GSMA

6G Terminal Vision White Paper

Feb, 2024

Table of Contents

Table of Contents

Table of Contents

1. Scope

1.0

Scope

Facing the 6th generation mobile networks (6G) industry in 2030, this research is to explore the vision of "6G terminal" in the 6G era based on the 6G vision reached by ITU-R, the current 6G research results of the industry, the research results of GSMA Intelligence, the development trend of the terminal itself and the emerging technologies.

2. Abbreviations, Terms and Definitions

2.0

Abbreviations, Terms and Definitions

2.1 Abbreviations

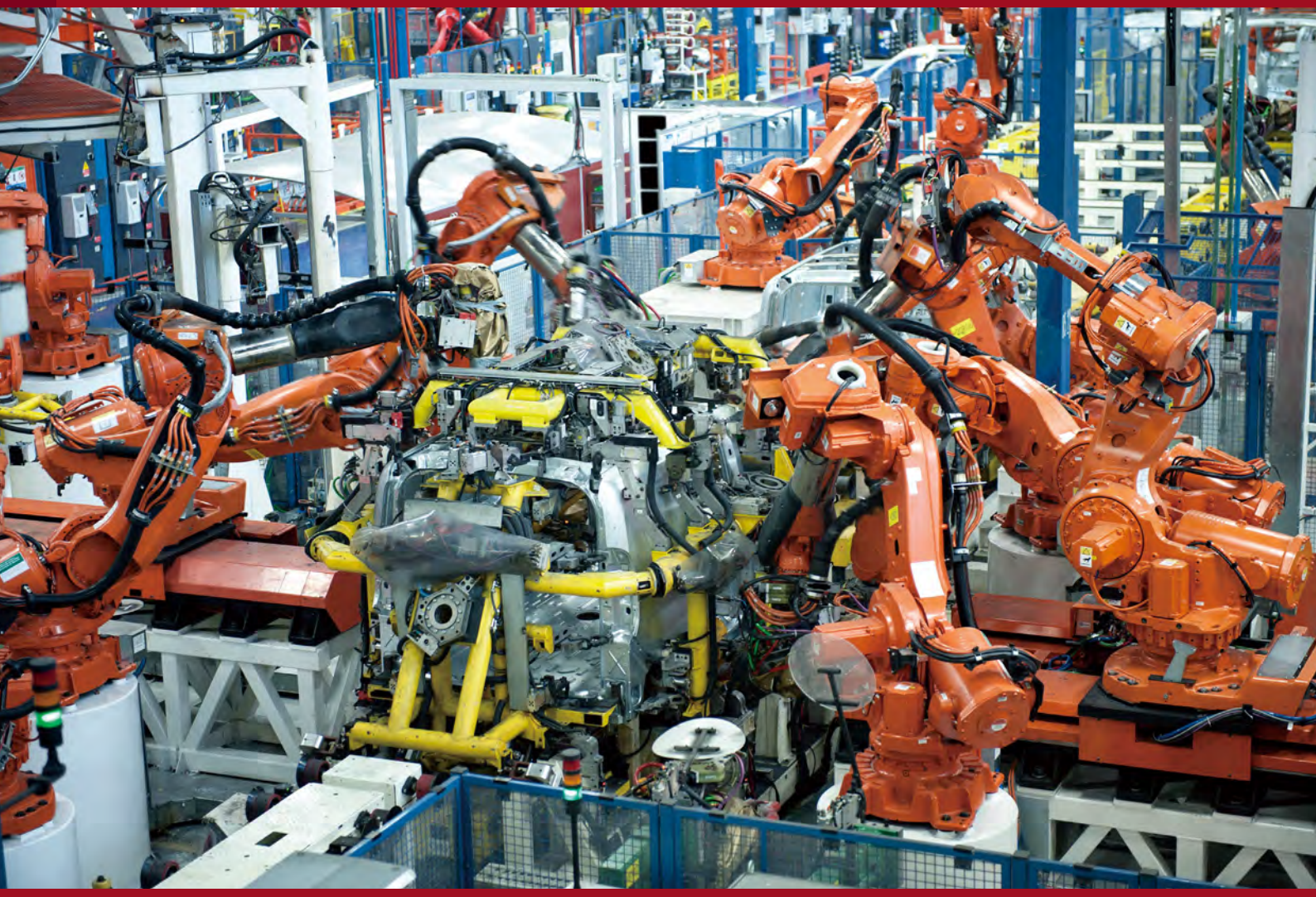
3GPP	3rd Generation Partner Project
AI	Artificial Intelligence
AR	Augmented Reality
CDMA	Code Division Multiple Access
ChatGPT	Chat Generative Pre-trained Transformer
CPU	Central Processing Unit
ERM	Eccenric Rotating Mass
GPU	Graphics Processing Unit
GTOPS	Giga Tera Operations Per Second
GSMA	Global System for Mobile Communications Association
HMD	Head-mounted Display
ICDT	Information, Communication, and Data Technology
IMT-2030	International MobileTelecommunications - 2030
ITU-R	International Telecommunication Union Radiocommunication Sector
LLM	Large Language Model
LRA	Linear Resonant Actuator
MTOPS	Million Tera Operations Per Second
MIMO	Multiple-Input Multiple-Output
MR	Mixed Reality
NPU	Neural Processing Unit

OAM	Orbital Angular Momentum
OEM	Original Equipment Manufacturer
OFDMA	Orthogonal Frequency Division Multiple Access
RIS	Reconfigurable Intelligent Surface
SDMA	Space Division Multiple Access
TDMA	Time Division Multiple Access
THz	Terahertz
VR	Virtual Reality
XR	Extended Reality

2.2 Terms

6G	6th Generation
6G Terminal	Terminals with their typical characteristics in the 6G era.
6G Satellite Interconnectivity	Enabling Data Transmission and Communication Interconnectivity Through Satellite Networks in the 6G Era.
Native AI	Artificial Intelligence as acore component and deep integration with it.
Intelligent Connectivity of Everything	By leveraging advanced information technology, achieve the efficient integration of people, processes, data, and things, forming an intelligent, highly interconnected network system.
Ubiquitous Intelligence	Integrating artificial intelligence technology with various devices, systems, and services to achieve pervasive intelligence.
Integrated Sensing And Communication	Combining communication technology with sensing technology to achieve the fusion of information transmission and environmental awareness.
AI communication	Integrating artificial intelligence technology with communication technology to enhance the performance and efficiency of communication systems.
Flexible Hardware	Electronic devices and systems made from flexible materials.
Immersive Extended Reality (XR)	Created based on augmented reality technology, a deeply immersive and interactive virtual environment.
All-around Communication	A system integrated with various communication methods and technologies, capable of achieving efficient and reliable information transmission in various environments and various requirements.

3. Background and the Current Situation



3.0

Background and the Current Situation

3.1 6G Terminals Bearing the Vision "Intelligent Connectivity of Everything"

In the 5G era, we are gradually moving towards the era of Internet of Everything, and 6G is expected to bring us into the era of Intelligent Connectivity of Everything, where the physical world and the virtual world are fused. 6G is no longer just a communication technology, but a huge distributed intelligent network, which integrates communication, perception, computing and other capabilities, connects the physical, biological, and digital worlds deeply, and brings the real "Intelligent Connectivity of Everything" to people. Based on 5G development, 6G will expand the connecting, not only connecting people to people, things to things, but further bringing "Intelligent Connectivity", popularizing smart connectivity to everyone, every family, and every enterprise, leading a new wave of innovation. In this vision, 6G's core capabilities, new application scenarios, new requirements, and major changes in communication and network architecture will be explored and practiced. It marks a glorious future, a future full of intelligence and connectivity, in which 6G will propel human society into a new digital era.

In the 6G-enabled digital era, individuals will have more customized digital services to make social communication more convenient. Families will improve their quality of life through smart home systems, and industries will achieve efficiency and energy enhancement through digital intelligence. Industries will gradually exceed the traditional constraints and create new business models and opportunities through digitalization. To achieve all this and move to a higher level of digital society, 6G terminals will play a key role. The widespread application of digitalization and the development of digital strategy worldwide have created an urgent requirement for the new capabilities of 6G terminals, making 6G terminals become the engine of the digital era to meet the growing demands for digitalization, and propel human society toward a smarter and highly connected future.

3.2 6G Vision Completed by Global Organizations

ITU-R WP 5D completed the IMT-2030 (6G) draft proposal and adopted it at the 44th meeting on 22 June 2023. ITU-R reached a global consensus on the vision of IMT-2030 (6G), which is an important milestone in the 6G development process and starts a new round of research on 6G. ITU-R reached 6 visions: immersive communication, hyper reliable and low-latency communication, massive communication, ubiquitous connectivity, artificial Intelligence and communication ,integrated sensing and communication, as well as 4 design principles applicable to all scenarios: sustainability, security and resilience, connecting the unconnected, ubiquitous intelligence. Integrated sensing and communication, AI and communication, ubiquitous connectivity are 3 new scenarios added by IMT-2030. Immersive communication, hyper reliable and low-latency communication massive communication, are the extensions based on the IMT-2020 vision.

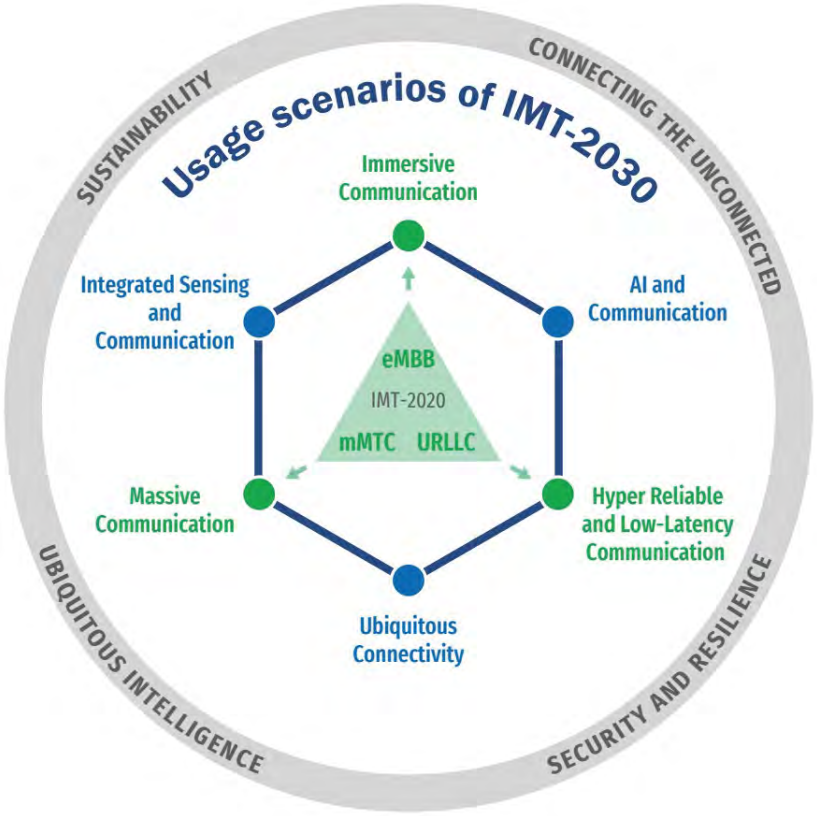


Figure 3-1 ITU-R 6 visions and 4 principles

In addition, multiple global standardization organizations, associations, and industrial partners have published their research results and visions on 6G, as shown in Table 3-1.

