6G Vision, Requirements and Challenges

vivo Communications Research Institute

6G Vision, Requirements and Challenges

V1.0

Contents

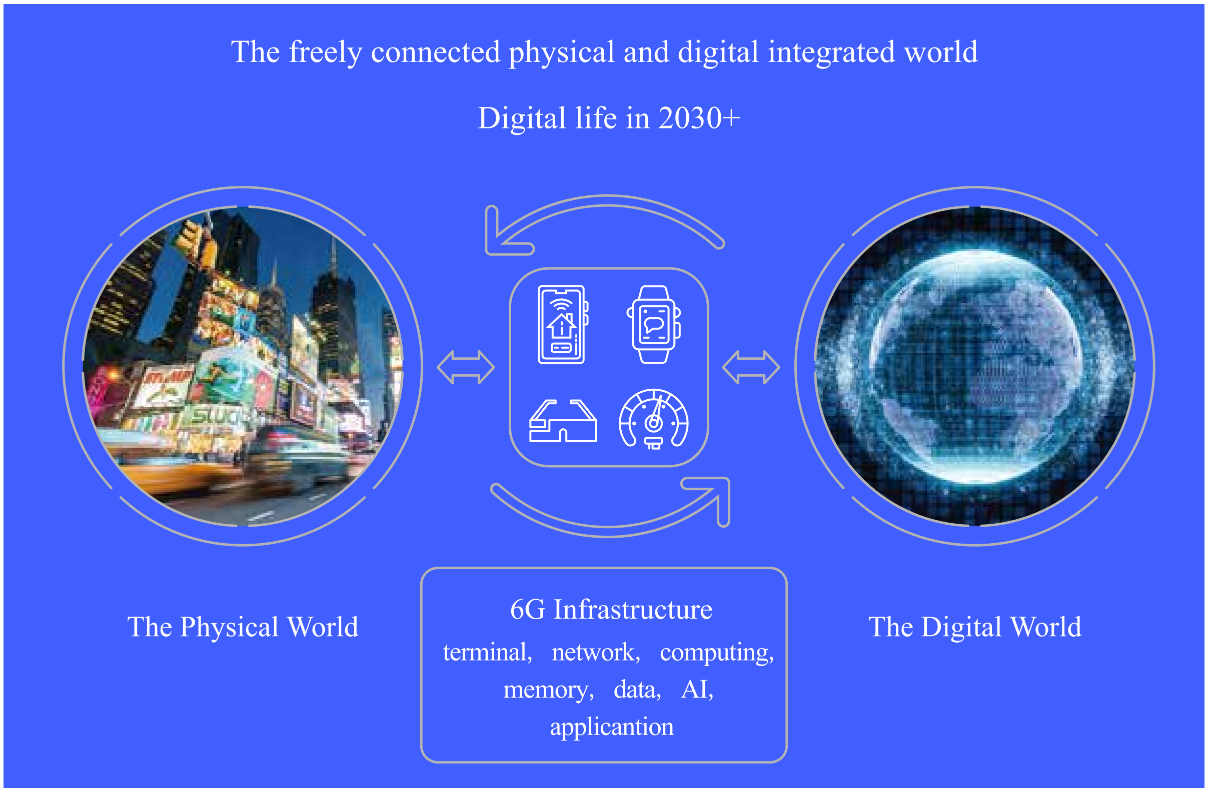
Abstract

While large scale commercial 5G networks are gradually deployed around the world, the industry starts focusing on research and exploration of future 6G technologies. Companies, research institutes and universities around the world are coming forward with the 6G vision and requirements, and have started exploration on potential 6G technologies. It is expected that the industry will reach consensus on the vision and requirements of 6G[1,2,3,4,5] around 2023. In Digital Life 2030+[6], 11 trends closely related to people's life in 2030 and beyond are analyzed, and more than 20 use cases are presented by vivo Communications Research Institute. Based on the scenarios surrounding people's digital life in 2030 and beyond, and the future technologies trend, this white paper presents a preliminary view on the 6G vision and requirements, and analyzes the challenges of 6G networks and terminals. It is expected that this paper will contribute to reach the industry consensus on the 6G vision and requirements.

6G Vision, Requirements and Challenges

6G vision

01



6G will build a ubiquitous digital world, enabling free connection between the physical world and the digital world in 2030 and beyond to realize the tight integration of the two worlds. It will provide rich business applications to make an easy and happy digital life, and promote an efficient and sustainable development of society. The 6G vision is the freely connected physical and digital integrated world.

In order to realize the 6G vision, highly developed infrastructure including hardware and software, communication systems, networks, terminals, computing and storage, etc. is required. Therefore, in general, 6G is the convergence of Information, Communication and Data Technology (ICDT) based on hardware and software infrastructure supporting the physical digital integrated world[6,7].

Different from the 5G mobile communication system, 6G networks will integrate a variety of access technologies, cover a broader physical space, provide stronger basic capabilities such as communication, computing, storage and data, and support more businesses and services[7,8].

6G terminals will be available in various forms with abundant functions and types, connecting and integrating services, and will play important roles in building the digital world. 6G terminal is the bridge between the physical world and the digital world.

What kind of digital world will we live in 2030 and beyond? What's degree of freedom can the physical and digital worlds be connected? In the highly integrated physical and digital worlds, what are the new business opportunities and how will the new services change people's life? How does the 6G terminal play a role in connecting the physical and digital worlds? To realize the 6G vision, what are the performance requirements of terminals and networks and therefore what are the corresponding challenges? In Section 2 to Section 6 in this white paper, we will try to answer these questions, and put forward preliminary requirements and challenges from 6G networks and terminals point of view.

The digital world of 2030+

02

What kind of digital world will we live in 2030 and beyond?

