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# 6G SERVICES AND REQUIREMENTS

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# 摘要

信息技术、移动通信技术、人工智能与大数据技术的深度融合（ICDT），推动着 5G 在技术和业务两个层面向 6G 演进。学界和业界已广泛讨论 6G 业务的发展趋势与特征，识别出多个驱动力要素，描述了丰富的业务类型、场景和用例，并定义了关键性能指标。同时，不断涌现的 6G 潜在关键技术进一步激发新业务与应用的可能性。

为了预见 6G 网络应具备的能力，需要对大量异构的新兴业务类型进行分类，借此从宏观层面提取出对 6G 网络架构、功能与性能的通用需求。本白皮书基于对移动业务驱动力要素和 AI 和数字孪生技术广泛渗透力的认识，指出了 6G 业务任务化、无人化、智能化、全球化与分布式的发展趋势。为了进一步地明晰业务特征，提出了 6G 业务分类模型，定义了人、智能体、物理空间和虚拟空间四个要素，以其交互关系定义了传统业务、AI 业务、沉浸式业务和数字孪生业务：

- 传统业务是指移动互联网业务、物联网业务和广播通信融合业务；
- AI 业务是指基于人机接口的助理类业务和基于机机接口的无人化业务
- 沉浸式业务指基于全息通信和 XR 的通感体验与控制业务
- 数字孪生业务是指基于物理与虚拟空间交互映射能力的仿真与控制业务

四类业务在个人场景，以及智能制造、智能交通、智慧能源、智慧医疗等垂直场景中具有广泛的应用可能性。

本白皮书认为，上述后三类业务具有感知、通信与计算高度耦合的特征，对 6G 网络提出了端到端信息处理能力的通用需求。这需要 6G 网络具有高度的端到端全局资源与底层能力调度的能力。为此，重点围绕网络架构、网络功能与关键性能三方面阐述 6G 业务对 6G 网络的需求。

在网络架构方面：

1) 6G 网络应具有端到端的微服务架构和软件定义网络架构，以支持网络快速的能力重构与升级，快速的资源与能力调度匹配动态业务需求
2) 6G 网络应具有分布式 AI 架构，以支持泛在的 AI 计算资源调度，保障泛在的 AI 应用与服务
3) 6G 网络应具有空天地一体化架构，以支持全球化业务部署与运营
4) 6G 网络应具有云网边端一体化架构，以支持流量与算力的全局均衡和端

到端信息处理能力，保障端到端业务质量

在网络能力（功能）方面：

1) 6G 网络应具有增强的通信与覆盖能力，进一步提升速率、降低时延、提高可靠性，保障全球宏观覆盖与人体等微空间覆盖
2) 6G 网络应具有内生感知能力，实现对业务、网络、用户、终端和环境的属性与状态的全局感知
3) 6G 网络应具有内生计算能力，全网算力可感知可封装可调度
4) 6G 网络应具有内生 AI，既要“网络为 AI”，又要“AI 为网络”
5) 6G 网络应具有确定性信息处理能力，支持准时及时的感知、传输与计算
6) 6G 网络应具有能力开放功能，实现底层的感知、通信与计算资源和能力的开放，实现能力即服务
7) 6G 网络应具有内生安全能力，做到零信任、主动防御、自免疫，可以引入区块链实现资源共享与多方协作

在关键性能（功能）方面：

1) 数据速率：全息通信具有 Tbps 级峰值需求，数字孪生业务具有 10~100Gbps 峰值需求，体验速率相应在 100Gbps 和 1~10Gbps 级
2) 同步精度：无人化现场业务、远程控制类业务需要
3) 定位精度：室内定位精度和垂直定位精度从米级提升到亚米级，无人制造现场 3D 定位精度将到毫米级
4) 确定性：端到端时延达到 ms 级，时延抖动 μs 级，无人制造可靠性要求 99.999999%
5) 移动性与业务连续性：支持 1000km/h 的航空器，感知、通信与计算的连续性达到 99.999%
6) 算力：全息类业务峰值算力需求在 100TOPS 级

6G 业务需求与 5G 网络在架构与能力上形成显著差距，加速了 6G 新技术的研发进程。预期 2030 年将有部分 6G 新业务得到商用。

# Executive Summary

The deep integration of information technology, mobile communication technology, and big data (ICDT) promotes 5G to evolve towards 6G at both technology and service level. The development trend and characteristics of 6G services have been widely discussed in academia and industry. Several driving factors have been identified, and a wealth of service types, scenarios and use cases have been described, key performance indicators have also been defined. Meanwhile, the emerging potential key technologies of 6G further stimulate the application possibility of new services.