Table 3-1 6G research results from multiple organizations around the world

Organizations	Research results
ITU-R	→ "Framework and overall objectives of the future development of IMT for 2030 and beyond" → "Future technology trends of terrestrial International Mobile Telecommunications systems towards 2030 and beyond"
GSMA	→ "The green generation: bridging 5G and 6G" → "Setting the Stage for 6G"
IMT2030	→ "6G Typical Scenarios and Key Capabilities White Paper" → "Research Report on Application Scenarios and Requirements of 6G Distributed Network Technology"
6GANA	→ "6G Network Native AI Technology Requirements White Paper" → "6GANA-Network-AI-White-Paper"
Hexa-X	→ "Hexa-X architecture for B5G/6G networks – final release" → "Final 6G architectural enablers and technological solutions"
6GIA	→ "What societal values will 6G address"
Next G Alliance	→ "6G: The Next Frontier of Innovation and Investment" → "Beyond Speed: Promoting Social and Economic Opportunities through 6G and beyond"
NGMN	→ "6G Driver And Vision" → "6G Requirements And Design Consideration"
Global 6G Conference	→ "ICDT Integrated 6G Network 3.0" → "Low-Carbon Smart 6G for Sustainable Development: Vision and Technology Trends"

3.3 The Emergence of New Digital Intelligence Technologies

The development of 6G terminals is also benefiting from the emergence of digital intelligence technologies, represented by artificial intelligence, satellite interconnectivity, industrial digitization, and flexible hardware, which will bring richer functionality to 6G terminals, as well as change the user experience and the applications scope.

3.3.1 Native AI

In recent years artificial intelligence has continued to develop at a high speed and has impacted all aspects of society, work, lifestyle, and production. AI algorithms gradually developed from single, small, lightweight models to ChatGPT as the typical representative of multiple, large, heavy models. Considering that AI will further affect every aspect of human life, ITU-R has incorporated AI technology into the 6G as one of the 6 visions, and GSMA also released "AI Mobile Device Requirements Specification" in 2023 which has carried out in-depth research and exploration of the AI implementation on the terminal side, including: the training and updating of AI models on the terminal side, various AI technologies implementation and user experience on the terminal and introduces a new concept of AI agent as the user's intelligent assistant that will provide a series of advanced functions. The AI technology will also become one of the key indispensable capabilities for the future 6G terminal.

3.3.2 6G Satellite Communication

In recent years, significant progress has been made in satellite communication technology, making its integration with 6G terminals. Satellite communication has been recognized as one of the 6 visions for the development of 6G technology, which suggests that satellite communication technology will be closely associated with the future development of 6G terminals. The integration of satellite communication technology will bring many potential advantages to 6G terminals. First, it will greatly expand the communication coverage of terminal devices, which will no longer be limited by the range of terrestrial base stations. This means that even in remote areas or places without traditional infrastructure, 6G terminals will still be able to stay connected and provide a seamless communication experience for users. Second, satellite communications will accelerate the global interconnection of 6G terminals. Users will be able to access high-speed data transmission and communications globally, no longer limited by geography. This will have a profound impact on global communications, emergency response and cross-border operations. In addition, satellite communication will provide satellite navigation and location services, enabling 6G terminals to have higher accuracy and availability in navigation, positioning and augmented reality applications. This will broaden the scope of application of 6G terminals in various fields, including transportation, agriculture, and emergency services.

3.3.3 Acceleration of Industrial Digitization

Digital transformation in industry has accelerated, and digital development has become a global consensus withing more than 170+ countries around the world releasing digital strategies. Along with digitization development, it will bring major changes to individuals, families, businesses, industries, and even cities and countries. The GSMA has been focusing and tracking digitization trends in the industry, as early as 2019, it gained insights into the digital transformation trends in the industry and launched the Digital Leaders Programee (DLP) with the aim of facilitating the mobile industry to innovate and collaborate with the wider ecosystem. The industry digitization is evolving rapidly, and in the future, industry will move towards flexibility, intelligence, customization, and servicing. Not only the industry will be digitized, but the world of the future will evolve into a digital world.

In the background of industrial digital transformation: 6G will serve as an important infrastructure for digitization. 6G will be deeply fused with digitized industries, the industry is currently discussing more about digitalization for network and network for digitization. Similarly, the terminal is closest to the user, from the perspective of the user and the terminal, it is necessary to consider digitalization for terminal and terminal for digitalization.

To sum up, under the background of the rapid development of digital society and digital intelligence technology, 6G terminal will fuse with native AI, satellite interconnection, industrial digitization, and other technologies, and profoundly change human society, production, work, and lifestyle, leading human beings to step into the digital and intelligent world, and realizing the seamless integration of the digital world and the physical world.

4. Terminals' Changes and Development Trends

4.0

Terminals' Changes and Development Trends

4.1 Terminals' Key Role in Information Flow

The information flow always occurs in the production, work and life of human society, and the terminal plays a key role in the information flow. The terminal is not only an important carrier of many kinds of information and the source of information generation, but aslo participates in and supports the entire information flow links. As shown in Figure 4-1 below, terminals are involved in many information flow links: information generation, input, storage, processing, transmission, presentation and so on.

- Information generation link: Use the terminal to make video call, the video call generating audio information and video information, etc.
- Information input link: Use the terminal's keyboard to enter text, use the terminal's microphone for voice input, etc.
- Information storage link: The terminal stores the obtained information such as image, video, audio in the terminal storage unit.
- Information processing link: The terminal performs signal processing such as modulation, coding, decoding, demodulation on images/videos to be transmitted.
- Information transmission link: Terminal transmission of pictures/videos requires uplink/downlink data transmission with network.
- Information presentation link: Display of received photos and videos on the terminal screen, play the sound using the terminal's microphone, etc.

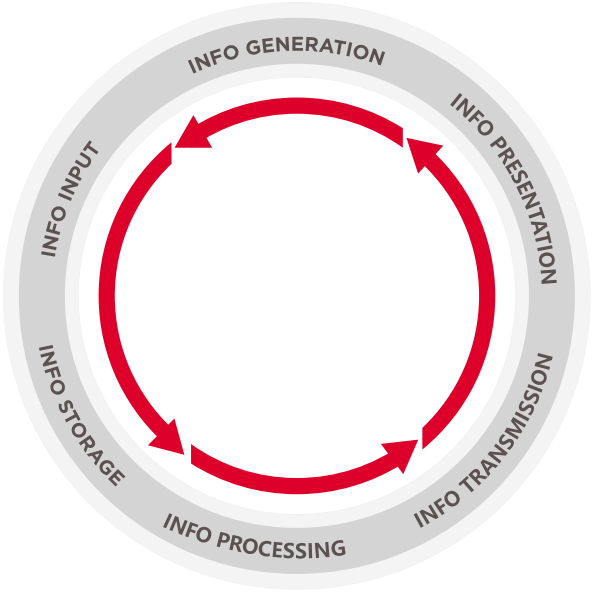


Figure 4-1: Terminals'key role in information flow

4.2 Terminals' Evolution in Different Generations

4.2.1 Terminals' Characteristics in Different Generations

It can be observed from the evolution trend of terminals in different eras from 2G to 5G, terminals are constantly driving the efficiency of the entire information flow:

2G: feature phones from Motorola,NOKIA, etc., as the typical representative of 2G era terminal has good performance, quality and portability and had the leading sales in the global market in the era of feature phones. 2G era terminals have its typical functions: voice call, SMS sending and receiving. 2G era terminals can be used regardless of space or time. The portability and mobility of 2G era terminal free users from being restricted to fixed places and time. The generation of information is free from the limitation of place and time, and information can be generated, inputted, transmitted, processed, and presented by users anytime and anywhere. 2G terminal promotes the efficiency of the whole information flow link, and greatly facilitates the communication for users at any time and any place, and the whole industry has also entered the mobile era.

3G: As the transition era before 4G, smartphones began to appear. The typical function is to support a variety of APPs' installation, although most of the typical APPs in 3G focus on social networking, light application, picture transmission, browsing the web, etc., but 3G era terminal has opened a window for the new era. Among them, NOKIA's smartphone with Symbian system has become the main representative of smartphones because of its smooth user experience and easy operation. 3G era terminals support the installation of many kinds of APPs, which generate a large amount of information to be processed for the information flow links, but 3G era terminals don't have a large high-definition screen, so they can't present the information adequately. In addition, the 3G network cannot support burst high speed information transmission, which makes the information transmission link restricted, and the whole information flow link is not efficiently improved. Although the smart terminal in the 3G era is short-lived, the terminal has generated a large amount of information that needs to be processed, and it also pushes the industry to enter the next generation quickly.

4G:As a typical representative of the 4G era terminal, single iPhone6 series sales up to more than 200 million. In addition, Samsung cell phone had the leading sales in the global market in the era of smartphones, the large screen display and innovative and convenient input methods have led to more APPs bringing users a revolutionary experience, supporting the installation and operation of various functional APPs, no longer limited to the few types of APPs in 3G. 4G terminals efficiently and timely process a variety of APPs, making them bring users the satisfaction of the function and experience. For the information flow links, users' usage of all kinds of APPs all the time generates a huge amount of information, and 4G era terminals do well in the processing, storage and transmission of huge amount of information, and at the same time, 4G era terminal has a high-definition large screen that can adequately present the information. In addition, 4G era terminals efficiently support and drive all the links in the information flow. 4G era terminals promote the efficiency of the entire information flow to a new stage, which profoundly affects and changes every aspect of users' work and life, and the industry has entered the mobile Internet era.

5G: Samsung, Huawei, HONOR, OPPO, VIVO, Xiaomi and other terminal companies launched a variety of foldable phones, including inward foldable phone, outward foldable phone, large foldable

phone, small foldable phone, which united to promote the foldable phone to become an important type of high-end phone. For the information flow links, different foldable screen sizes make the information presentation ability greatly improved while considering terminal's portability. Foldable screen phone is expected to become the mainstream of terminal in the future. For the information input link, 5G era terminals support natural speech inputting, which enhance the convenience and accuracy of human-computer interaction and significantly improve the efficiency for information input link. In addition, the cell phone can efficiently collaborate with nearby devices, such as watches, computers, tablets, PCs, TVs, speakers, etc. to form a unique information ecosystem. This creates efficient local information flow in the production, input, processing, and presentation of information and so on. In the 5G era, the various terminals will continue to promote the efficiency of the entire information flow.