Information and communication technology have experienced rapid development in the past 30 years, and acceleration of digitization occurs in all walks of life. However, the current digital systems are still relatively isolated from the physical world, existing as an auxiliary tool for everyday life. Current digital systems are not yet able to become a part of the physical world with seamless boundary, and they are not yet able to dynamically connect the physical surrounding with the digital systems and hence it is not a complete digital world. In 2030 and beyond, 6G technologies will create a ubiquitous, sophisticated, real-time, and integrated digital world[4,9]. The features described in Table 2-1 can be envisioned for the digital world in 2030 and beyond.

Table 2-1 Features of the digital world in 2030+

Features of the Digital World	2020	2030+	Requirements Analysis	Main Challenges
Digital range	Partially	Ubiquitous	Realize the physical digital integrated world for the Internet of everything	Number of connections, connection density, connection accessibility
Digital level	Rudimentary	Sophisticated	Achieve precise control and efficient operation of the physical digital integrated world	Connection capability (including bandwidth and delay), system sensing and storage capability
Digital update	Semi-static	Dynamic and real-time	Realize real-time update, efficient operation, secure and reliable physical digital integrated world	Bandwidth and delay, system storage capacity
Digital integration	Isolated	Integrated	Realize a physical and digital integrated world of interconnection, efficient operation and sustainable development	The AI capabilities, information security and privacy protection, communication capabilities, regulations

In 2030+, a city, a factory, a building, a classroom, a person, a tree, an insect and so on may be digitalized and stored. Taking the digitalization of human being as an example, the characteristics of the ‘digital person’ in 2030+ can be envisioned as in Table 2-2 below.

Table 2-2 Digital person in 2030+

Characteristics	Main Content	Information Size and Update Cycle	Applicantion Examples	Requirements
Basic information	ID number, facial recognition, photo, etc.	~1 MB, update cycle in the range of month	Identity, such as: authentication, etc.	Low data rate* (<1 Mbps), high information security requirements
Health information	Physical examination, nutrition, and genetic information	~MB × n (n depends on content), update cycle in the range of day	Intelligent health management, such as intelligent food assistant, fitness assistant	Medium and low data rate (1-10 Mbps), high privacy requirements, medium computing and storage requirements
User profiles	Games, shopping, food, reading, videos and other comprehensive portraits of people's interests and hobbies	(100 Kbits - 100 Mbits) × n (n depends on profiles), update cycle in the range of day	Intelligent recommendation, clothing, food, housing, transportation and other aspects of intelligent services	Medium data rate (10-100 Mbps), medium-to-high computing and storage requirements, high security and privacy requirements
Digital healthcare	CT, Ultrasound scanning, X-ray and other digital medical images of various parts of the human body, and wearable monitoring data (e.g. heart rate, temperature)	GB × n (n means multiple body parts), update cycle or remote transfer in seconds	Remote diagnosis and treatment service, intelligent medical management	Medium-to-high data rate (100-1000 Mbps), high reliability requirements
Holographic portrait[8,9,10]	A holographic reproduction of portrait in retinal level resolution	30 Gbit per frame, more than 30 frames per second	Immersive holographic interactive applications, such as telecommuting, distance learning, etc.	Ultra-high data rate (~Tbps), high computing and storage requirements
Digitalization of human cognition and skills	Modeling and digitization of people's intelligence, learning ability, cognitive ability, knowledge level, professional skills, etc.	>10 GB per year, increasing with age	Used for future education evaluation, job skill improvement, career recommendation, etc.	Medium data rate (10-100 Mbps), high computing and storage requirements
Brain memory digitization**	The human brain has about 100 billion neurons, with a total storage of 10^9 TB	About 10^9 TB, assuming day level transmission duration	Brain machine interactive applications	Ultra-high data rate (10^5 Tbps) and ultra-high storage requirements, which are beyond 6G capability
Nanoscale digital twins for human being**	The human body (about 0.059 m^3) is digitalized by 100nm granularity, and 24 bits is needed for the digitalization of one unit	About 10^9 TB, assuming day level transmission duration	Application, food, clothing, housing and transportation, medical and health	Ultra-high data rate (10^5 Tbps) and ultra-high storage requirements, which are beyond 6G capability

* The data rate requirement in the above table is the user experienced data rate requirement.

** A preliminary view is that it is difficult to be realized in 2030s.

In 2030+, the digitization of a person will gradually improve from the current basic personal information and limited personal profiles information. The digitization of the human from physical perspective will include more abundant basic information, real-time and accurate human health data information, ultra-high definition digital medical images, holographic portraits, and potentially nanoscale human features. From spiritual perspective, a more holistic 'individual profiles', digitization of the individual's cognitive and ability levels, and the potential replica of the brain's memory can be envisioned. When people are digitalized from both the physical and spiritual perspective, it becomes utmost important to protect personal privacy data. In addition to advancement of security technologies, administration regulations are also needed to ensure secure transmission, storage and application of personal digital information.

With the continuous innovations of brain-computer interface, biotechnology and nanotechnology, the digitalization of human brain and organs will constantly improve. It can be used in education, health care and many other fields. However, there are still many technical obstacles which require breakthrough in brain-computer interface, nanotechnology and biotechnology areas. The requirement of typical communication data rate for mature brain-computer interface exceeds Tbps, which will be the target of beyond 6G system.

The free connection in physical and digital integrated world

03

The free connection in physical and digital integrated world

What's degree of freedom can the physical and digital worlds be connected?

The free connection between the physical and digital integrated worlds includes the connection between the physical world and the digital world, the connection between the physical world and the physical world, the connection between the digital world and the digital world, and the connection between all kinds of ubiquitous connectivity needs[4,7]. The higher degree of freedom of these connections, the tighter the integration between systems, and the better experience in connectivity and performance. 6G will improve the degree of freedom in connection in the following 6 domains:

√ Space domain freedom: The continuous expansion of coverage area and the seamless connection in wireless environment of 6G communication system will improve the freedom in space domain connection.

√ Time domain freedom: The 6G communication system supports tremendous data rate, ultra-low latency, and increased reliability, which will improve the freedom in time domain connection.

