instance, in network planning, digital twins can simulate coverage and performance scenarios, aiding in the deployment of optimal infrastructure. Furthermore, in autonomous vehicles, digital twins could simulate real-world conditions for enhanced testing and training, contributing to safer and more reliable self-driving capabilities.

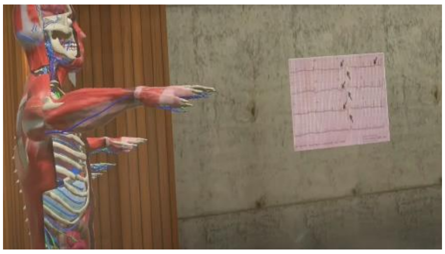
✓ Improve design, inspection & maintenance of complex machines & devices.

Teleportation

Holograms are composed to revolutionize visual communication and interaction, empowered by the network's ultra-high data rates, minimal latency, and massive device connectivity. These advancements enable the seamless transmission of complex holographic images, facilitating immersive remote collaboration, telepresence, and virtual meetings with realism. Holograms in 6G can transform fields like healthcare, where medical professionals can visualize and manipulate 3D holographic representations of patient data for precise diagnostics and surgical planning. Additionally, education and entertainment stand to benefit as holographic content becomes accessible on a global scale, enhancing learning experiences and delivering attractive entertainment in unprecedented ways.

✓ Improve communication, interaction & productivity.

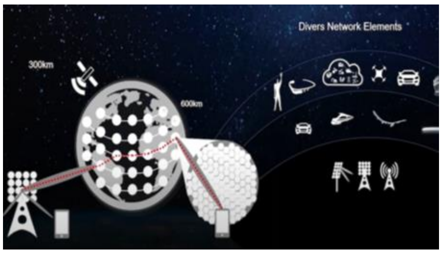
Digital healthcare



In health care, 6G will bring revolutionary use cases, such as real-time remote patient monitoring through wearable devices, enabling instant transmission of vital data to healthcare providers for timely interventions. Moreover, the high bandwidth and reliability of 6G facilitate advanced telemedicine applications, including high-definition video consultations and augmented reality-assisted surgeries, bridging geographical barriers and enhancing healthcare accessibility. Additionally, the Internet of Medical Things (IoMT) flourishes with 6G, enabling seamless integration of medical devices, smart sensors, and health data analytics, leading to personalized treatments, preventive care, and improved patient outcomes within an interconnected digital health ecosystem.

✓ Individualized assistance via virtual patient consultation & monitoring involving all the senses & health indicators.

NTN



Non-Terrestrial Networks (NTNs) stand as a vital role, leveraging the network's high data rates, ultra-low latency, and expansive coverage. This synergy facilitates an array of cutting-edge use cases, including ubiquitous global connectivity through Low Earth Orbit (LEO) satellites, revolutionizing industries like telecommunications, internet access, and emergency response in remote and underserved areas. NTN-powered applications extend to disaster management, where real-time communication between satellites and ground stations enhances situational awareness and response coordination. Furthermore, seamless integration of NTN with terrestrial 6G networks empowers enhanced mobile broadband experiences, IoT deployment at scale, and real-time data transmission for futuristic applications like autonomous vehicles and smart cities.

✓ Improve connectivity over all the globe.

COBOT

Collaborative Robots (COBOTS) take a transformative jump, COBOTS seamlessly collaborate with human operators through haptic feedback and shared augmented reality interfaces, ensuring safer and more efficient operations.

Moreover, with 6G's capabilities, COBOTS extend their reach beyond physical boundaries, enabling telepresence and remote operation scenarios where experts can guide and assist tasks from far, fostering global collaboration and knowledge sharing.

✓ *Evolution of Industry with COBOTS.*

Cyborg

Cyborgs are cybernetic organisms — humans enhanced with machines. In the landscape shaped by 6G, the concept of cyborgs takes on new dimensions, facilitated by the network's ultra-low latency, high data rates, and seamless connectivity. This convergence holds transformative potential, enabling symbiotic interactions between humans and technology.

Cyborgs empowered by 6G could embody augmented senses, merging the biological with the digital to enhance perception and cognition. By seamlessly integrating with cloud-based AI and extended reality interfaces, 6G-enabled cyborgs bridge the gap between human potential and technological capabilities. Developing coexistence of biology and innovation.

The following table provides descriptive examples of some of the most innovative 6G use cases and applications anticipated

1

Digital twins

Description	References	Key requirements
A digital twin (DT) is a virtual and real-time replica of assets or processes in the physical world, which connects to and receives data from the latter. A DT can monitor, create, simulate, analyze, optimize, and anticipate the behavior of physical systems.	Samsung, Ericsson, Hexa-X	To duplicate the physical items requires advanced sensors to collect data. Latency must also be greatly improved compared to 5G.