In order to predict the capabilities that 6G network should have, it is necessary to classify a large number of heterogeneous emerging services, so as to extract the general requirements on 6G network architecture, function and performance from the macro level. Based on the understanding of the driving factors of mobile services and the wide penetration of AI and digital twin technologies, this white paper points out the development trends of 6G services, such as task-centric, unmanned, intelligent, global and distributed services. In order to further clarify the service characteristics, a 6G service classification model is proposed, which defines four elements: human, autonomous things, physical space and virtual space. According to their interaction relationships, traditional services, AI services, immersive services and digital twin services are defined respectively:

1) The traditional services refer to the mobile Internet services, Internet of things services and integration services of broadcast and communication;
2) The AI services refer to the assistant services based on human-machine interface and the unmanned services based on machine-machine interface;
3) The immersive services refer to the virtual multi-sensory experience and control services based on holographic communication or XR;
4) The digital twin services refer to the simulation and control services based on the interactive mapping ability between physical space and virtual space.

These four types of services have a wide range of application possibilities in personal scenarios, as well as in vertical scenarios such as intelligent manufacturing, intelligent transportation, intelligent energy, and intelligent health care.

Especially, the last three types of services have the high coupling characteristics of sensing, communication and computing, and put forward the general requirements

of end-to-end information processing capability for 6G network. This requires 6G network has a high scheduling ability of global resource and underlying capabilities. Therefore, this paper mainly discusses the requirements of 6G services on network architecture, function and key performance.

In terms of network architecture:

1) The 6G network should have an E2E micro service architecture and software defined network architecture to support rapid network function reconfiguration and upgrading, and rapid resource and function scheduling to match dynamic service requirements.
2) The 6G network should have a distributed AI architecture to support ubiquitous AI computing resource scheduling and guarantee ubiquitous AI applications and services.
3) The 6G network should have an integrated space ground architecture to support global service deployment and operation.
4) The 6G network should have a cloud-network-edge-terminal integration architecture to support the global balance of traffic and computing power and E2E information processing capability, and ensure the E2E service quality.

In terms of network capability (function):

1) 6G network should have enhanced communication and coverage capabilities, further improve the data rate, reduce delay, improve reliability, and ensure global coverage and body-like micro space coverage;
2) The 6G network should have the ability of native sensing to realize the global perception of the attributes and states of services, networks, users, terminals and environments;
3) The 6G network should have the ability of native computing. The computing power of the whole network can be perceived, encapsulated and schedulable;
4) The 6G network should have native AI to realize both "network for AI" and "AI for/in network";
5) The 6G network should have the ability of deterministic information processing and support sensing, transmission and computing on time and in time;
6) The 6G network should have the capability exposure function to realize the opening of the underlying sensing, communication and computing resources

and capabilities, and realize the capability as a service;

7) The 6G network should have the ability of native security to achieve zero trust, active defense and self-immunity, and can introduce blockchain to realize resource sharing and multi-party cooperation.

In terms of key performance (function):

1) Data rate: holographic communication has peak data rate requirement at Tbps level, digital twin services demand 10~100Gbps peak data rate, and the experience rate is correspondingly 100Gbps and 1~10Gbps.
2) Synchronization accuracy: The synchronization accuracy will reach ns level regarding unmanned field services and remote-control services needs.
3) Positioning accuracy: indoor positioning accuracy and vertical positioning accuracy will be improved from meter level to sub-meter level, and unmanned manufacturing demands 3D positioning accuracy at millimeter level;
4) Determinacy: The E2E delay will reach ms level, the delay jitter will reach μs level, and reliability requirement of unmanned manufacturing is 99.999999%;
5) Mobility and service continuity: The aircraft-like terminal speed will reach 1000 km/h, and the availability of sensing, communication and computing reaches 99.999% .
6) Computing power: holographic services demands the peak computing power at 100TOPS level.

There is a clear gap between the 6G service requirements and the 5G network in terms of architecture and capabilities. This accelerates the research and development process of 6G new technologies. It is expected that some 6G new services will be put into commercial use by 2030.

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# 1. Introduction

Since the deployment of 5G mobile networks, as well as eMBB, URLLC and eMTC services across the globe, there has been a significant number of discussions on what the next generation of network (6G) would look like [1], especially what mobile service would be like [1-3]. By taking into account multifold driving forces, abundant services and applications are identified or imagined. As one of driving forces, a large number of advanced information and communication technologies are also involved. This makes it quite difficult to understand the requirements indeed and figure out a network framework to meet the requirements.

The challenge asks us to find a common ground regarding mobile service trends in a simple way. This white paper aims to identify a limited number of 6G typical services and application scenarios, and evaluate the requirements on network architecture, functions and performances only considering the potential applications of cloud native, AI, and digital twin technologies in 6G network.

# 2. 6G Service Development Trends

## 2.1 Driving forces for 6G service

### 2.1.1 5G service bottleneck

5G promises to provide eMBB, URLLC and eMTC services for diverse personal and vertical applications. In the future, ultra-high-definition (UHD) services represented by 4K/8K live broadcast and 4K/8K VR will become the mainstream. UHD services need to meet the requirements of ultra-100M bandwidth and millisecond latency simultaneously. 5G networks can no longer meet both the needs of large bandwidth and low latency, so new networks with stronger capabilities are required. At the same time, users also need to enjoy ultra-high-definition video services in areas that are difficult to cover by current broadcast and television signals, such as remote area, sea and air. Due to current technology, equipment, and venues, it is still difficult to achieve full-area coverage and high-throughput transmission. Therefore, new coverage and transmission modes are needed.