√ Range domain freedom: 6G communication system supports diverse applications, scenarios, terminal varieties and functions with reduced cost, size and power consumption. This will improve the freedom in application domain connection.

√ Sensory domain freedom: 6G supports ultra-high data rate, with enhanced computing and sensing capability, and human communication will be augmented with sense domain freedom (exchange of senses includes visual, aural, smell, taste, touch).

√ Interaction domain freedom: With improved 6G communication capability, the continuous evolution of man-machine interface and brain-machine interface technology will further improve the freedom of interaction domain connection.

√ Financial domain freedom: Further improvement of energy efficiency, spectral efficiency and cost efficiency of 6G will ensure all the freedoms discussed above, ultimately realizing people’s "financial" domain freedom of connection.

Compared to the current communication system, 6G will enhance all 6 domains freedom in connection, as shown in Table 3-1.

Table 3-1 6 domains of connection freedom

Degree of Connection Freedom	2020	2030+	Main Challenges
Space	Covering more than 98% of the population by terrestrial deployment	More than 98% of the space can be reached by human activities, including space, sky, land and sea[8,11]	Low-cost wide-area coverage technology, multi-access network integration design, multi-frequency and multi-RATs terminal complexity
Time	End-to-end ms-level delay, microsecond-level time accuracy	End to end delay is < ms, ns level time accuracy[12,13]	Data rate, delay, cost, reliability
Range	About 80% of the world's population is connected, about 10 billion terminals are connected IoT devices, but low inter-system connectivity	Everybody on earth are connected; 100-fold more connected IoT devices; Enhanced inter-system connection security[3,13]	Connection number; Connection accessibility; Communication capabilities; Information security
Sense	Audio and visual (2D- UHD, VR)	Immersive audio and visual experience; Touch, smell, taste transmission[1,8,11]	Data rate and delay; Improved human-machine interface
Interaction	Keyboard, touch screen, voice recognition, gesture recognition, facial recognition and other interactive ways are gradually evolving	Diverse terminal types; Free tactile interconnection; Mature somatosensory interaction; Primary brain-computer interface	Size, cost and power consumption; material and industrial design; man-machine interface; brain-computer interface; bionic technology; AI capability
Finance	For example, in China, ARPU is ~1% of the per capita GDP, and the average monthly data volume exceeds 8 GB	100 times traffic with similar cost level	CAPEX and OPEX, spectrum efficiency, energy efficiency

As shown in the Figure 3-1, compared to 5G, 6G will improve in the orders of two or more magnitude in terms of space, range and finance domain freedom, and improve in about one order of magnitude in time, sensory and interaction domain freedom.

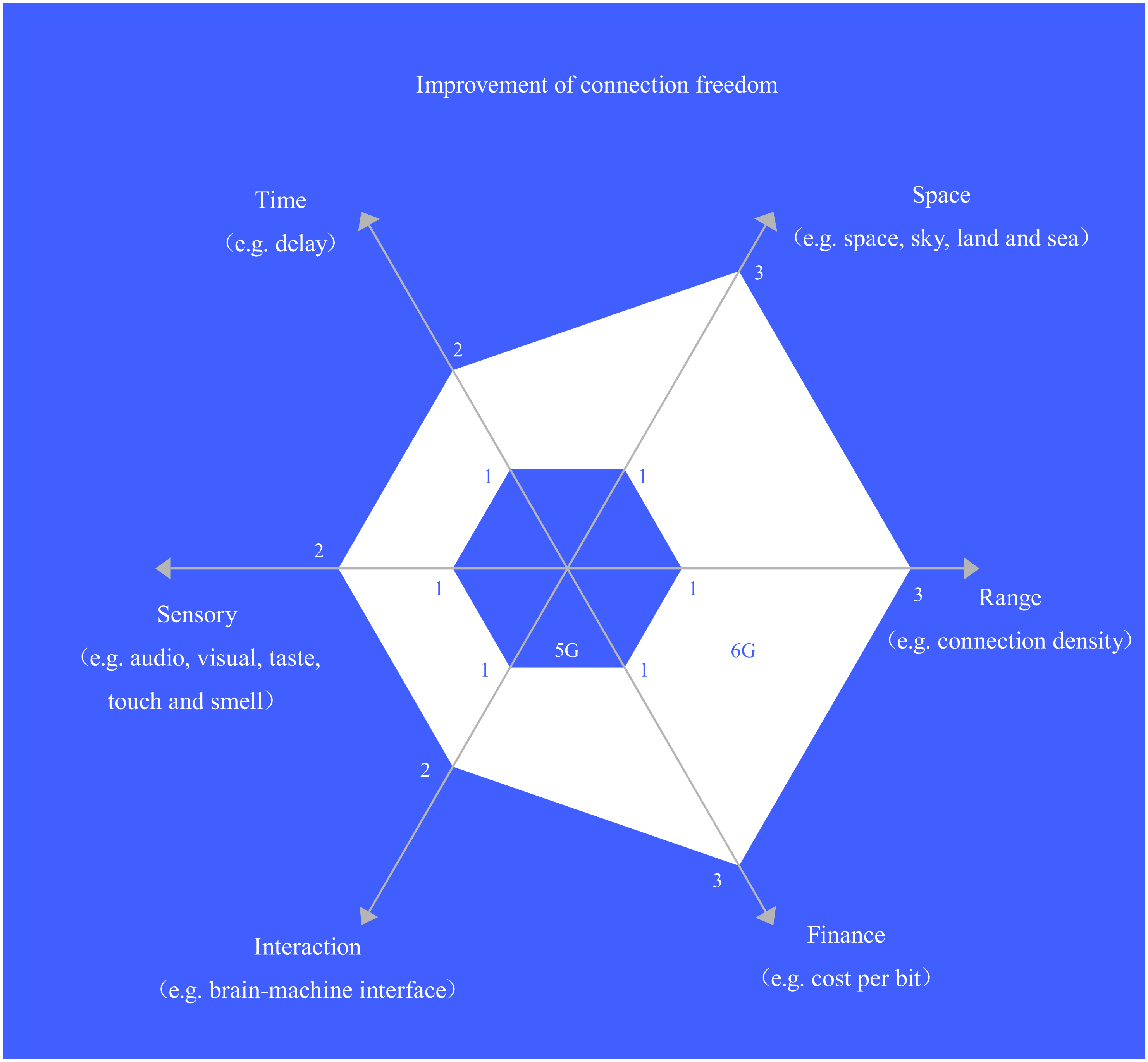


Figure 3-1: 6 domains of connection freedom for 5G and 6G

2 一 an increase of 1 order of magnitude, compared with ‘1’
3 一 an increase of 2 orders of magnitude, compared with ‘2’

6G Vision, Requirements and Challenges

The ubiquitous services of the physical and digital integrated world

04

The ubiquitous services of the physical and digital integrated world

What kind of new services can the physical and digital integrated world provide?