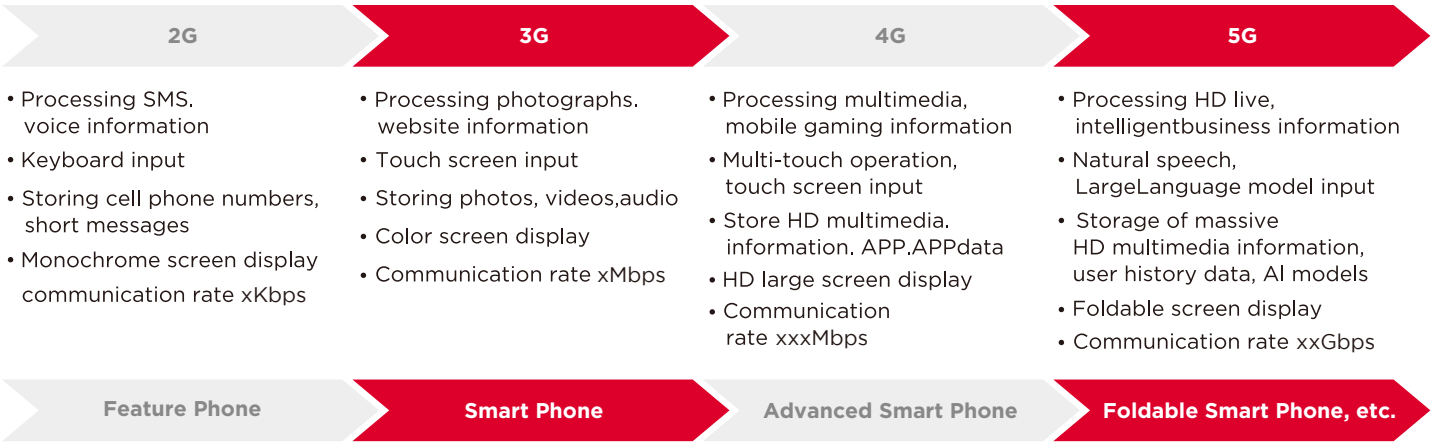


Figure 4-2 Terminal characteristics in different generations

4.2.2 Specific Terminals' Evolution Trends from 2G to 5G

With the evolution in different generations terminals play an increasingly important role in the information flow as shown in Table 4-1 below:

Table 4-1 Terminals' evolution trends from 2G to 5G

Info Flow	Generations	2G	3G	4G	5G
Info Generation	Business forms	→ SMS → Calls	→ Social → Website	→ Multimedia → Mobile games	→ Online HD live broadcast → Smart business
Info Generation	Multimedia Input	No Camera	Low resolution Camera	→ HD → Telephoto → Wide-angle camera	→ 3D camera → Camera array → Hyper-spectral camera
	Human-computer interaction	Keyboard	Touch screen	Multi-touch screen	→ Natural speech → Large Language Model
Info Storage	Storage size	N/A	~MB	~GB	~TB
	Stored content	→ Contacts → SMS	→ Photos → Videos → Audio	→ HD Multimedia information → APP → APP data	→ Massive high-definition multimedia information → User history data → Nearby device data → AI models
Info Processing	Processing unit	CPU	CPU	CPU,GPU	CPU,GPU,NPU
	Computing power	N/A	~MTOPS	~GTOPS	~TTOPS
Info Trans-mission	Info forms	Voice	→ Picture → Streaming media	→ Video → Rich media	2D high-definition video
	Peak rate	xKbps	xMbps	xxxMbps	XXGbps
	Typical tech	→ TDMA → FDMA	CDMA	→ OFDMA → MIMO	→ OFDMA +SDMA → Massive MIMO → Flexible spectrum → New carriers

Info Flow	Generations	2G	3G	4G	5G
Info Presentation	Visual information	Monochrome screen display	Color screen display, Low resolution	HD 2K large screen display	Foldable Screen 4K HD display
	Auditory information	Audio	Digital audio	HD audio	3D audio
	Touch/smell/taste information	N/A	N/A	ERM	LRA

4.2.3 Terminals' Evolution Trends in 6G

According to trend that the terminal in different generations promotes the high efficiency of information flow and supports new technology, we explore the terminal evolution trend in 6G:

Terminals generate a larger amount of information at a faster speed. As the source of information generation, generate massive information immediately on the terminal side. In the information generation link, 6G terminal will support generating 3D audio(spatial audio),3D video(spatial video), intelligent assistant, and digital world business information.

Terminals are getting more and more efficient in obtaining user input. Terminal using diverse and intelligent human-computer interaction methods obtain information input immediately. 6G terminals in the information input link, sensors will support the input and collection of information such as touch, smell, taste, and other human senses, and the human-computer interaction methods will support holographic interaction input methods and even brain-computer input methods.

The increasingly large local storage of terminals stores the acquired information timely and locally. In the information storage link, 6G terminals will support 1,000 times enhancement to reach PB level. The stored information will not only contain the information of the physical world but also the information of the digital world.

Increasingly powerful processing capabilities allow terminals to process information immediately. In the information processing link,6G terminals will expand their capabilities from processing image and voice data to supporting 3D and virtual data processing. To achieve this, they will adopt more efficient new processors, and the terminal's computational capabilities will be upgraded from ~TTOPS to ~PTOPS.

Terminal's increasingly transmission high rate and low latency enable the real-time transmission of massive information (sending and receiving). In the information transmission link: 6G terminal will support the transmission of 3D multimedia information, and the peak rate supported will also have a 1,000 times enhancement to reach the ~Tbps level, and the typical communication technology will also support AI communication, the integration of communication and sensing, and space-air-ground integrated network, etc.

The terminals will have increasingly rich presentation capabilities, enabling them to display complex multi-dimensional information in real-time. In the information presentation link: 6G terminals will go beyond the current 2D information presentation and support the presentation of 3D video, holographic images, and 3D audio. Furthermore, they will also support the presentation of multi-dimensional information such as touch, smell, and taste.

4.2.4 Other Terminals' Evolution Trends

4.2.4.1 Trends in security and privacy protection

As defined by ITU-R, the 6 visions will involve the collection, use, and transmission of data. With the deep integration of AI, digital big data, blockchain, and 6G, the security and privacy of data are facing more diversified and intelligent attacks. In order to realize the information flow in a highly efficient, secure, and compliant way, it is necessary to consider designing corresponding security and privacy protection mechanisms.

For the future of intelligent interconnection of all things, massive devices, massive connections and ubiquitous intelligent functions, whether for the protection of a single terminal device's information flow link, multiple collaborative terminals', or cross-device information flow link, the security and privacy will involve every aspect of the user. To provide products and services that can generate endogenous security and privacy protection for the user will be the whole industry partners' responsibility and obligation.

4.2.4.2 Trends in Energy Efficiency

The Eco-design Regulation and Energy Efficiency Labelling Scheme released by European Union on June 16, 2023 for mobile phones and tablets will be formally implemented in 2025. Many countries around the world set their own carbon peaking and carbon neutrality goals. However, the realization of the goals poses a new challenge to the innovation of new technologies. At the same time, the elimination of a large number of old terminals every year is also causing a large amount of e-waste. In the 6G era, a huge number of devices, connections, and devices working all the time and everywhere will bring huge energy consumption, therefore the low-carbon environmental protection and high energy efficiency for terminals will be the important trend.

Whether it is the low power consumption research on screen display in the information presentation link, the low power consumption research on the specific data processor in the information processing link, or the high-speed and low power consumption transmission in the information transmission link, each link in the information flow needs to be studied and the energy efficiency needs to be improved to realize the high-efficiency operation and low power consumption of the information flow to bring sustainable and low-carbon benefits to the society, production and life.

5. 9 Potential Scenarios for 6G Terminal

5.0

9 Potential Scenarios for 6G Terminal

5.1 Holographic Multi-sensory Entertainment Scenario

5.1.1 Scenario Description

6G technology will support human beings to have a deeper understanding and perception of the physical world, help human beings to build a virtual world and a virtual-reality integration world, to expand the activity space of human beings. At the same time, it will support many intelligent agents to be interconnected, to extend the level of physical ability and intelligence of human beings. Combined with 6G technology, immersive entertainment extends the activity space and the baseline of physical and intellectual capabilities, reflecting the perfect collaboration of "human-computer-object-environment". Users can simultaneously enjoy the immersive entertainment experience from the physical world and the virtual world, respectively, for their synergy and integration, and flexible switching. 6G immersive entertainment scenarios will make use of human senses and cognition, including immersive XR, holographic communication and five senses interaction and other technologies, to create an immersive experience for the user and provide a series business of high-fidelity experience.

Holographic technology can stereoscopically reproduce any object including the human body, equipment, buildings, natural landscapes and so on. Holographic communication, based on the naked eye or with the help of head-mounted display equipment (HMD), transmits the holographic information of the subject to the designated location through the network. It uses holographic projection or imaging technology to stereoscopically reproduce the subject, and to realize the real-time interactive operations such as communication and manipulation with the subject so that people are not subject to the limitations of time or space, and to open up the boundaries between the virtual scene and the real scene, so that the user can enjoy an immersive experience. By the 6G era, holographic three-dimensional display will be realized. The user can see 360-degree 3D effects only by naked eyes, and from different angles different information will be displayed, bringing users an immersive visual experience. In addition, through real-time interaction between the user and the holographic 3D object, holographic communication can control the object being presented while the user is viewing the holographic content to achieve a high sense of immersion in the human-computer interaction.

XR refers to all environments and human-computer interactions that combine the real and virtual worlds created by computer technology and wearable devices. It combines the technical concepts of VR, AR, and MR. Immersive XR is a form of deeper development of XR, and is known as the ultimate form of future interaction. It realizes user experience expansion and human-computer interaction through complete simulation and real-time interaction of sensory information such as vision, hearing, touch, and smell. Immersive XR services will provide higher

service characteristics including ultra-high resolution, high frame rate, wide color gamut, high bit depth and high dynamic range (HDR), wide field of view, and more natural interaction. The 6G terminal will utilize the new service features to create an immersive experience for users.

6G immersive service cover a wide range of entertainment scenarios including media livestreaming, immersive online gaming, etc. For example, in the gaming scenario, users can start the game through their cell phones, wear wireless helmets, gloves, watches, wear/hold gaming equipment deployed with various haptic sensors. 3D surround sound speakers are deployed in the room, and multiple users will play the game with each other. The users will be able to see the HD images from up/down, left/right, and front/back, and hear and recognize the sounds from different directions. The sensors of the gaming equipment transmit a series of haptic feedback (vibration, weight, impact, etc.) according to the changes of scenarios, so the users can sense the mood of the gaming companions and manipulate the game by gaming equipment, gestures, and voice. Or the users can use their smartphones to select a game of interest, such as soccer, basketball, car racing or extreme sports, and then create or join a multiplayer gaming room. By wearing XR helmets, watches, and putting on/holding sports equipment deploying multiple haptic sensors, the users can enter the sports field in the virtual world and adjust the virtual character's movements in the match according to the actual body postures to feel the real sports experience. The high-quality audio and visual effects will immerse users in the intense competition. The built-in sensors in the watch can accurately capture the users' physiological indicators and present them in real time to the users.