5G along with MEC accelerates the integration of radio and television services and mobile communication, but faces many security risks and challenges. Without mechanisms such as trust and isolation, it is easy to breed internal threats to the platform and increase risk of leakage of sensitive data assets in the industry. Therefore, a more reliable security guarantee mechanism is needed.

### 2.1.2 Governance and emergency

With the continuous development of the times, the status of users in the field of content consumption has gradually changed from passively accepting designated content to hoping to obtain personalized content that meets their interests. However, completely personalized content recommendation will result in too single information obtained by users, which is not conducive to promoting traditional culture and enhancing national cohesion. Pushing audio and video content in the form of broadcast not only solves the problem of high bandwidth consumption of the access network, but also gives full play to the important role of publicity, education and supervision. Disseminate different knowledge to the broad masses of people, effectively improve the scientific and cultural literacy of the whole nation. Comprehensively supervise social and economic activities and public opinion from all walks of life, establish correct social values, correct bad social practices, and promote the healthy development of society. Therefore, it is necessary to provide a new 6G broadcast service with wide area coverage and high-throughput transmission.

5G networks cannot effectively deal with the risks brought by natural disasters and public health emergency such as COVID-19. The 6G broadcast base stations outside the disaster area can cover part of the disaster area and provide broadcast services uninterruptedly, which will play an important role in disaster warning and emergency communications. Furthermore, 6G accelerates AI applications which can help to deal with public health emergency.

### 2.1.3 Technological innovation

With the accelerated development of ICDT, there’s been an explosion of intelligent end-to-end information processing requirements from advanced technologies, such as AI, digital twin, biology computing, brain computer interface, etc. AI and ML techniques, especially deep learning (DL), have rapidly advanced over the last decade and are now central to several domains involving image classification and computer vision, ranging from social networks to security. They are applied in problem areas where significant amounts of data are readily available for training.

Along with this, a large number of autonomous things (ATs), such as Unmanned Aerial Vehicles (UAV), autonomous vehicles, robots, etc. and virtual spaces (XR, digital twin system, intelligent space, hologram, etc.) are emerging. The interconnection between ATs and virtual spaces with/through mobile network on one hand bring us a large number of new services, and on another hand highlight the shortcomings and bottlenecks of 5G.

#### 2.1.4 Information consumption upgrade

As the scale of emerging consumer groups continues to grow, consumption capacity continues to increase, consumption habits are gradually changed, and consumer demand is transformed and upgraded, information consumption and new technologies continue to be deeply integrated, and new models, new formats and new industries continue to emerge, information consumption has become an important force in promoting economic growth.

To meet people's ever-expanding demand for information consumption, information infrastructure has a lot of room for improvement, and it is necessary to improve the supply capacity of information consumption products and services. From the point of view of network coverage, the network coverage in remote areas and areas with low population density has not yet reached the user experience requirements; from the point of view of network capabilities, it is necessary to improve the speed through network upgrading and reduce charges through market competition. In addition, network security issues such as personal information protection, online payment security and website trust services are still prominent, requiring continuous and systematic management of the online consumer environment.

#### 2.1.5 Business competition

The killer services are the core business competitiveness. IoT vertical services and XR services are believed to be the killer services for 5G. In order to maintain competitive advantage, service providers must focus on new services, such as AI services, immersive XR and digital twin services, due to the service universality.

### 2.2 6G service trends and features

5G has opened a new era of interconnection of all things, penetrating all walks of life. And 5G+ empowers vertical industries with innovative applications that cover multiple aspects of people's lives, production and social governance, creating new services and new business models. 6G fully supports the digitalization of the world on the basis of 5G, and combines with the development of AI, cloud native, digital twin, and other technologies to achieve the ubiquitous intelligence, driving society towards a digital twin world that combines virtual and reality. This promotes the upgrading of social and economic informatization from “Internet+” to “AI+” and “digital twin+”.

6G services are foreseen to be more immersive, remotely controlled, and unmanned. The real-time interactions in future life, society and industry comprises of human-machine interaction, inter-AT interaction and virtual-physical space interaction with both mundane and sophisticated tasks. These services mandate very tight requirements of reliability, throughput, short latencies, etc. as well as programmability, customizability, and security.

The trend of 6G services has the following characteristics:

- Task-centric: The service presents a life-cycle process characteristics.
- Unmanned services: Upgraded automation without human intervention especially in dynamic and emergency environment.
- Intelligence-oriented services: intelligent interaction, media self-organization, content self-generation and intelligent distribution.
- Immersive services: Holographic type communication, interactive XR
- Global and deep coverage: from space-based global coverage for ocean, remote areas, air and space to mircrospace/body coverage
- Distributed services: services provided with distributed resource scheduling and function combination.

# 3. 6G Typical Services and Application Scenarios

## 3.1 Classification model for mobile services

The diverse communication and service scenarios toward 6G can be described in term of interconnection model, which is outlined by four elements: Human, AT, physical space and virtual space, as shown in Fig. 1.