6G will build a digital world, freely connect the physical and digital worlds, where the two can be highly integrated and interact with each other. It will serve thousands of industries with varieties of applications creating efficient, sustainable, ecofriendly and healthy society.

vivo is committed to providing consumers with the ultimate experience of intelligent terminal products and intelligent connectivity services, as the bridge to connect the people and the digital world. In highly integrated physical and digital world, what new business opportunities and what kind of services can be offered and how does it change everyday life of people? In the Digital Life 2030+ white paper[6], vivo Communications Research Institute carried out prediction on 11 aspects closely related to everyday life of people in 2030 and beyond. They are summarized in Table 4-1 below.

Table 4-1 Scenarios and challenges for 2030 and beyond

Scenario	Trends in 2020	Trends in 2030+	Use Cases	Requirements and Challenges
Clothing	Comfortable, elegant and convenient	Comfortable and functional, elegant and personalized, low carbon emission	The Magic Swimsuit 2030; Private Customization	Ubiquitous connections, size, power consumption and cost of terminal, ultra-high data rate, information security
Food	Delicious, healthy and convenient	Delicious+, digitalized health, convenient+, low carbon	Future Food Farm; Quantified Healthy Diet; The Taste of Love	AI and big data, man-machine interface, nearly zero power consumption, information security
Housing	Comfortable, smart home	Comfortable+, intelligent+, low carbon, warm home, harmonious community	Smart Homes 2.0; Make Yourself at Home; Harmonious Community 2.0	AI and computing services, ultra-high data rate, ubiquitous connectivity, low-cost communications, accurate positioning
Trans-portation	Convenient and fast, ride sharing, safety	More freedom and fast traveling, efficient and low carbon	Smart City Traffic; Smart Journey Arrangement	High data rate, low latency, high reliability, accurate positioning, data sharing and information communi-cation security
Learning	Efficient learning, online learning	Intelligence education and assessment, happy learning, personality shaping, creative and cognitive learning	One Happy Day at School; Insects Detective; 'I'm a Speaker'	High data rate, holographic technology development, AR technology mature, AI capability improvement

Scenario	Trends in 2020	Trends in 2030+	Use Cases	Requirements and Challenges
Work	Work together in an office	Distributed dynamic office, knowledge and skills collaboration	Flexible Work Mode Smart Office; Smart Industries.	Virtual reality, holographic communication, low latency communication, timing accurate communication
Entertainment	Videos and games continue to be popularm, AR tours and AI guides are	Fully immersive games, movies, and virtual travelling	Mars Exploration; Stars and Fans; The Glory of Tang Dynasty	XR sensor capability improvement, high data rate and low latency, high computing capability requirements
Medical Treatment	Reactive medicine, digital medicine	Proactive prevention, precision therapy, remote diagnosis and treatment, AI treatment	One-stop Online Clinic; Digital Twin based Diagnosis and Treatment; Micro-robot Surgery	Deterministic network, high data rate and low latency, high computing capabilities, security for information communication
Healthcare	Reactive response to epidemics, reactive response to health issues	Proactive physical and mental health management, proactive disease prevention	Family Healthcare; Soul Mate	Data security, sensing capabilities, data rate and latency
Environment	Reactive response to environmental damage, digitally sensing environmental change	Build proactive and sustainable environmental management system	Balcony Vegetable Garden; Green New Life	Connectivity capabilities and accessibility, supporting ubiquitous terminals and sensors
Safety	Reactive response to natural disasters	Proactive response to natural disasters	Fire Escape; Emergency Capsule; Earthquake Rescue.	Low latency, high reliability, precise positioning, large capacity communication, satellite communication and other access

6G terminal is the bridge between the physical world and the digital world

05

6G terminal is the bridge between the physical world and the digital world

In 2030 and beyond, a huge number of terminals will be widely distributed in the physical world connecting the physical and digital worlds. The capability of the terminal affects the depth and breadth it can reach in the physical world, thus directly determining the digitalization level and operational efficiency of the digital world. vivo believes that terminals will be the bridge connecting the physical world and the digital world.

5.1 6G terminals are the ‘nerve endings’ that construct the digital world

In the future communication systems, a terminal is similar to the ‘nerve ending’ of the physical world, which are scattered in all corners (such as cities, forests, mountains, rivers and oceans, infrastructure and building bodies, human bodies, migratory birds and insect bodies, etc.) to realize the agile perception and accurate control of the physical world. Similar to sensory nerve endings and control nerve endings, on one hand, the terminal senses and collects the operational status of the physical world, and transmits it to the system through the network, so as to build a ubiquitous, precise and dynamic digital world. On the other hand, the ‘digital brain’ and the ‘central nervous system’ analyze, predict and then deduce the results of the digital world developments, which will be input to the physical world through a large number of terminal control nodes, and realize the elaborate management and complex control of the physical world[1].

The breadth and depth terminals can reach in the physical world determine the digital level of the future world. To realize the vision of a physical and digital integrated world in 2030+, the following requirements and challenges are proposed for future networks and terminals:

1) Huge number of connections. For example, the digitization of people requires smart phones and a large number of wearable devices. Precise monitoring of the environment in a given area may require more than 10 terminal nodes in a range of 1 square meter.