Figure5-1 Holographic multi-sensory gaming scenario

5.1.2 Scenario Characteristics

- High-speed information transmission: uploading and downloading.
- Extremely strong information processing ability, such as rendering data.
- Low latency to ensure experience, non-dizziness, and cooperation between devices.
- Collaboration of multiple types of devices.
- High-precision perceptual positioning is needed between multiple types of devices.
- Portability of terminal devices.
- Integration of multiple sensors in terminal devices.
- Limited mobility of terminal devices.
- AI recognizes user's movement, gesture, voice, expression, etc.
- Ultra-high precision media processing.

5.1.3 Terminal Forms and Capability Requirements

Capability requirements are derived from 9 enhanced capabilities (peak data rate, user experienced data rate, spectrum efficiency, area traffic capacity, connection density, mobility, latency, reliability, security and resilience), and 6 new capabilities (coverage, positioning, sensing-related capabilities, applicable AI-related capabilities, sustainability and interoperability) in the ITU-R IMT.

Note: N indicates not relevant; M indicates moderately relevant and can be met by current 5G; H indicates highly relevant and requires 6G.

Capability requirements	Phone	XR helmet	Holographic device	Network access point	Watch	Gaming device	Smart gloves
Peak data rate	M	H	H	H	M	M	M
User experienced data rate	M	H	H	H	M	M	M
Spectrum efficiency	M	H	M	H	M	M	M
Area traffic capacity	M	H	M	H	M	M	M
Connection density	M	M	M	H	M	M	M
Mobility	H	M	M	M	M	M	M
Latency	M	H	H	H	H	H	H
Reliability	M	M	M	M	M	M	M
Security and resilience	H	M	M	M	M	M	M

Capability requirements	Phone	XR helmet	Holographic device	Network access point	Watch	Gaming device	Smart gloves
Coverage	M	M	M	H	M	M	M
Sensing-related capabilities	H	M	M	N	M	H	H
Applicable AI-related capabilities	H	M	M	N	M	M	M
Sustainability	H	H	H	H	H	H	H
Interoperability	H	H	H	H	H	H	H
Positioning	H	N	N	N	H	N	N

5.2 Personalized Flexible Shopping Scenario

5.2.1 Scenario Description

In the 6G shopping scenario, consumers demand a smarter, more interesting and personalized shopping experience. The ultimate flexible shopping scenario will be a huge leap forward in the future shopping experience, integrating 6G communications, artificial intelligence and virtual reality technology to provide consumers with an unparalleled personalized shopping experience.

In this scenario, shoppers can enter the virtual shopping world through their own 6G smart devices (e.g., XR helmets, XR glasses, etc.), and they will be immersed in exploring various virtual stores and shopping centers. Smart shopping assistant terminals, based on in-depth analysis of various factors such as consumers' preferences, shopping history, body measurement data and fashion trends, recommend precise products and services for consumers. Consumers can try on a variety of clothing, match different accessories, experience different cosmetics and view themselves in the virtual world.

Once shoppers finalize their purchase, the smart assistant will assist them in choosing payment methods, providing shopping cart and order tracking functions. The order information will be transmitted in real time to the flexible factory, which will use a highly intelligent production process to personalize and customize the production according to the size and style selected by the consumer in the virtual shopping world. After the factory completes the production, the products will be delivered directly to consumers via drones.

Figure 5-2 Personalized flexible shopping scenario

5.2.2 Scenario Characteristics

- High-speed information transmission: uploading and downloading.
- Extremely strong information processing ability, such as data rendering.
- Low latency to ensure experience, non-dizziness, and cooperation with devices.
- Integration of multiple sensors in terminal devices.
- Cloud connectivity and data analytics.
- AI interaction.
- Communication wide-area coverage.

5.2.3 Terminal Forms and Capability Requirements

Capability requirements	XR helmet	Holographic device	Drones	XR glasses	Assistant terminal
Peak data rate	H	H	M	H	M
User experienced data rate	H	H	M	H	M
Spectrum efficiency	H	M	M	H	M
Area traffic capacity	H	M	M	H	M
Connection density	M	M	M	M	M
Mobility	M	M	M	M	M
Latency	H	H	M	H	H
Reliability	M	M	M	M	M
Security and resilience	M	M	M	M	M
Coverage	M	M	H	M	M
Sensing-related capabilities	M	M	M	M	M
Applicable AI-related capabilities	M	M	M	M	H
Sustainability	H	H	H	H	H
Interoperability	H	H	H	H	H
Positioning	N	N	H	N	N

5.3 Smart Nanny Scenario

5.3.1 Scenario Description

In the 6G home scene, users demand a more intelligent, convenient, and attentive service experience. The integration of 6G communication, artificial intelligence, Internet of Things and other important technologies creates a Smart Nanny scenario full of scientific and technological innovation. The Smart Nanny Robot has a highly intelligent perception and thinking ability. It can independently perceive the home environment, understand the needs of family members, and intelligently interconnect with a variety of devices at home, which can provide diversified services according to user needs.

Equipped with high-precision sensors and highly sensitive robots, Smart Nanny can perform daily household chores such as cleaning, cooking, and washing. Users can talk to the smart nanny through their cell phones and schedule tasks, such as, "Hello Smartie, I'm a little hungry and I'll be back home at 7:00. Mop the floor and set the air-conditioning temperature to 25 degrees." When the user returns home, he or she can enjoy delicious food and a comfortable and elegant home.

In terms of entertainment and socialization, Smart Nanny can help family members plan activities, purchase tickets, make restaurant reservations and interact with family members. In addition, the Smart Nanny is equipped with a vital signs monitor, which can monitor family members' vital signs in real time, such as heart rate, blood pressure, body temperature and blood sugar level, etc. It can call for emergency services if it detects abnormalities in the user's vital signs.

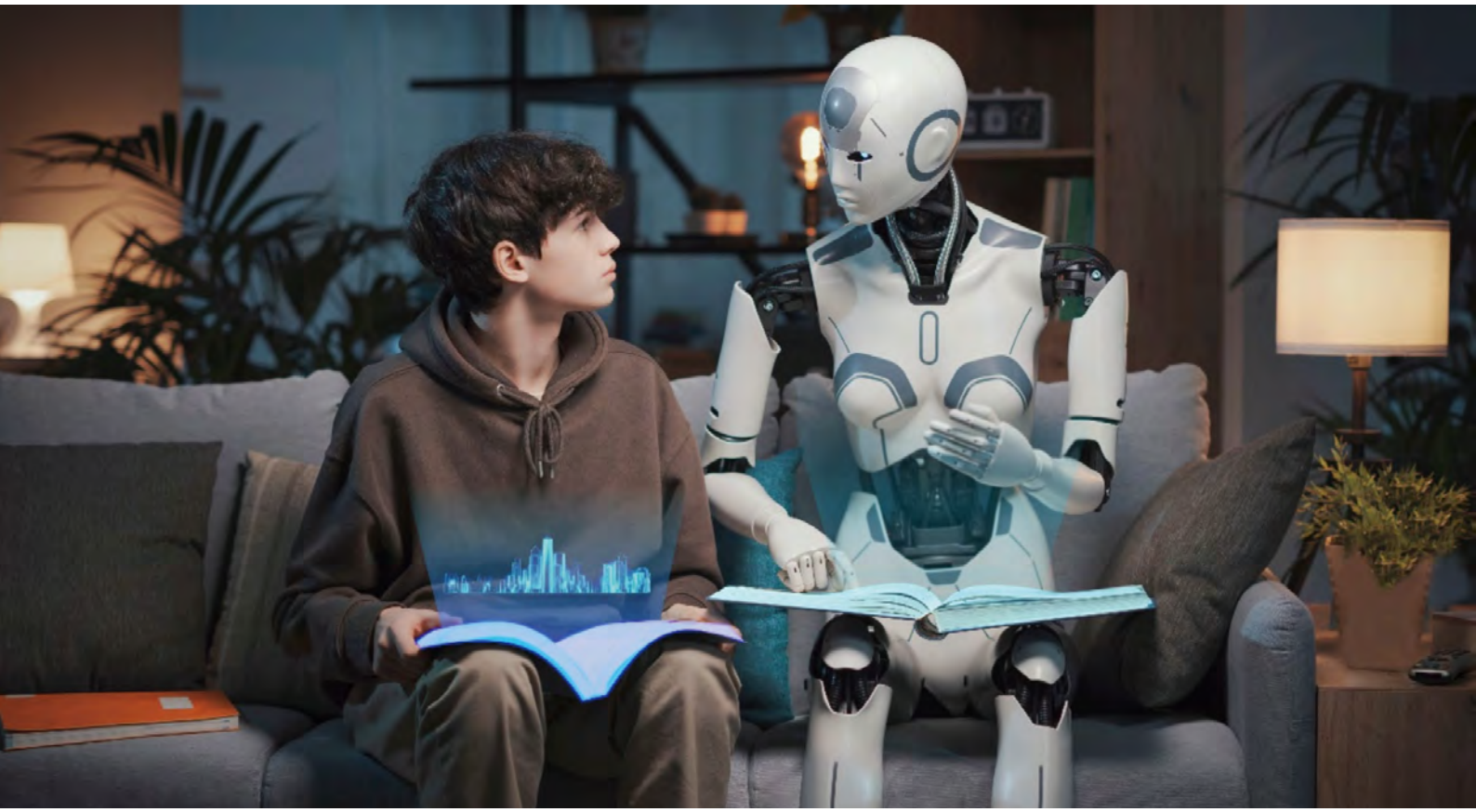


Figure 5-3 Smart Nanny scenario

5.3.2 Scenario Characteristics

- Ultra-high speed and low latency.
- Extremely strong information processing ability, real-time data processing.
- Large-scale IoT connectivity.
- Highly accurate perceptual positioning required between multiple types of devices.
- AI interaction.
- Multimodal communication.
- Global coverage of communication signals.

5.3.3 Terminal Forms and Capability Requirements

Capability requirements	Smart Nanny Robot	VSM monitor	phone	Smart rice cooker	Smart air conditioner
Peak data rate	M	M	M	M	M
User experienced data rate	M	M	M	M	M
Spectrum efficiency	M	M	M	M	M
Area traffic capacity	M	M	M	M	M
Connection density	M	M	M	M	M
Mobility	M	M	H	M	M
Latency	H	H	M	M	M
Reliability	H	M	M	M	M
Security and resilience	H	M	M	M	M
Coverage	M	M	H	M	M
Sensing-related capabilities	H	N	H	M	M
Applicable AI-related capabilities	H	N	H	M	M
Sustainability	H	H	H	H	H
Interoperability	H	H	H	M	M
Positioning	H	N	H	M	M

5.4 Immersive Cloud Office Scenario

5.4.1 Scenario Description

In 6G telecommuting scenarios, users demand a more immersive, real-time and convenient office experience. In the 6G era, terminal devices will be equipped with more powerful computing and connectivity capabilities to support high-definition virtual meetings, enhance the collaboration of working in office and telecommuting.

In an immersive cloud office scenario, users don't need to go to the office to work and clock in. They can select their preferred office scenario on their cell phones, put on the XR device, and then interact with their colleagues and share documents in the virtual world as if they are working in the same office. Team members participate in meeting discussions from all over the world, share screens and edit documents. Remote work is more social and interactive. Users choose to print the designed three-dimensional model in the virtual world, and the intelligent 3D printer in the physical world can print the model in real time.