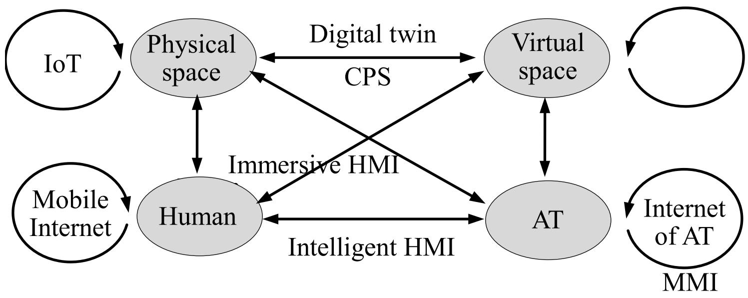


Fig. 1; Classification model for mobile services

The interconnection among humans mainly refers to the mobile Internet service provided by the existing mobile networks, such as eMBB (UHD video, XR) services, while the interconnection among physical spaces refers to vertical IoT applications, such as URLLC and eMTC services.

A human interacts with an AT or a virtual space with the help of an intelligent human-machine interface (HMI) or an immersive HMI. Such interconnection will bring us a large number of new services, such as assisted/remote driving, remote operation, robot services, interactive XR.

The interconnection between physical space and virtual space creates a kind of digital twin applications, such as digital twin body, digital twin city, digital twin network, digital twin workshop, etc. The interconnection between virtual spaces may be the parallel world beyond 6G.

The emerging interconnection among ATs is the typical 6G scenario of interest. An AT has the capabilities of sensing, wireless communication, machine learning, and actuation. It maybe a virtual system living in a cloud platform as an application, or a physical thing with sensors and actuators as a terminal to the mobile network. It interacts with each other through machine-to-machine interface (MMI), aiming to achieve a cooperation on a target task. This will bring us more attractive unmanned services.

## 3.2 AI services

From a long-term perspective, the increasing application of AI in all walks of life must be one of the latest social development trends. It is expecting that AI services will provide intelligence and capabilities of AI computing which will be empowered by 6G. In order to implement such services, MMI and HMI will be required for access. More specifically, AI services are mainly divided into two categories: unmanned service based on MMI and assisted services based on HMI.

### 3.2.1 Unmanned services based on MMI

Along with advances in sensing, positioning, computer vision, and other machine intelligent techniques, more human-involved activities will evolve to unmanned services such as autonomous driving, unmanned logistics and unmanned intelligent factory. Unmanned service refers to the service capability of completing a task through one AT or multi-AT cooperation without human intervention.

Autonomous driving will advance to Level 5, where complete autonomous can be achieved without human intervention. With the development of autonomous driving, traffic accidents will be reduced dramatically. And then the safety of passengers and pedestrians can be guaranteed. In addition, the information of vehicles can be interacted through wireless communication or sensing in the process of automatic driving. The vehicles are able to perform route scheduling intelligently according to the obtained interactive information. Traffic jams will be alleviated based on the intelligent route scheduling. In final, the efficiency of transportation system will be optimized and improved, so that commuters will no longer suffer from congestion during peak hours. However, the complicated and changeable traffic environment has resulted in higher training cost. Thus, the limited computing power of vehicles has great limitations on automatic driving

Future logistics will be created as a comprehensive intelligent and unmanned logistics system based on technological innovation. Autonomous logistics describes systems that provide unmanned, autonomous transfer of equipment, baggage, people, information or resources from point-to-point with minimal human intervention. Unmanned logistics mainly includes two stages: storage and transportation. In the storage stage, AI technology is used to make a large number of robots work together in the warehouse, which is easy to deploy, expand and efficient full-link warehouse automation solution. In the process of transportation, people who live in the remote areas can also receive delivery in time by utilizing UAVs. Through massive deployment of delivery robots, bulky and/or heavy goods can reach to customer's hands easily. And the transportation route can be intelligently adjusted to meet the current business needs. Through the information interaction among multiple UAVs, the operational efficiency will be boosted. At the same time, it is still necessary to obtain the size and weight of goods in addition to the quantity of goods to be transported, which aims to distribute the transportation business in a more balanced and efficient manner. Unmanned logistics will provide us more opportunities for more business models.

Unmanned factory is another AI-based service. In such intelligent factory, the whole process from raw material input, product design, process design, processing, inspection and packaging to the final product is automatic without workers. However, the unmanned factory is not a simple fully automated factory, which has the ability to actively sense the environment, exchange information and make decisions. And the schedule can be intelligently adjusted based on perception data during the production process. Therefore, just a few workers are arranged to monitor the production status.

### 3.2.2 Assisted services based on HMI

An assisted service refers to the dedicated service provided by an AT to help a user achieve his target. These services include virtual doctor, virtual teacher, virtual guider, virtual scientist and so on.