2) Abundant terminal types. To realize the ubiquitous connection of the whole world, advanced smart phones and AR/VR/XR terminals are needed, as well as terminal modules in automobiles, robots and large-scale equipment in factories. More importantly, a large number of micro terminals can be installed into human bodies, clothing, buildings, trees and even insects.

3) Continuous optimization of cost, size and power consumption. Continuous optimization of cost, size and power consumption of terminals is the basis for improving the penetration capability of terminals in the physical world. In extreme scenarios such as embedded buildings or insects, ‘zero’ power lightweight terminals[13] are the key to digitizing the physical world.

4) Ubiquitous coverage capability. To build a ubiquitous digital world, it is necessary to have ubiquitous network coverage capability to support comprehensive coverage on the ground and in the air. Coverage accessibility includes both the coverage of downlink radio waves and the accessibility of terminal uplink signals on the network side. On one hand, it requires the optimization of the continuous cost, size and power consumption of terminals; on the other hand, it requires the improvement of uplink coverage capacity. This contradiction will be the biggest challenge to realize ‘Internet of Everything’ in the future.

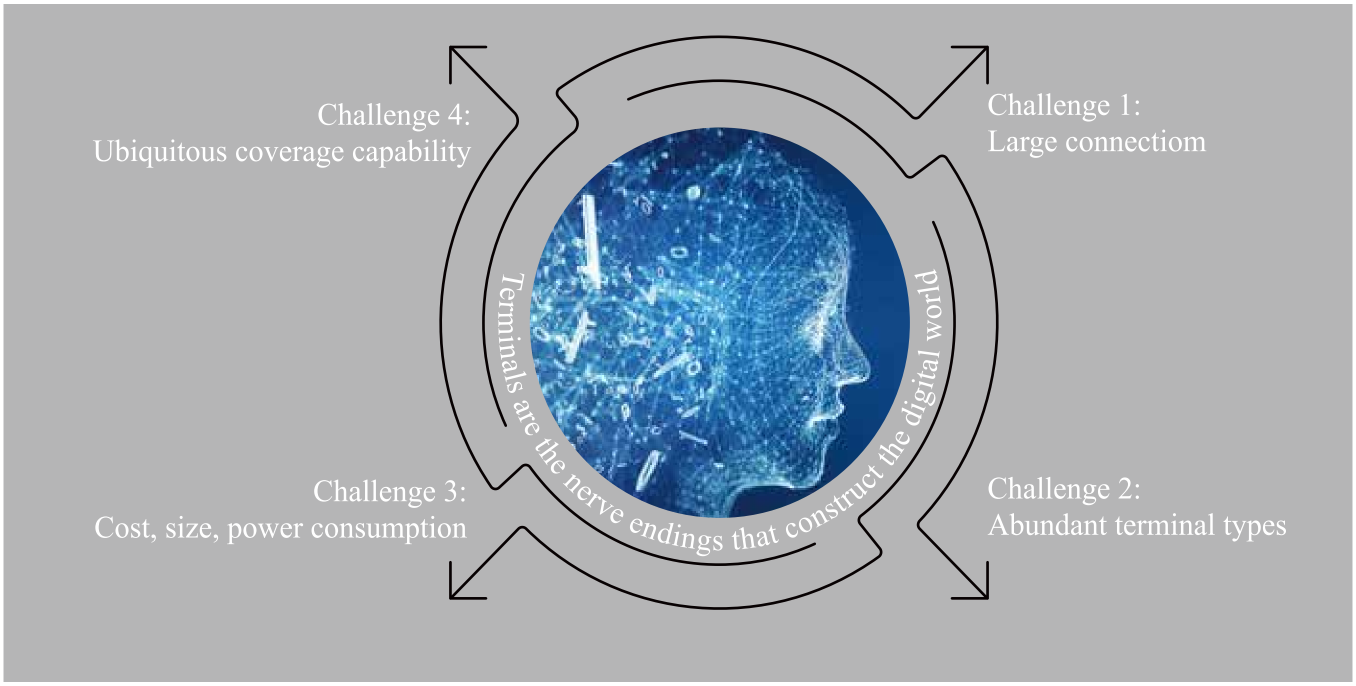


Figure 5-1 4 Challenges of ‘nerve endings’

5.2 6G terminal is the medium of the physical world and the digital world

The interaction between the physical world and the digital world requires terminals as the medium. The bandwidth, computing and interaction capability of the medium determine the freedom of interaction between the physical world and the digital world. In future, people will control the physical world through the digital method with the smart phone terminal as the entrance. For example, parents can remotely control the car to pick up their children from school with the smart phone. Doctors wear AR glasses to control the capsule endoscopy terminal in the human body remotely for medical examination, or operate the capsule robot to perform minimally invasive surgery in the body. To realize the free connection and interaction between the physical world and the digital world, the terminals in the future need to be greatly improved in communication and computing capabilities, human-machine interface technology, and other functions. At the same time, there are also high requirements for the future network:

1) Bandwidth and data volume. People in the physical world, enter into the digital world, and realize immersive real-time interaction. This causes higher requirements on the user experienced data rate and total data volume under an acceptable cost. For example, the preliminary assessment shows that a dynamic holographic portrait needs 1 Tbps data rate[14]. It is estimated that the per capita traffic demand in 2030 will increase by 100 times compared to data consumption today (2020), and the network throughput per unit area will increase by nearly 1,000 times.

2) Latency and jitter. Scenarios such as remote surgery and remote driving require precise interaction between the physical world and the digital world, as well as agile and real-time information exchange. The requirements on end-to-end latency and jitter will be very high. The air interface latency requirement is less than 1ms[1,13].In industrial manufacture, some precise collaborative operations require jitter control at ns level[13, 15].