Users can conduct immersive work even in high-speed trains, airplanes, ships or remote areas without worrying about connection interrupted or data loss. Global network coverage and high-speed data transmission services will effectively enhance the users' business travel experience.

Figure 5-4 Immersive cloud office

5.4.2 Scenario Characteristics

- High-speed information transmission: uploading and downloading.
- Extremely strong information processing ability, such as data rendering, etc.
- Low latency to ensure experience, non-dizziness, and cooperation between devices.
- Multi-type device collaboration.
- High-precision perceptual positioning.
- Portability of terminal devices.
- Multi-network support for devices.
- Wide coverage of communication.
- AI interaction.
- 3D printing.

5.4.3 Terminal Forms and Capability Requirements

Capability requirements	Phone	Smart 3D printer	XR device Device	Network access point	Holographic device
Peak data rate	M	M	H	H	H
User experienced data rate	M	M	H	H	H
Spectrum efficiency	M	M	H	H	M
Area traffic capacity	M	M	H	H	M
Connection density	M	M	M	H	M
Mobility	H	M	M	M	M
Latency	M	H	H	H	H
Reliability	M	M	M	M	M
Security and resilience	H	M	M	M	M
Coverage	M	M	M	H	M
Sensing-related capabilities	H	N	M	N	M
Applicable AI-related capabilities	H	N	H	M	M
Sustainability	H	H	H	H	H
Interoperability	H	H	H	H	H
Positioning	H	N	N	N	N

5.5 Autonomous Vehicle Transportation Scenario

5.5.1 Scenario Description

In 6G intelligent transportation, users demand a more intelligent, comfortable, and safer driving experience. And 6G technologies such as intelligent interconnection, real-time sensing, and ultra-low latency will provide an important guarantee for users' intelligent, comfortable, and safe travel. These technologies include fully autonomous vehicles, intelligent traffic management systems and the deep integration of smart city infrastructures. Vehicles can realize highly autonomous driving, real-time sensing and adapt to complex road conditions without human intervention.

In the autonomous vehicle transportation scenario, the user remotely starts the car via cell phone and the car will automatically move to the designated location. When the user rides in the autonomous car, it utilizes sensors to perceive the surrounding environment in real time and performs high-precision positioning on a digital map. The vehicle is equipped with an intelligent terminal navigation system, which can independently plan the best route and make intelligent decisions based on traffic and road conditions. The autonomous vehicles do not need to stop when driving to an intersection, and only need to appropriately adjust the speed to avoid each other, and they can also move safely in various extreme environments. Users can view real-time navigation, road conditions and arrival times on the screen. High-speed communication between vehicles and vehicles, vehicles and infrastructure (e.g., smart traffic lights, environment monitoring terminals, etc.) makes autonomous vehicles safer and more reliable.

The in-vehicle terminal considers the user's travel preferences and schedule and provides personalized travel suggestions to the user, significantly improving the travel experience. In addition, the in-vehicle terminal provides a high-quality Internet connection so that users can enjoy real-time media streaming and gaming entertainment services, which makes traveling more comfortable.

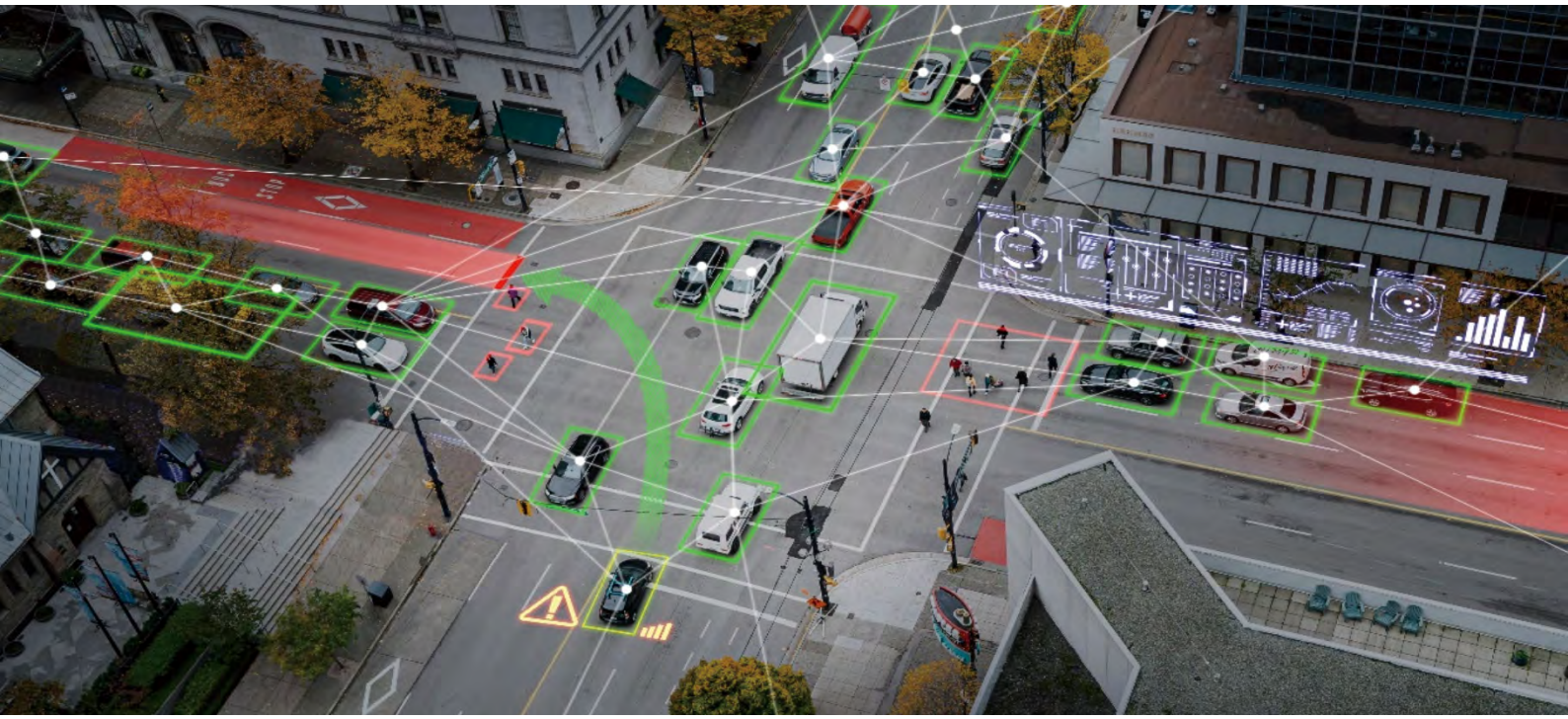


Figure 5-5 Autonomous vehicle transportation scenario

5.5.2 Scenario Characteristics

- Ultra-high speed and low latency.
- Extremely strong information processing capability, real-time data processing.
- Terminal devices support edge computing.
- Massive connectivity of terminal devices.
- Support cloud connection.
- Intelligent perception and high-precision positioning of terminal devices.
- Terminal devices have AI interaction capability.
- Terminal devices support multimodal protocol interoperability.
- Global coverage of communication signals.

5.5.3 Terminal Forms and Capability Requirements

Capability requirements	Phone	Autonomous vehicle	Smart traffic lights	In-vehicle terminal	Environment monitoring terminal
Peak data rate	M	H	M	M	M
User experienced data rate	M	H	M	M	M
Spectrum efficiency	M	H	M	M	M
Area traffic capacity	M	H	M	M	M
Connection density	M	H	H	M	M
Mobility	H	H	N	H	N
Latency	M	H	H	M	H
Reliability	M	H	M	M	M
Security and resilience	H	H	M	M	H
Coverage	M	H	H	M	H
Sensing-related capabilities	H	H	H	M	H
Applicable AI-related capabilities	H	H	M	M	N
Sustainability	H	H	H	H	H
Interoperability	H	H	H	M	M
Positioning	H	H	N	H	N

5.6 Personalized Virtual Classroom Scenario

5.6.1 Scenario Description

In the future 6G education scenario, students demand more vivid, interesting, and personalized learning. Technologies such as extended reality, holographic communication, and sensory interconnection can create personalized virtual learning environments for students, making learning more vivid and interesting. In the 6G personalized virtual classroom scenario, students can choose to experience different subjects such as history, science experiments or world geography according to their preference.

Students can access the virtual classroom at any time and place by selecting teaching scenarios via smartphones and wearing XR helmets and watches.

The virtual classroom provides a wealth of virtual teaching resources, including virtual labs, 3D models, teaching materials and virtual reality scenarios. These resources enable students to better understand and master the course content.

In the virtual classroom, students can enjoy a high-quality visual and auditory experience. Students can choose their seats, interact with other students and teachers from all over the world, engage in voice and text chats, ask questions, watch teachers' presentations on the virtual blackboard, view 3D models and virtual experiments as if they were there.

Figure 5-6 Personalized virtual classroom scenario

5.6.2 Scenario Characteristics

- High-speed information transmission: uploading and downloading.
- Extremely strong information processing ability, such as data rendering.
- Low latency to ensure experience, non-dizziness, and cooperation between devices.
- Multi-type device collaboration.
- High-precision perceptual positioning.
- Portability of terminal devices.
- Multi-network support for devices.
- AI interaction.
- Cloud connectivity and data analytics.

5.6.3 Terminal Forms and Capability Requirements

Capability requirements	Phone	Tablet	Watch	XR helmet	Network access point	3D surround sound speaker
Peak data rate	M	M	M	H	H	M
User experienced data rate	M	M	M	H	H	M
Spectrum efficiency	M	M	M	H	H	M
Area traffic capacity	M	M	M	H	H	M
Connection density	M	M	M	M	H	M
Mobility	H	H	M	M	M	N
Latency	M	M	H	H	H	M
Reliability	M	M	M	M	M	M
Security and resilience	H	M	M	M	M	N
Coverage	H	H	M	M	H	M
Sensing-related capabilities	H	M	M	M	N	N
Applicable AI-related capabilities	H	H	M	M	N	N
Sustainability	H	H	H	H	H	H
Interoperability	H	M	M	H	H	M
Positioning	H	M	M	N	N	N

5.7 Remote Smart Healthcare Scenario

5.7.1 Scenario Description

In the 6G healthcare scenario, patients need more efficient and accessible smart healthcare services and experiences of higher quality, and key technologies such as 6G communications, smart robotic arms, and extended reality provide important support for remote smart healthcare.

In the future remote intelligent healthcare scenario, patients do not have to go to the hospital to register to enjoy high-quality healthcare services, and medical professionals conduct remote consultations with patients through medical terminal equipment. The medical terminal equipment supports high-definition medical image transmission, vital signs monitoring and medical data analysis to help doctors make remote diagnosis and treatment decisions.

When a patient undergoes surgical treatment, the doctor wears an XR helmet to access the virtual operating room, where he or she can see the internal structure of the patient in the XR interface, as well as communicate with the surgical team in real time. Through gestures and voice commands, the doctor can manipulate the robotic arm to perform surgical operations such as cutting, suturing and organ transplantation. The robotic arm device will perform surgical operations according to the doctor's instructions, and the doctor can monitor the surgical process through the XR interface to make timely adjustments and corrections to the robotic arm operations. At the same time, the biomedical sensors also provide real-time monitoring of vital signs indicators, so that the doctor can better track the patient's vital signs during the operation.