In assisted services, HMI acts as a special interface to connect human behaviors with a service platform or a database. Then, user will access various services through such HMI. HMI now develops towards natural interaction along with the ubiquitous computing power and broadband transmission capability. Users input multi-dimensional and imprecise intend to the AT in the most natural way, and the AT will accurately understand the information and respond to it. Intelligent HMI will not only be greatly improved in speech interaction, visual interaction and sensory interaction, but also be expected to make breakthroughs in emotional interaction and brain computer interaction (BCI).

Speech interaction technology mainly focuses on the processing of voice information, which enables AT to analyze, understand and synthesize speech, so as to realize "listening and speaking". It generally includes four parts: speech acquisition, speech recognition, semantic understanding and speech synthesis. Voice interaction has accelerated the penetration and landing in smart home, mobile phone, car, robot, etc. However, it is still not natural enough, and will be restricted in many conditions, such as the need to wake up in a quiet environment. It can't understand the context information in case of a single round of "one question and one answer" dialogue. With the development of voice interaction technology, the AT will predict and infer the next voice instruction according to the context, generate the response in real time and control the dialogue rhythm, so as to realize a natural and smooth multi-round conversation. The visual interaction is based on the posture characteristics of the human body to complete the interaction process. With the development of computer vision and the continuous breakthrough of deep learning algorithms, agents are able to acquire one's intentions and needs by recognizing human body information, such as faces, fingerprints, facial expressions and body movements. The process of directly interacting with peripheral agents or intelligent environment by body movements is named sensory interaction. The traditional intelligent interactions are mainly carried out in a blunt mechanized way, where the emotional communication between agents is always ignored. Therefore, emotional interaction severs as a high-level information supplement to convey emotion when expressing functions and information. And then, BCI refers to a new intelligent interaction technology that the information can be transmitted directly from the outside world input the brain. And the whole process relies on a specific interface instead of a conventional neural channel.

Virtual doctors interact with patients through HMI in order to understand their language description and limb behavior. And make the initial decision for the patient according to the sensed age, height, weight and other physical condition. Then virtual doctor communicates with the patient through speech interaction and visual interaction to give the further medical treatment. And it is available and effective for acute disease. The existence of virtual doctors is conducive to sharing the high-quality medical teams. To a great extent, the problems of insufficient medical resources and difficulty in seeing a doctor will be alleviated.

Virtual teachers will gradually appear to enrich the diversity of courses and break the geographical restrictions. The virtual teacher first acquires knowledge to build their own database, and then makes an initial teaching schedule according to tasks. Then virtual teachers interact with students by speech interaction, visual interaction and emotional interaction in order to gain students' learning status. And it pays more attention in emotional interaction. Then the initial schedule is going to be upgraded following the learning status of student. And it is perfect for multiple virtual teachers to share their own experiences in a knowledge sharing model. In a word, the virtual teachers will formulate a more flexible and applicable scheme to match various students with the help of interaction.

Virtual scientists make use of BCI to share and preserve precious expert knowledge. It is more convenient for human beings to obtain effective knowledge by reading and converting electroencephalogram signal than learning. We take measures to input the precious expert knowledge that is obtained from experienced scientists by BCI into an agent. Then the agent is regarded as a virtual scientist, which has the ability to complete complicated work. The effective knowledge obtain from multiple experts can be involved in the same agent through BCI interface, so that the agent have comprehensive ability. And it will continuously adjust its decisions to adapt to the time-varying environment assisted by interaction.

Unmanned services based on MMI and Assisted services based on HMI will be the mainstream direction of intelligent business in 6G mobile communication network. The MMI and HMI, as the interface of information input, help to better sense demands and make appropriate response timely. With the development of AI services, it is vital to take sufficient security measures so as to ensure the security of users' private data.

## 3.3 Immersive services

Immersive services aims to promote the interaction manner of human from audio, video, AR/VR to extended reality（XR）and hologram, enabling immersive experience in terms of senses of vision, hearing, touch, smell, taste and even emotion, without constraints of time and space.

Immersive services mainly include holographic type communication and interactive XR. Both of them can be applied into remote driving, remote surgery, remote teaching, remote inspection, remote meeting, virtual classroom, virtual shopping, virtual tourism, virtual concert, virtual museum, etc.

### 3.3.1 Holographic type communication services

Holographic type communication (HTC) is expected to digitally deliver 3D images from one or multiple sources to one or multiple destination nodes in an interactive manner. It is foreseen that fully immersive 3D imaging will impose great challenges on future networks.

### 3.3.2 XR services

XR refers to all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables. It includes representative forms such as AR, MR and VR and the areas interpolated among them. The levels of virtuality range from partially sensory inputs to fully immersive VR. A key aspect of XR is the extension of human experiences especially relating to the senses of existence (represented by VR) and the acquisition of cognition (represented by AR).

In the future, 6G needs to support interactive XR services. In the 6G converged network, in order to improve the user experience of XR services, it is necessary to enhance the execution efficiency of cloud rendering and reduce the service experience delay through cloud rendering pipelines, fast encoding and decoding, transmission protocols, etc. The key processing modules are redesigned and optimized, and the transmission characteristics of the 6G mobile network are comprehensively considered to design an efficient business processing system. At the same time, it is also necessary to explore the integration of network and XR services under the 6G network architecture, such as cloud-side collaboration and other mechanisms, to ensure the high-quality user experience of XR services under the 6G network.