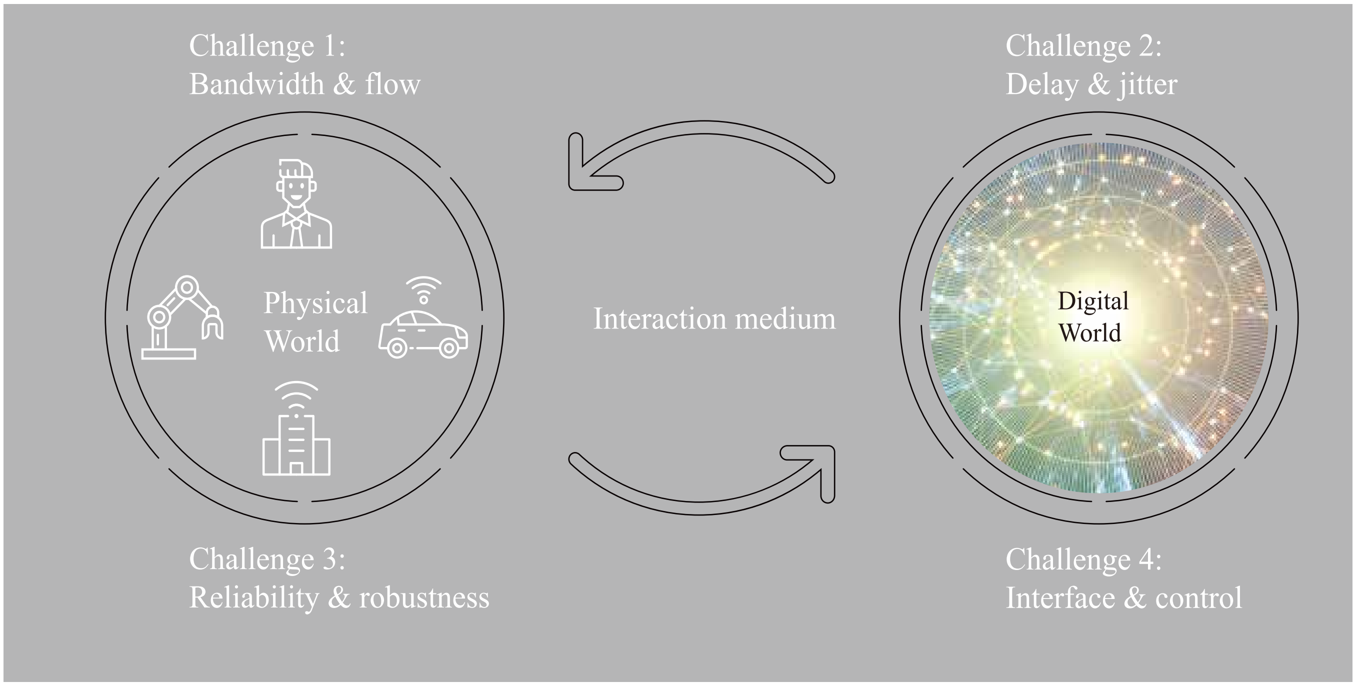


Figure 5-2 Medium and challenges

3) Reliability and robustness. Remote surgery and driving, high-value asset management, smart grid, industrial manufacture and other scenarios are critical for the safety of life and property. These scenarios require extremely high reliability of the future network to support ultra-high reliability of 0.99999~0.9999999[15~18,] . In addition, in the end-to-end transmission of information, each node needs to have extremely high robustness to ensure that the system is stable and reliable.

4) Easy interface and control. As the medium between the physical and the digital world, the continuous development of the man-machine interface and brain-machine interface is very important for the convenience of connection and control. The human-computer interface will gradually evolve from a traditional keyboard, voice, text and touch screen operation to more advanced input of gesture, expression and eye movement recognition. In the future, the brain-computer interface technology will bring a new experience of controlling the physical world and the digital world. In terms of output, in addition to sound, text, pictures and video, AR/VR and hologram are gradually maturing and providing immersive audio-visual experience. Furthermore, the joint presentation of full senses (vision, hearing, smell, taste and touch) is also a problem to be solved in the future. How to standardize coding of the smell, taste and touch need to be further studied.