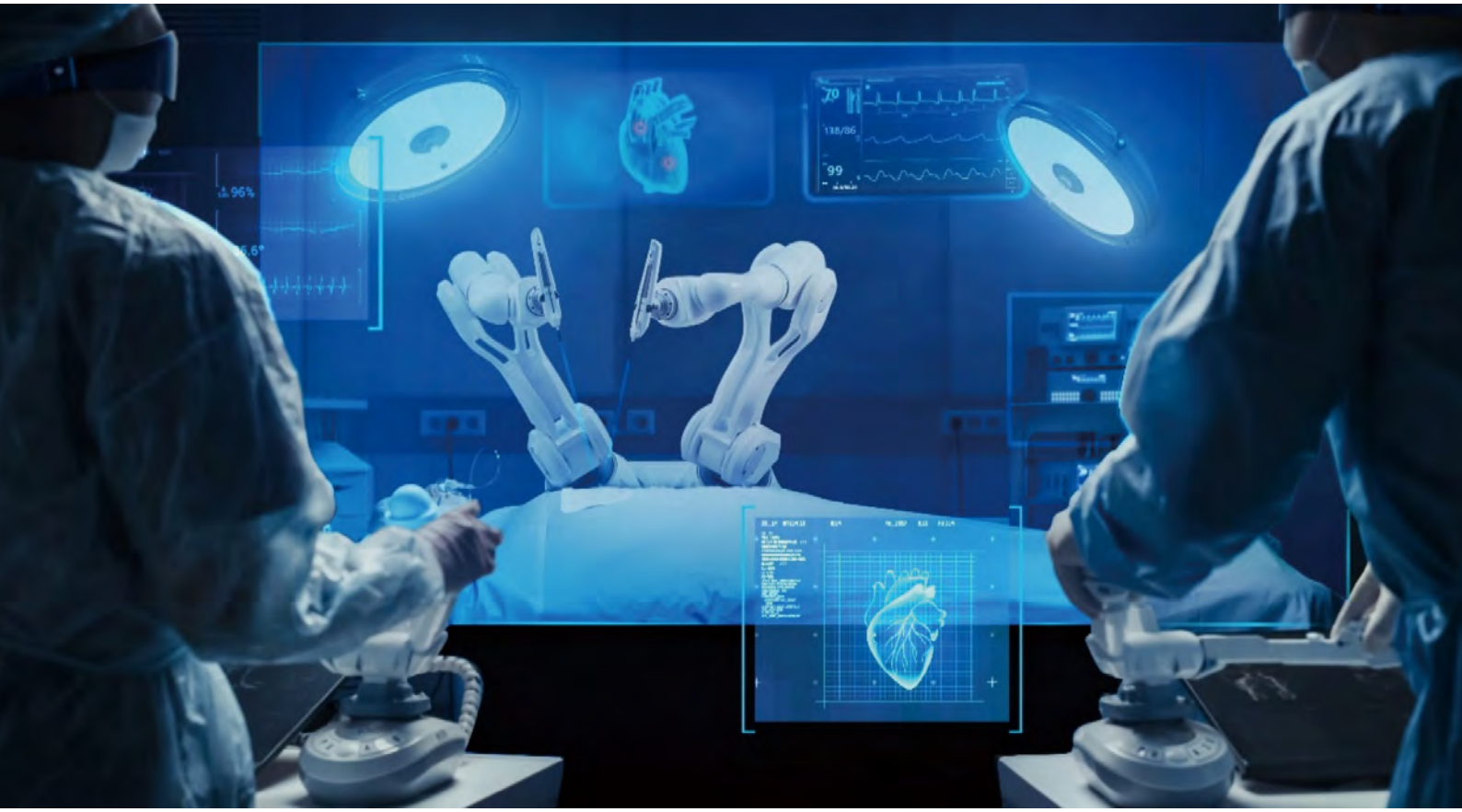


Figure 5-7 Remote smart healthcare scenario

5.7.2 Scenario Characteristics

- Large bandwidth, ultra-high reliability, low latency communication.
- Extremely strong information processing capability, such as data rendering.
- The terminal device supports cloud connection.
- Integrated multiple sensors in the terminal device.
- Ultra-high reliable robotic arm.
- Medical AI and machine learning
- Multimodal protocol interoperability across different terminal devices.
- Highly sensitive vital signs monitoring.
- Highly accurate perceptual positioning is required between multiple types of devices.

5.7.3 Terminal Forms and Capability Requirements

Capability requirements	Biomedical sensors	Medical robotic arms	Smart health monitor	Medical XR helmet	Medical terminals
Peak data rate	M	H	M	H	M
User experienced data rate	M	H	M	H	M
Spectrum efficiency	M	H	M	H	M
Area traffic capacity	M	H	M	H	M
Connection density	H	H	M	M	M
Mobility	M	M	M	M	M
Latency	H	H	H	H	H
Reliability	M	H	M	M	M
Security and resilience	M	M	M	M	M
Coverage	M	H	M	M	M
Sensing-related capabilities	N	N	N	M	H
Applicable AI-related capabilities	N	N	N	M	H
Sustainability	H	H	H	H	H
Interoperability	H	H	H	H	H
Positioning	N	N	N	N	N

5.8 Space-air-ground Integrated All-area Logistics Scenario

5.8.1 Scenario Description

In the 6G logistics scenario, users will demand an all-area logistics with shorter shipping time, lower cost and more visualization of the transportation status. In the scenario of a space-air-ground integrated all-area logistics network, all kinds of communication and data transmission technologies of the sea, land and air will work together, and logistics will become smarter, more efficient, and traceable through the integration of ocean, land, and air transportation.

Maritime logistics will benefit from satellite communications and underwater communications technology. Unmanned cargo ships can navigate autonomously across oceans, reporting in real time on location, weather conditions and cargo status through high-speed satellite communications. Submersibles and underwater sensors can perform undersea exploration or monitor the marine environment to ensure cargo safety.

Unmanned vans can intelligently plan routes, powered by green energy (wind, solar, etc.), and perform cargo delivery tasks in remote areas or even in no-man's land.

High-altitude drones are used for the transportation of goods, as well as for monitoring road traffic conditions. These high-altitude drones can transmit data in real time to assist in the scheduling and navigation of transport vehicles. High elliptical orbit satellite systems provide global communications' coverage, ensuring real-time tracking of cargo. No matter where the cargo is, it can be communicated and monitored through the satellite network.

Figure 5-8 Space-air-ground integrated all-area logistics scenario

5.8.2 Scenario Characteristics

- High-speed, low-latency communications.
- Large bandwidth support.
- Global communication coverage.
- Cloud connectivity support.
- Communication reliability and stability.
- Multimodal protocol interoperability of device.
- High-precision positioning of device.
- Green energy.

5.8.3 Terminal Forms and Capability Requirements

Capability requirements	Underwater sensors	High elliptical orbit satellites	Drones	Unmanned cargo ship	Unmanned transport vehicle
Peak data rate	M	H	M	M	M
User experienced data rate	M	H	M	M	M
Spectrum efficiency	M	H	M	M	M
Area traffic capacity	M	H	M	M	M
Connection density	M	H	M	M	M
Mobility	M	M	M	M	M
Latency	M	H	H	H	H
Reliability	M	M	M	M	M
Security and resilience	M	M	M	M	M
Coverage	M	M	H	H	H
Sensing-related capabilities	N	M	M	M	M
Applicable AI-related capabilities	N	M	M	M	M
Sustainability	H	H	H	H	H
Interoperability	M	H	H	H	H
Positioning	M	M	H	H	H

5.9 Digital Twin City Scenario

5.9.1 Scenario Description

In the 6G future city scenario, users demand highly digitalized, intelligent, and convenient urban lifestyles, and key technologies such as massive connectivity, communication awareness, and extended reality provide the possibility for the emergence of digital twin city. T he digital twin city needs to simulate and replicate all aspects of the real city in the digital world, and the entities in the physical world will be digitally mirrored in the digital world, so that the intelligent interaction can be achieved between people and people, people and things, and things and things through their mapping in the digital world.

The user enters the digital twin city by using their smartphone, selecting the digital twin city app, wearing the XR helmet and watch, and connecting to the 6G network.

The digital twin city system analyzes users' interests and preferences to recommend personalized activities and places to them. Users can view virtual tags to learn more about each location and select destinations that interest them. Users can interact with objects in the twin city and participate in VR activities such as parties, concerts, city tours, etc.

Users can also use digital payments to purchase goods in the digital twin city, where order information is synchronized in real time to the physical world factory and the goods will be delivered by drones to their homes.

Figure 5-9 Digital twin city scenario

5.9.2 Scenario Characteristics

- High-speed, low-latency communications.
- Large bandwidth support.
- Ultra-massive connectivity.
- High regional traffic density.
- Precise sensing.
- Data privacy security.
- Communication reliability and stability.
- High-precision positioning of terminal devices.
- AI recognizes users' movements, gestures, voices, expressions, etc.

5.9.3 Terminal Forms and Capability Requirements

Capability requirements	Phone	Sensors	XR helmet	Network access point	Watch	Drones
Peak data rate	M	M	H	H	M	M
User experienced data rate	M	M	H	H	M	M
Spectrum efficiency	M	M	H	H	M	M
Area traffic capacity	M	M	H	H	M	M
Connection density	M	M	M	H	M	M
Mobility	H	M	M	M	M	M
Latency	M	H	H	H	H	H
Reliability	H	M	M	M	M	M
Security and resilience	M	M	M	M	M	H
Coverage	M	M	M	H	M	H
Sensing-related capabilities	H	N	M	N	M	M
Applicable AI-related capabilities	H	N	M	N	M	M
Sustainability	H	H	H	H	H	H
Interoperability	H	M	H	H	M	H
Positioning	H	N	N	N	M	H

6. 5 key Research Directions for 6G Terminals

6.0

5 key Research Directions for 6G Terminals

Terminals in 6G not only support the 6 visions in ITU-R, but also support the 9 potential typical scenarios mentioned in the article, and at the same time deal with the changes and opportunities brought by new industries and technologies. New scenarios, changes, technologies, and user demands, all these factors bring numerous challenges to 6G terminals and point out the direction of research for 6G terminals.