## 3.4 Digital twin services

Digital twin (DT) refers to interactive mapping between physical space and virtual space and the ability to clone physical objects into virtual objects. It uses sensing, computing, modeling, etc., through software definition to describe, diagnose, predict and make decisions on physical objects. The virtual objects reflect all the important properties and characteristics of the original objects.

DT service refers to the life-cycle information processing and service capability within a specific DT application scenario. It consists of five elements: physical objects, virtual objects, DT platform, DT data and DT model. Support technologies such as sensing and AI, as well as sensors and actuators equipped within physical objects are needed.

### 3.4.1 Digital twin city

Digital twin city will play an important role in the future to facilitate human life, enable high efficiency running of the society, to help conserve resources and protect the environment. Through collecting information from the urban environment via the IoT, processing information via big data, artificial intelligence and cloud computing, a digital copy of urban information can be built. In the field of public management, digital twins can be used to monitor existing public services or test future planning in a virtualized way, so as to allocate resources more effectively for smart cities. For example, by modeling the urban network, the time of on-site optimization can be saved; or by simulating the risk of urban buildings in bad weather, the architectural design can be reasonably planned in advance.

When the digital twin technologies are used to establish a city replica, two factors should be taken into consideration to determine the required digital resources. The first is spatial: whether the application needs two-dimensional or three-dimensional models. The second is time: whether the application needs static or dynamic models. Different applications need different digital twin models to balance the resources invested and the benefits obtained.

The development of digital twin technologies needs the end-to-end promotion of industrial chain, including communication infrastructure, big data/artificial intelligence platform, security standards, government and enterprise applications, etc. In order to promote the digital twin technologies, the collaborative development of ecosystem needs to be focused, instead of taking a certain subdivision technology as the main body. Hence, to support the digital twin city, the design of 6G network should consider the native integration of IT and CT technologies.

### 3.4.2 Digital twin workshop

Digital twin provides an effective way for the cyber-physical integration of manufacturing and then achieve intelligent manufacturing. Intelligent manufacturing services are expected to optimize the entire business processes and operation procedure of manufacturing, to achieve a new higher level of productivity.

Intelligent manufacturing takes digital twin workshop as most important components. Digital twin workshop is a new workshop operation mode with various concepts defined by different companies. It is mainly composed of physical workshop/devices, virtual workshop/devices, workshop service system and workshop digital twin data. It will generate more reasonable manufacturing planning, efficient production element management and precise production process control, through the two-way connectivity between the virtual and physical manufacturing devices. The key elements of digital twin workshop are data, model, and application, and the corresponding function requirements are real-time sensing, data transmission and computing.

Industrial Internet technology and the technical support of industrial Internet technology benefits for the realization of digital twin workshop along as digital twin technology.

### 3.4.3 Digital twin body

Digital twin body service refers to the predictive management on physical and psychological health and safety by mapping all the important properties and characteristics of physical body to virtual body. The key elements of digital twin body are data, model and platform. The service supporting technologies are in vivo data collecting, in vivo communication, organ modeling and behavior modeling. Body edge platform is the key enabler to achieve low information processing latency and data security. Digital twin body services can be applied into both medical and nonmedical scenarios, such as health care, drug testing, training, and city management.

## 3.5 Application Scenarios

5G, as well as AI and digital twin have been widely applied into vertical scenarios. 6G services will further extend vertical scenarios, as shown in Fig. 2.

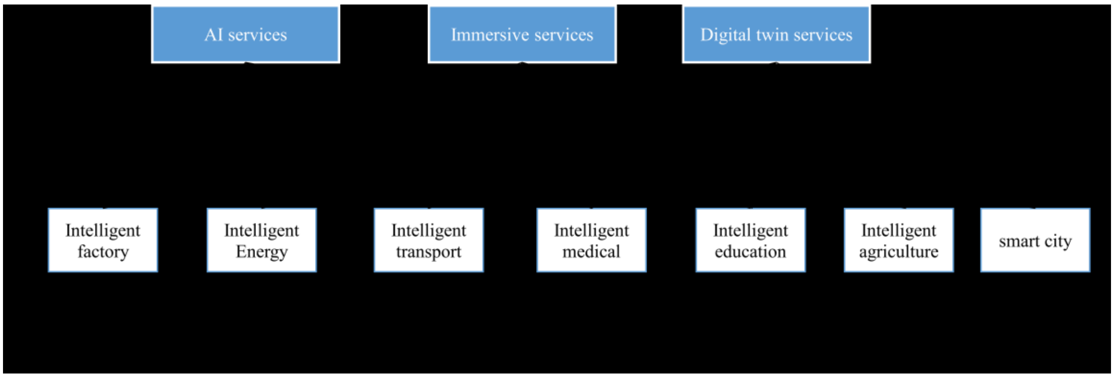


Fig. 2: 6G typical vertical application scenarios

# 4. 6G Service Requirement

## 4.1 Requirements on network architecture

6G services may demand new kinds of absolute and precise information processing attributes such as determinacy, trust and coordinated guarantees of services. This asks us to think out a novel architecture to support the services described above.