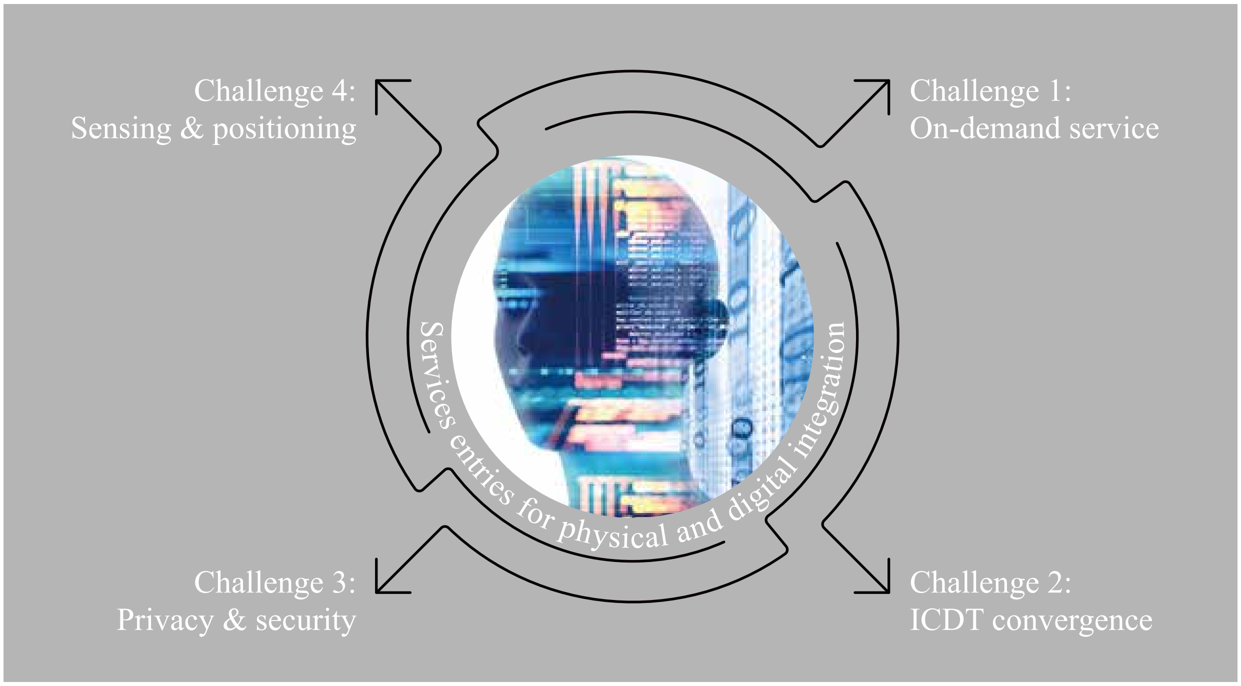


Figure 5-3 Challenges for 6G terminals and networks

5.3 6G terminal provides services of the physical and digital integrated world

Ubiquitous 6G terminals connected by 6G network distributed in the physical world is the basis of the digital world. With cloud computing, big data and AI, in the digital world, the system can learn the operation law of the physical world and predict its development. The prediction can be converted into action in the physical world to provide efficient management and operation. With the terminal as the entrance, 6G will provide innovative applications, to serve thousands of industries, greatly improving the efficiency of social operation, and maintaining the sustainable development of the world.

To realize the high integration of the physical world and the digital world, and to serve thousands of industries, the following requirements and challenges are envisioned for terminals and networks:

1) On-demand service. The future network needs to build a user centric and on-demand service system based on different scenarios to meet the diverse needs of different industry users[1,6,9].

2) Convergence service. The integration of the physical world and the digital world needs the network to provide integrated services including communication, perception, computing and AI, storage and data [7,10].

3) Privacy and security. Highly integrated intelligent services must be built on the premise that data can be securely shared among all layers of networks, all levels of systems and all different entities. Data sharing and communication have brought great challenges to privacy protection and information security, which require more advanced security protection technologies and more reasonable regulations.

4) Sensing and positioning. The high integration of physical world and digital world is based on the precise positioning, service perception and intention perception of the physical world. In the future, networks and terminals need to further improve positioning accuracy, perceive and transmit service intentions, so as to better realize the intelligent integration of the physical world and the digital world.

6G key requirements and challenges

06

6.1 Key requirements of 6G system

The 6G communication system will be an efficient system for communication, computing, storage and data integrated services. Its coverage, connectivity, communication performance, communication efficiency, accuracy and reliability, and convergence service capability will be greatly improved. The 6G network will be built on a user-centric architecture. It can provide more terminal friendly convergence services for perception, communication and computing. A preliminary view of the requirements and challenges for the 6G system is shown in Table 6-1 below.

Table 6-1 Key requirements of 6G system

Classification	Specific Characteristic	5G[19, 20]	6G	Notification
Coverage capability	Coverage range	Covering more than 98% population by terrestrial deployment	More than 98% of the space can be reached by human activities, including space, sky, land and sea	High-value areas to further improve coverage energy efficiency and user experience, while low-value areas to address coverage cost issues
	‘Terminal friendly’ coverage	Maximum transmission power of terminals: 23 dBm and 26 dBm	Support nearly zero power terminal; Maximum transmission power of terminals can be reduced by 6~10 dB	The ‘0’ power terminal can be connected; Terminal power be reduced while maintaining the communication performance experience
Connection capability	Connection density	$1/m^2$	$10\text{-}100/m^2$	In a 6G stereoscopic coverage scenario, the connection density refers to the number of terminals projected into a 1 square meter area
	Mobility	500 km/h	1000 km/h	Aircraft

Classification	Specific Characteristic	5G[19, 20]	6G	Notification
Communication performance	Peak data rate	20 Gbps	>100 Gbps	The peak rate is the maximum data rate of single user in single cell under ideal conditions
	Experienced data rate	0.1-1 Gbps	>1 Gbps	The maximum data rate that can be guaranteed with a probability of more than 95% (when the user's business needs)
	User plane latency	1-5 ms	0.1 ms	User plane latency is the latency of air interface
Accuracy and reliability	End-to-end reliability	0.99999	0.9999999	Under the error control mechanism, the percentage of packets successfully received within a certain delay budget
	Timing accuracy	Delay jitter of microsecond level	Delay jitter ns level	The clock accuracy of the devices needs to be synchronized to ns-level
	Positioning accuracy	1-10 meters	0.1-1 meter	Some scenarios, such as indoor, require positioning accuracy of 0.1-1 m
Convergence service	Convergence services	Data transmission and IMS; Computing and storage service based on MEC/CDN/ cloud	Native convergence service of communications, computing, storage, and data	Native ICDT convergence services, rather than Over the Top (OTT) architecture-based services
	On-demand service	Use QoS, network slice, NEF to realize part of on demand service	User-centric native on-demand capabilities	New architecture and protocols support native on-demand service capabilities
	Privacy and security	Passive security, defense algorithmic based safety	Proactive security, system-level	Proactive security and regulations to achieve privacy and security
Efficiency of communication	Spectrum efficiency	Average spectral efficiency of typical scenarios is 5-8 bps /Hz/TxRP (dense urban area)	The average spectral efficiency per unit area is improved by 2-3 times[2,3,13]	The improvement of spectral efficiency requires continuous innovation of wireless technologies
	Energy efficiency	Power of typical base station is about 1-2 kW, with transmission capacity of about 10 Gbps	100 times increase	The total capacity of the system is increased by 1000 times, but the total energy consumption is increased by no more than 10 times
	Cost/price per bit	It is expected 5G users will reach 100GB/ user/month in the mature stage, with AURP about 1% of per capita GDP	About 10 TB/ user/month, with similar AURP of 1% of per capita GDP	It is difficult to achieve this goal by reducing OPEX and CAPEX, so it is necessary to enhance the value of unit bit and develop a new profit model

The expansion of 6G requirements relative to 5G in terms of peak data rate, user experienced data rate, latency, connection density, reliability, positioning accuracy, latency jitter, and mobility is shown Figure 6-1.