6.1 All-round Communication Research Direction for Terminals

Terminals participate in and support multiple links of information flow, especially in information transmission, terminals need to complete sending and receiving of massive information timely. Terminals in 6G era need to support the enhanced capabilities of 6G communication: higher rate, larger bandwidth, lower latency, higher speed mobility, higher reliability, massive connectivity, and space-air-ground communication capabilities. Terminal side requires research to support: terminal-side ultra large MIMO transmission technology, terminal-side full-duplex communication technology, human-machine-object fully-connected technology, integrated wireless and AI technology, integrated communication, sensing and computing technology, space-air-ground integration and collaboration technology, semantic communication technology, ultra-low latency communication technology, ultra-low-power communication technology, weak signal enhancement communication technology, indoor location-aware communication technology, real-time and online low-power sensing and communication technology, multiple communication technologies and standards integration and collaboration technology: cellular communication and near-field communication integration, satellite communication and cellular communication integration, cross-layer and cross-protocol stack optimization technology, end-to-end collaboration and optimization solution from terminal to network , end-to-end slicing technology, new coding technology, new multiple access technology, RIS (Reconfigurable Intelligence Surface) communication technology, OAM (Orbital Angular Momentum) technology, Terahertz (THz) communication technology, visible light communication technology, and other cutting-edge technologies to be applied on the terminals.

Whether the 6G terminal supports the above communication capabilities at the same time or flexibly supports one of the communication capabilities according to different scenarios, the complex and diverse communication scenarios and user demands have posed a great challenge to the communication capabilities of the terminal, while the terminal should ensure its own portability and usability. However, the terminal's own capabilities and resources are limited and cannot unlimitedly support a variety of capabilities, so how the terminal can realize all-around communication capabilities needs to be explored jointly by the industry and academia.

6.2 Native AI Research Direction for Terminals

Terminals participate in and support multiple links of information flow, especially in the information processing, terminals need to complete the processing of various information timely. With the rapid development of AI technology represented by AIGC, most of the large models and multimodal models are currently running on the server side. Because the terminal is closer to user and the source of data, running AI models on the terminal side can process the information in a more timely manner to improve the efficiency of the information flow, and at the same time ensure that the data does not exit the terminal, which greatly protects the user's security and privacy. Therefore, models running on the server side will be migrated to the terminal locally. Terminal side needs research to support: the design of a new architecture for terminal native AI, the design of terminal native AI capabilities, terminal energy efficient processing capabilities, the design of terminal native computing power enhancement, native supporting large model: LLM(large language model), the training and prediction technology of large models on the terminal side, the protection of data collection and use on terminal side, the scheduling and sharing of multiple computing units on terminal side, the adaptive models and algorithmic solutions for matching terminal capabilities, the accuracy enhancement technology of terminal side models, and the low power consumption technology for long-time running for terminal side models, personalized model development and updating technology on terminal side, terminal-network intelligent cooperation mechanism, terminal-terminal cooperation mechanism, etc.

Whether the AI models used by 6G terminals are running on the server side, on the terminal side, or jointly training and by the terminal and server, these scenarios propose new requirements to the three dimensions: terminal's own computing power, algorithms, and data. Additionally, terminals are energy and capability limited, and while ensuring portability, ease of use, and long battery life, the native AI capabilities that need to be developed still require joint research and exploration by the industry.

6.3 Research Direction of Real-virtual Fusion and Multi-sensory Information Presentation for Terminals

Terminal participates and supports multiple links of information flow, especially in the information input link, terminal is an important tool for information input and perception. In the future, the physical world and the digital world will be seamlessly fused, and 6G terminals need to input and perceive the information not only in the physical world, but also in the virtual world. To exceed the existing information input methods, the 6G terminal needs research to support: exceeding the text and voice input methods, the visual information input technology: the perception and input of the user's expression, gesture, movement, emotion, and sentiment information, the perception and input technology of multi-dimensional sensory information: touch, smell, and taste, semantic perception and input technology of multi-dimensional sensory information, the perception and input technology of emotion and sentiment information in multi-dimensional sensory information intention recognition technology, communication and perception integration technology, high-precision perception technology: precise position, speed, posture and movement, to integrate solutions of a variety of sensors.

The terminal not only perceives the user, the events that the user concerned, and the changes in the surrounding environment, but also needs to perceive the terminal's own information: the changes in the terminal's own capacity, resource changes, energy changes, etc. The terminal also needs to cooperate with other terminals in perception due to the limited capacity. The information flow also occurs in the virtual digital world all the time, so the terminal also needs to perceive the information generation, input, transmission, storage, etc. in the virtual digital world. 6G terminals need to perceive both the local information of a specific scene and information of global scene. In order to face the seamless fusion of the physical world and the digital world, how the 6G terminal can perceive the information of the global scene in the physical world and the virtual digital world needs to be deeply explored.

Terminals participate in and support multiple links of information flow, especially in the key link of information presentation, terminals are the key carriers. With the rapid development of artificial intelligence and industrial digitization, multi-dimensional and massive data will be presented in an outbreak, so 6G terminals need to significantly increase the amount of information to be presented, and need to further enhance the ability to present visual and auditory information to reach and exceed the resolution that can be perceived by a natural person. The terminal side needs research to support: larger, higher-definition display technology, naked-eye 3D display technology, holographic display technology, single and multi-eye tracking technology, adaptive display technology that matches users, personalized 3D display technology for different users, just-in-time generation and rendering technology for 3D content, 3D audio(spatial audio) presentation technology, multi-microphone array collaboration technology, 3D audio processing technology, 3D audio generation and rendering technology, multi-sensory information presentation technology: touch, smell, and taste information, multi-sensory high-definition and high-resolution information presentation technology.

6G terminal information presentation will evolve from 2D to 3D information(spatial video) presentation, while supporting the presentation of multi-dimensional sensory information: touch, smell, and taste information, etc. The presentation of multi-dimensional sensory information also requires seamless collaboration to present ultra-high-definition, multi-dimensional sensory information through one or more 6G terminals to reach or even exceed the resolution that a natural human can perceive, bringing an immersive user experience.

6.4 Research Direction of Fundamental Materials and Craft for Terminals

The typical scenarios faced by 6G terminals require a series of key technologies and design solutions. As the terminal is highly integrated with a variety of key components, the optimization of each key component will bring significant experience enhancement to users, and the basic materials, basic craft and technology maturity are all key elements affecting the terminal performance and user experience. Terminal side needs research to support: basic materials to improve the screen resolution, brightness, energy efficiency, flexibility and durability, the development of basic material display technology for naked-eye 3D screens, thinner, more stable and reliable materials and craft for foldable screen hinge, the development of thinner and more stable basic materials and craft for terminal middle frame, the basic materials and craft to improve the antenna gain, the miniaturization technology aimed at large-scale antenna array, transmission materials with low-loss signals within the terminal, the study of new battery materials: graphene, silicon-carbon anode battery technology, the study of new charging technology and materials: passive charging, environmental charging, more efficient terminal heat dissipation materials and manufacturing craft, more efficient conductive materials and craft.

The breakthrough for terminals' basic materials and craft not only requires OEMs to persist in long-term investment in basic research, but also needs to unite with the academic community and cross-industry partners to research to achieve the theoretical and technological breakthroughs.

6.5 Research Direction of Expansion and Collaboration for Terminals

Based on the previously mentioned 6G scenarios and research directions, faced with diverse terminal forms and complex scenarios of human-machine-object interactions, 6G terminals require more new capabilities. Due to the limitations of terminals in terms of size, energy consumption, portability, etc., the terminals can't continuously acquire new capabilities. The terminal needs to have flexible capabilities that can expand and be configured as needed, and the terminal can use the device's own capabilities on demand, upgrade its own capabilities, and cooperate with the nearby devices on demand to expand the capabilities to support the processing of high-load tasks. The design of the terminal will exceed the fixed and closed architecture of the traditional terminal and develop into a flexible, expandable, and collaborative terminal architecture. The terminal side needs research to support: open and expandable collaborative architecture that can be flexibly upgraded, the design of new hardware and software architecture that is different from traditional terminals, the design of hardware and software decoupling scheme for terminal side resources, the design of virtualization solution for computing, communication, perception and other resources, breakthroughs in the theories related to the integration technology of terminal communication, perception, and computing resources, the design of on-demand combination, configuration, and isolation of terminal resources and functions, the design of expandable hardware interface, device modular design, the design of terminal software upgrade, compatible and standardized hardware interface, software interface, standard protocol design, multi-terminal heterogeneous fusion and collaboration technology, efficient collaboration technology between terminal side and network, cloud, edge and other end sides, resource (storage, computing, communication, etc.) sharing resolution design, and efficient collaboration technology between multiple functional modules within the terminal.

In the 6G era and the post-Moore era，Innovative expandable and collaborative terminal architecture will support terminals to improve their capabilities under conditions of limited hardware, volume, weight, power consumption, and cost. This will create 6G super terminals that can handle complex and diverse 6G scenarios.

7. Summary and Outlook

7.0

Summary and Outlook

7.1 6G Era Calls for Innovative 6G Terminal

Terminal represents the real needs of users and carries the latest innovative technologies. The dual-wheel drive of user needs and technological innovation is widely recognized by the industry as the driving method of terminal development, and the terminals under different eras from 2G to 5G are committed to meeting the key needs of users and carrying new innovative technologies to bring a revolutionary and ultimate user experience. Especially in the 4G era, the release of the typical "4G terminal" iPhone is praised as the iPhone moment, and the "4G terminal" brings revolutionary technology innovation and greatly enhances user experience with the killer application. The popularization and development of "4G terminals" also promoted the evolution of the network. In 6G era, terminals and the network will still promote each other and develop together, and the evolution of 6G network will promote the development and upgrade of terminals. Terminals and their killer application will put forward new demands for 6G network and promote the development of 6G network. As the standards defined in 3GPP and GSMA, there is a need for standardized collaboration between terminal and network. The 6 scenarios described by ITU-R and various new technologies (AI integrated communication, industrial digitization, communication and sensing integration, space-air-ground full coverage, etc.) will become the powerful driving force of "6G terminal", giving rise to terminals with unique characteristics of the 6G era, and the iPhone moment for "6G terminal" in 6G era also becomes the pursuing goal for terminal manufactures.