### 4.1.1 E2E service-based architecture and SDN

5G NR introduced cloud native technologies, software defined network, and service-based architecture in core network. A lot of network functions are redefined and optimized to achieve flexible network management and deployment. With the trends of AI and digital twin being applied in 6G and accurate service personalization down to the lower layers, an E2E service-based architecture should be considered to introduce micro service capabilities at edge and radio. The common functions of sensing and wireless transmission can be identified from diverse sensing technologies and devices, and wireless transmission technologies. Similarly, an E2E SDN architecture should be figured out to collaborate with E2E SBA to achieve a global resource scheduling and load balance capability.

### 4.1.2 Distributed AI architecture

6G should introduce new architecture to move from AI ‘for’ 5G to AI ‘in’ 6G as fundamental of 6G and provide ubiquitous AI capability for intelligent network and new service operation. So far, the mobile network provides mainly the connectivity of the world for information exchange. As AI becomes more powerful and widespread, the mobile network is expected to provide intelligence not just information. The intelligence refers to the human-like capabilities, such as sensing/cognitive to the world, data analysis, and making decision/reaction to the worlds, no matter in physical world or digital world.

In general, AI/ML application in mobile network aims for performance improvement, complexity reduction, or solving problems difficult to model. It will involve almost each network element and layer. It first focuses on network automation and then on RAN/air interface enhancement, optimization and reconstruction, with user cases including AI/ML “orchestration” for network slicing, “platform” for analytics application, location and MEC for emerging services, anomaly detection / correction for RAN optimization algorithms, RRM/Scheduler/PHY/BF optimization, RRM (control plane) in network layer, UP /QoE optimization in network & transport layer, scheduler in MAC layer, receiver/channel estimation in L1 high layer, digital beamforming in L1 low layer, DPD and analog BF in RF, and AI/ML cross-layer optimization involving RAN and edge cloud. Thus, accurate service personalization down to the lower layers can be achieved. A distributed multi-level AI architecture is then required to enable application layer AI, network AI, edge AI, radio AI, physical AI and terminal AI.

Besides multi-level AI architecture, various forms of ML, such as transfer learning, federated learning and deep reinforcement learning, will need to be used across different nodes or environments. AI/ML function, such as cooperative sensing, data set sharing, model sharing, cooperative learning and operation between various nodes needs distributed manner.

5G has introduced AI/ML function in its network structure, such as RAN intelligence controller (RIC) function with E2 and A1 interface in O-RAN and network data analytics function with specification of structured data in 3GPP 5G core network. Both of them employ centralized architecture, although RIC introduces two-level architecture.


Fig. 3; Distributed computing/AI/ML in 6G network

The distributed AI architecture facilitates seamless integration of context awareness into the optimization of transmission and computing schemes under the AI/ML framework, as shown in Fig.3. The context may include the attribute and state of services, network, terminals, users and environment. State prediction, long term pattern and higher-level semantic knowledge can be derived from the context with

AI/ML technology, and then used for several different use cases. Essentially, this can reduce the randomness in the communication links.

Finally, the distributed AI architecture should be designed taking into account the capabilities of the hardware, which are distributed in each network elements for transmission computing or AI/ML computing. Both the ML algorithm performance and the transmission scheme performance optimized by the ML algorithm are limited by hardware capabilities.

### 4.1.3 Space-air-ground integrated architecture

With the development of space-air-ground integrated communication technology, the space or an airborne platform processing capacity will be greatly enhanced, the payload will realize on-planet signal regeneration processing, routing and switching and other functions, this is effectively equivalent to having base station functions (e.g. gNB) on board the space/airborne vehicle. Thus, extensive and comprehensive connections can be established between different satellites through inter-satellite links, flexible and reconfigurable network service capabilities can be provided according to business scenarios and demands.

As shown in Fig.4, the future space-air-ground integrated communication network is a three-dimensional hierarchical, integrated and coordinated heterogeneous network based on the ground network and expanded by the space-based network. It adopts an unified network architecture, a unified technical system, and a unified standard specification. Satellites (including high, middle and low orbit), nearby space platforms (such as hot air balloons, drones, etc.) and ground nodes form a multi-level network architecture. All levels of networks are connected and coordinated to build a "global coverage, an integrated world-earth information network system with easy access, on-demand services, safe and reliable".