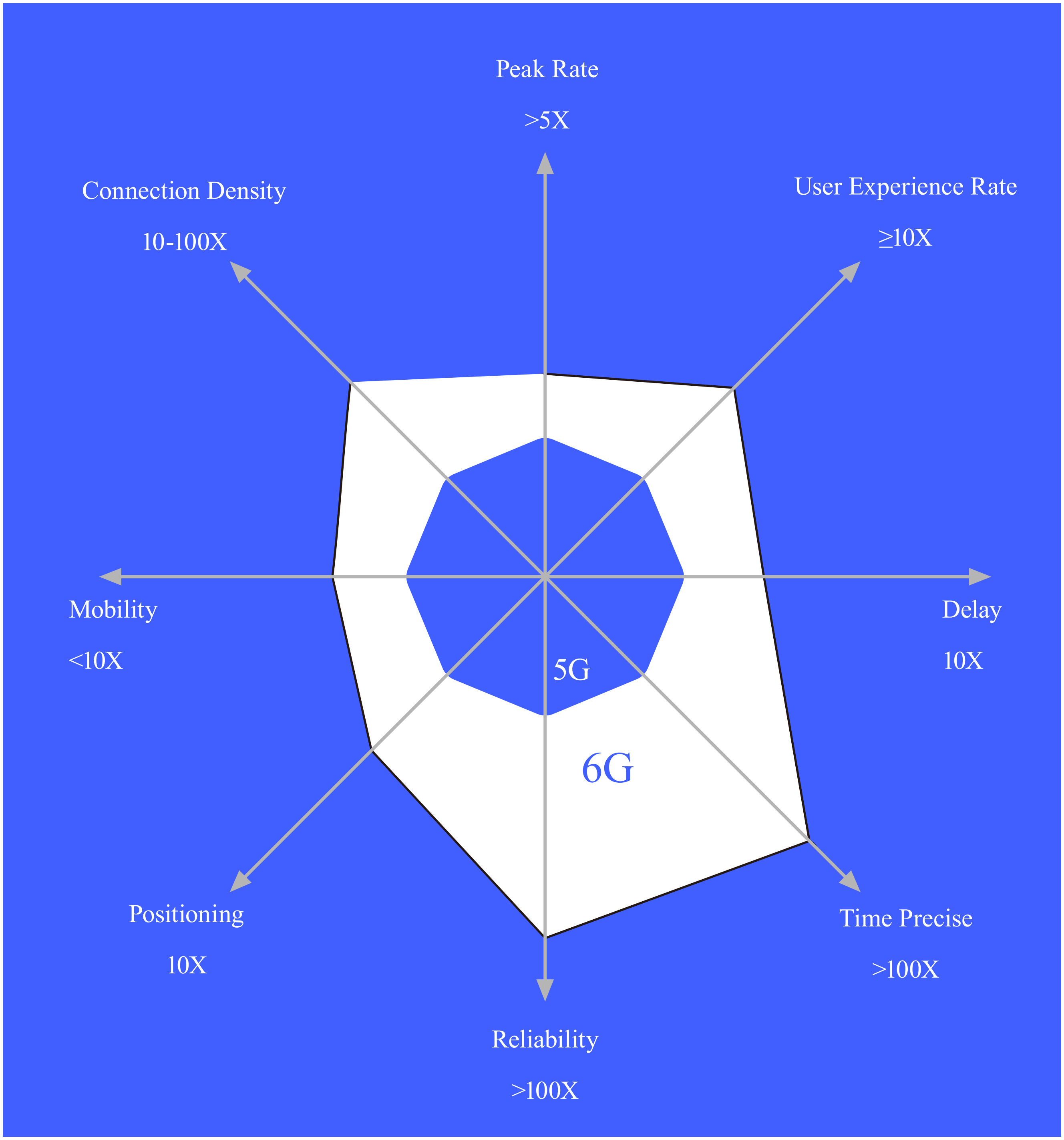


Figure 6-1 Key requirements of 6G system

6.2 6G terminal challenges and technical direction

6G terminal is the bridge connecting the physical world and the digital world. In the future, the development of terminals will be characterized by ubiquitous, intelligent, lightweight and diversification[14]. The corresponding challenges for 6G terminals include:

- √ The contradiction between ubiquitous coverage and uplink coverage limitation;
- √ The contradiction between ubiquitous connection and the tight requirement of cost, size and power consumption;
- √ Support of full spectrum, multi-RATs and very high throughput but restricted cost, size and power consumption;
- √ Collaborative and seamless experience among multiple terminals for one user;
- √ The contradiction between high intelligent requirements and limited AI capability especially for lightweight terminals;
- √ The contradiction between data sharing and personal privacy;
- √ Battery and power supply techniques need breakthroughs;
- √ Sensing, storage, and display techniques need breakthroughs;
- √ Man-machine interface and brain-machine interface need breakthroughs;
- √ The healthy and safe use of terminals.

There are four core problems for 6G terminals consisting of uplink coverage, cost, size and power consumption, ubiquitous intelligence, nearly zero power communication.

vivo will work with industry partners to enrich future application scenarios, reach consensus on 6G requirements, and continue to explore and develop key enabler technologies of 6G.

AI	Artificial Intelligence
AR	Augmented Reality
ARPU	Average Revenue Per User
CAPEX	capital expenditures
CDN	Content Delivery Network
GDP	Gross Domestic Product
ICDT	Information，Communication and Data Technology
IMS	Internet protocol Multimedia Subsystem
MEC	Mobile Edge Computing
NEF	Network Exposure Function
OPEX	Operating Expense
QoS	Quality of Service
TxRP	Transmission Reception Point
VR	Virtual Reality

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