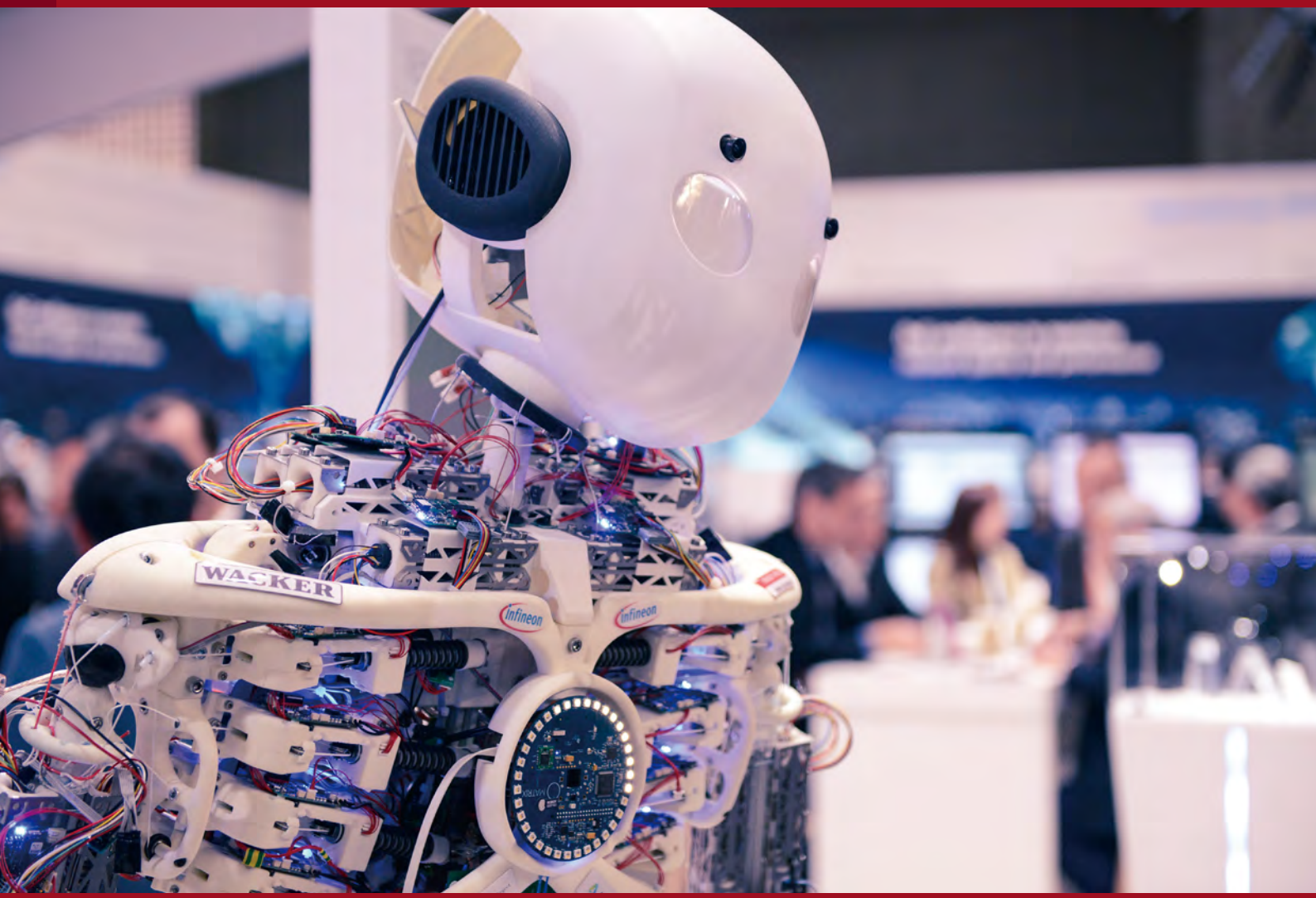
7.2 Preliminary Exploration of the 4 Typical Capabilities of 6G Terminal

Based on the accelerated development of 6G, AI and industrial digitization, the volume of information will further explode, and terminals are faced with processing massive amounts of information, so the efficiency of information flow has to be improved. Terminals will continue to support 6G scenarios and carry new technologies in the 6G era, and 6G terminals will continue to participate in multiple links of information flow and play a more important role in each link, promoting further improvement of information flow efficiency. According to the 9 potential typical scenarios and 5 key research directions of 6G terminals, 6G terminals will have its own typical characteristics different from 5G terminals, and 6G terminals will have 4 typical capabilities as following:

- Terminal all-around communication capability: higher rate, larger bandwidth, lower latency, higher-speed mobility, higher reliability, massive connectivity, space-air-ground integrated communication, communication and AI integration, communication and perception integration, etc., to support the complex and diverse connectivity and transmission capabilities of 6G communication.
- Terminal native AI capability: terminal-side large model running, terminal-side strong computing power, terminal-side energy-efficient data processing, terminal-side data protection, terminal-side model training and updating, terminal-side collaboration of multiple computing units, terminal-side personalized model training and updating, collaboration of terminal side and server side, the capability to support the terminal side itself to collaborate with other devices to conduct computing power, algorithms, data, and other elements.
- Terminal real-virtual fusion perception and multi-dimensional sensory information presentation capability: 3D vision (spatial video), 3D hearing(spatial audio), touch, smell, and taste information and other multi-sensory high-resolution information perception and presentation capabilities, as well as the capability of simultaneously conducting all-round perception of the physical world and the virtual digital world.
- Terminal expansion collaboration capability: Flexible configuration of terminal resources, support for on-demand expansion and upgrading of terminals, and expandable terminal architecture capabilities that support collaboration with network side, cloud side, edge side, and various forms of terminals.

Looking to the future, after 6G terminals are equipped with the above 4 typical capabilities, the terminals will connect the physical world and the digital world, creating an intelligent world for each user.

8. References



8.0

References

[01]《Framework and overall objectives of the future development of IMT for 2030 and beyond》
[02]《Future technology trends of terrestrial International Mobile Telecommunications systems towards 2030 and beyond》
[03]《6G典型场景和关键能力》
[04]《6G网络架构愿景与关键技术展望》
[05]《6G总体愿景与潜在关键技术》
[06]《6G沉浸式多媒体业务需求及关键技术》
[07]《6G分布式网络技术的应用场景及需求》
[08]《6G区块链技术场景和需求研究》
[09]《6G无线网络架构和功能技术》
[10]《OAM传输技术》
[11]《超大规模MIMO技术》（第二版）
[12]《6G网络安全愿景》
[13]《面向6G的信道测量与建模研究》
[14]《面向6G网络的智能内生体系架构研究》
[15]《太赫兹通信技术》（第二版）
[16]《通信感知一体化》（第二版）
[17]《无线AI技术》（第二版）
[18]《先进调制编码技术》
[19]《新型双工专题组技术报告》
[20]《智能超表面任务组研究报告》（第二版）
[21]《智能全息无线电技术研究报告》
[22]《6G前沿关键技术研究报告》
[23]《超大规模天线技术研究报告》
[24]《6G网络AI概念术语白皮书》
[25]《6G网络原生AI技术需求白皮书》
[26]《6G网络内生AI网络架构十问》
[27]《6G数据服务概念与需求白皮书》
[28]《B5G6G网络智能数据采析》
[29]《6G知识定义的编排与管控白皮书》
[30]《6GANA-Network-AI-White-Paper》
[31]《6GNetGPT倡议书》
[32]《Proposal of 6GNetGPT》
[33]《Hexa-X architecture for B5G 6G networks – final release》
[34]《Enabling radio technologies and roadmap towards 6G》
[35]《Final 6G architectural enablers and technological solutions》
[36]《What societal values will 6G address?》
[37]《Green G: The Path Toward Sustainable 6G》
[38]《6G: The Next Frontier of Innovation and Investment》
[39]《6G Spectrum Considerations》
[40]《Beyond Speed: Promoting Social and Economic Opportunities through 6G and Beyond》
[41]《6G Technologies for Wide Area Cloud Evolution》
[42]《Network-Enabled Robotic and Autonomous Systems》
[43]《6G Roadmap for Vertical Industries》
[44]《AI-Native Wireless Networks》
[45]《6G Sustainability KPI Assessment Introduction and Gap Analysis》
[46]《Sustainable 6G Connectivity A Powerful Means of Doing Good》
[47]《Multi-Sensory Extended Reality (XR) in 6G》
[48]《Terminology for Frequency Ranges》
[49]《Digital World Experiences》
[50]《Cost-Efficient Solutions》
[51]《Trust, Security, and Resilience for 6G Systems》
[52]《6G Distributed Cloud and Communications Systems》
[53]《6G Technologies》
[54]《6G Applications and Use Cases》
[55]《Roadmap to 6G》
[56]《6G Use Cases and Analysis》
[57]《6G DRIVERS AND VISION》
[58]《6G REQUIREMENTS AND DESIGN CONSIDERATIONS》
[59]《中国移动6G网络架构技术白皮书》
[60]《6G物联网未来应用场景及能力白皮书》
[61]《6G全息通信业务发展趋势白皮书》
[62]《6G至简无线接入网白皮书》
[63]《6G服务化RAN白皮书》
[64]《基于数字孪生网络的6G无线网络自治白皮书》
[65]《6G无线内生AI架构与技术白皮书》
[66]《6G物理层AI关键技术白皮书》

[67]《6G信息超材料技术白皮书》
[68]《6G可见光通信技术白皮书》
[69]《6G需求与设计考虑》
[70]《中国联通6G业务白皮书》
[71]《中国联通6G白皮书》
[72]《中国联通6G网络机制架构白皮书》
[73]《中国联通6G通感智算一体化无线网络白皮书》
[74]《6G可重构智能表面白皮书》
[75]《6G全双工技术白皮书》
[76]《6G无线智能网络白皮书》
[77]《6G通信感知一体化技术白皮书》
[78]《反向散射通信技术白皮书》
[79]《6G智能频谱共享白皮书》
[80]《6G愿景与技术白皮书》
[81]《6G网络架构展望白皮书》
[82]《6G Common Requirements》
[83]《Beyond 5G/6G》
[84]《智能世界2030报告》
[85]《通信网络2030产业报告》
[86]《计算2030产业报告》
[87]《数字能源2030产业报告》
[88]《智能汽车解决方案2030产业报告》
[89]《6G：无线通信新征程白皮书》
[90]《5G Advanced: Evolution towards 6G》
[91]《6G spectrum - enabling the future mobile life beyond 2030》
[92]《6G – Connecting a cyber-physical world》
[93]《无线网络数字孪生即服务技术白皮书》
[94]《Vision market drivers and research directions on the path to 6G》
[95]《The future of AI is hybrid Part 1 Unlocking the generative AI future with on device and hybrid AI》
[96]《The future of AI is hybrid Part 2 Qualcomm is uniquely posi tioned to scale hybrid AI》
[97]《Why and what you need to know about 6G in 2022》
[98]《A novel approach to radio protocols design for 6G》
[99]《Simplifying spectrum migration from 5G to 6G》
[100]《6G orchestration – a scalable application driven network optimizing approach》
[101]《Technology innovations for 6G system architecture》
[102]《Extreme communications in 6G: Vision and challenges for'in-X' subnetworks》
[103]《Extreme massive MIMO for macro cell capacity boost in 5G-Ad vanced and 6G》
[104]《Security and trust in the 6G era》
[105]《Joint Design of Communication and Sensing for Beyond 5G and 6G Systems》
[106]《Toward a 6G AI-Native Air Interface》
[107]《The Next Hyper-Connected Experience for All》
[108]《6G Spectrum: Expanding the Frontier》
[109]《ICDT融合的6G网络3.0》
[110]《可持续发展的低碳智简6G：愿景与技术趋势》
[111]《下一代协议栈5.0》
[112]《通感一体化系统架构与关键技术》
[113]《面向典型行业的云网边端智能协同与剪裁》
[114]《面向6G时代前沿技术初探：量子信息技术2023》

Annex A Contributors

Company	Name
GSMA	Liu Hong
Honor Device Co., Ltd.	Pang Gaokun, Zhong Haijing, Li Chengfang
China Unicom Co., Ltd.	Ye XiaoYu, Cheng Xinzhou, Wang Xin, Xu Lexi
China Mobile Co., Ltd.	Yang Benzhi, Yang Xiaowei, Dong Weiye
China Telecom Co., Ltd.	Zhang Nuoya, Zhao Jing, ZhangDi
Du UAE	Fathi Abdeldayem
Telstra	Steve Vodicka
inmarsat	Thomas Picard