2

Metaverse and telepresence

Description	References	Key requirements
The metaverse describes a network of 3D virtual spaces where users can interact, play or work. Live virtual events, virtual professional meetings and immersive gaming are some of the obvious use cases. Telepresence describes the possibility to perform actions in a distant location or in a virtual location as if present at the location itself. Among other things, it can, for example, enable the control of a machine or vehicle in a remote or dangerous environment.	Nokia, Samsung, Hexa-X, Next G Alliance	Such scenarios require ultra-high data rates and low end-to-end latency, but also high synchronicity to manage different streams as well as high localization precision.

3

Intelligent robotic communication

Description	References	Key requirements
6G will enable the communication between robots or between humans and robots. This includes consumer/household robotics applications such as elderly care/personal assistance, as well as industrial robots for flexible manufacturing or activities in dangerous scenarios such as disaster rescue.	Nokia, Ericsson, Huawei, Hexa-X, Next G Alliance	AI and machine learning must be integrated to achieve robotic learning. Again, higher date rates and low latency are key network requirements to transmit robotic images and videos and locations. Security is another important consideration for critical use cases.

4

Digital healthcare

Description	References	Key requirements
Next-generation healthcare services will depend more on new and improved wearable devices that can measure body vital parameters and transmit these data to external devices.	Ericsson, Huawei, Hexa-X	To manage all this information gathered in real time, the network must be able to manage a larger number of devices while guaranteeing data privacy.

5

3D full coverage

Description	References	Key requirements
The need for mobile communications is moving beyond traditional ground connectivity. It is envisioned that in 6G, users will be able to connect more easily when on an airplane or at sea.	Huawei	Connectivity can be expanded using different platforms, such as low-earth orbit satellites (LEO) and HAPS.

6

Autonomous driving vehicles

Description	References	Key requirements
The evolution of vehicles, including personal cars and transportation trucks, to fully autonomous systems is underway. These systems will often depend on onboard sensors to make decisions, but 6G connectivity will bring additional features and safety.	6G IA, Hexa-X	Ultra-reliable connectivity and extremely low latency while moving at high-speed.

	Description	References	Key requirements
7 **Unmanned drones**	Unmanned drones are expected to enable delivery services, air surveillance, and monitoring and improved location services. Additionally, these can be deployed in areas where additional network coverage is needed.	Nokia, Huawei	Apart from increasingly sophisticated onboard sensors, the network must deliver extremely high bandwidth, ultra-low latency for precision control, and extreme reliability.

	Description	References	Key requirements
8 **Extreme low power communications**	As mobile networks become more ubiquitous, the number of access points and antennas will naturally increase. Both networks and devices will need to become much more energy-efficient to enable CSPs and their enterprise clients to meet their sustainability goals in the 2030s.	NTT DOCOMO	Multiple levers can be activated to improve energy efficiency, including more efficient silicon and network hardware, advanced power savings software features, and more intelligent network management and operations

Contributors

Lead authors

Ziyad A. Alsadun
Senior Mobile Access Strategy Analysis

Sohail A Ahmed
Mobile Access Strategy Consultant

Abrarul Haq Mohammed
Mobile Access Strategy Consultant

Abid Jameel
Mobile Access Strategy Consultant

Researchers

Osamah Mohamed Al Shamrani
Mobile Access Strategy Consultant

Mai B. Aljedani
Applications Strategy Analysis

Reviewers

Yazan Ali Ibdah
Mobile Access Strategy Consultant

Mubasher Mohammed Rafiq
Network Planning Expert Mobile Access Strategy

Advisor

Ahmad Suliman Al Slaiem
Mobile Access Strategy Consultant

Project Managers

Hossain M. Almotairi
Mobile Technologies Strategy Section Manager

Turki H. Almarghalani
Mobile Spectrum Strategy Section Manager

Abdulaziz R. Alanazi
Technology R&D & Innovation Enablement Manager

Governance

Mohammed A. Elabdulkreem
Mobile Access Strategy Director

Ahmed A. Alhamran
Technology Alliances & Partnership Director

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Centre for the Fourth Industrial Revolution KSA, in affiliation with the World Economic Forum

Basma AlBuhairan
Managing Director

Ibrahim AlShunaifi
Project Lead

Sara Al Hudaithy
Fellowship Program

Fanan Al Jammaz
Project Specialist

stc

Haithem M. Alfaraj
Group Chief Technology Officer

Khaled I. Aldharrab
Technology Strategy & Architecture VP

Hamdan S. Alfarraj
Technology Strategy GM

Sami H. Alzomaia
Business Architecture GM

Endnotes

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