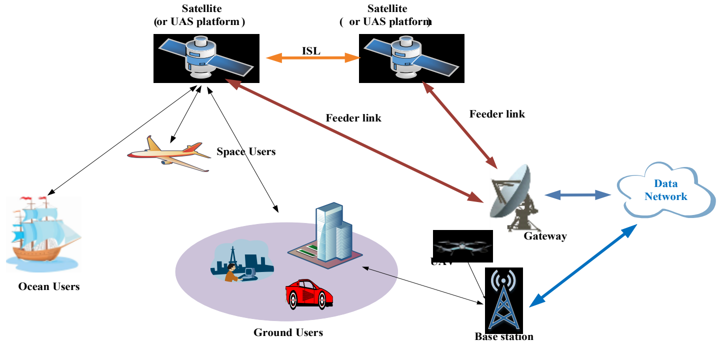


Fig. 4; Space-air-ground integrated network

The space-air-ground integrated communication network can divide into three parts: access network, bearer network and core network. The access network consists of non-terrestrial network nodes and terrestrial cellular access nodes, forming a wireless access network to covering the whole world, and meeting the network access service demands of a large number of users in a wide area of land, sea, air and space. The bearer network includes ground bearer network and satellite bearer network. Ground bearer network refers to the bearer network in the traditional terrestrial cellular communication system. Satellite bearer network consists of the satellite constellation and high-altitude platform nodes, each node has broadband transmission, routing and switching capabilities, and can completes the fast forwarding of various business data in the air network through the link between nodes. The core network consists of the edge core network deployed in non-ground network nodes and the cloud core network deployed in ground nodes. The edge core network and the cloud core network realize edge cloud cooperation through computing power scheduling.

#### 4.1.4 Integration of cloud, edge, network and terminal

To realize the 5G features, the integration of cloud, network, edge and terminal has been partially addressed for the purpose of E2E information processing. For example, E2E network slicing and cloud applications needs cooperation of cloud and network. Edge service continuity needs cooperation of edge and terminal. 5G non-public network needs cooperation of cloud, network, edge and terminal. Internet of vehicles even needs the cooperation of cloud, network, edge, terminal and road. In practical design, such cooperation can be decomposed into multi-dimensional cooperation, such as multi-access cooperation, resource scheduling cooperation, data sharing, traffic cooperation, capability exposure cooperation, security cooperation, orchestration cooperation, etc.

Integration of cloud and network refers to the cooperation mechanism where network is able to acquire the service attribute and status to optimize resource allocation, while application layer is able to learn about network attribute and status to optimize service process. It embeds computing into the network and selects the optimal computing node in context of network to ensure service QoS, such as cloud XR, cloud games, and cloud video monitoring.

Integration of cloud, network and edge refers to the deep integration of cloud computing, edge computing and network architecture, where three-dimensional network slicing is introduced to support the deep decoupling and flexible reconfiguration of the network. Computation load and traffic load will be balanced by optimizing network resources and computing task between cloud computing and edge computing according to the service requirements.

Integration of cloud, edge and terminal mainly refers to the distributed cooperative computing among cloud, edge and terminal. The interaction and cooperation within AI services, immersive services and digital twin services require multifold computing power, and the computing task should be decomposed and assigned among the cloud, edge and terminal.

#### 4.1.5 Convergence of broadcasting and communication

By adopting bi-directional, point-to-point (PTP) link and cellular structure, mobile communication network is suitable to transmit personalized content or provide interactive service, while the coverage is smaller when comparing with broadcast network and the transmission efficiency is low when it is used to provide multicast/broadcast services. Broadcast network adopts uni-directional, large coverage (usually with high transmission power) and point-to-multipoint (PTM) or multicast/broadcasting mode, which is suitable to the transmission of public media service (PMS), however, it does not have uplink return channel, which cannot realize personalized and interactive services such as Video-on-Demand (VoD), Virtual Reality (VR) and conversational video.

With the development trend of video content to ultra-high definition (UHD), multi-dimensional (3D or VR) and conversational, network video will bring more and more traffic to the network. In the communication network, when a lot of users watch video programs at the same time, the limited spectrum resources and transmission capacity will not be able to withstand the high traffic load and high concurrent level requirements. Therefore, it is necessary to aggregate the same video stream and transmit it by multicast/broadcast, which will greatly reduce the traffic load, save bandwidth and release spectrum resources of network.

With the convergence of broadcast and communication, video content can be transmitted to the mobile terminal in a way compatible with the underlying technology of mobile communication. One modem chip can not only send/receive communication signals, but also receive broadcast signals. Users can watch broadcast TV programs anytime and anywhere without generating any data traffic cost.

Broadcast and communication converged network not only can provide common content and public services with broadcast mode, provide personalized and interactive services with communication mode, but also can schedule content and handover user between the two modes, and optimize the use of transmission resources according to the content favorite degree, user mobility and network coverage.

In the future, 6G network will be required to be able to schedule wireless resources intelligently and dynamically according to the content, network and user states, and utilize transmission modes such as uni-cast, multicast and broadcast in a convergence manner to provide efficient transmission services.

## 4.2 Requirements on network capabilities

### 4.2.1 Enhanced wireless transmission and coverage

6G should further enhance wireless transmission performance to meet the tighter requirements of 6G services on data rates, reliability, delay, global coverage and micro-space coverage.

In order to reduce the transmission delay, 3GPP R15 has specified a shorter time slot frame structure, smaller scheduling resource unit, flexible scheduling cycle and feedback mechanism, and priority mechanism that can occupy eMBB resources. R16 proposes a two-step access mechanism and a solution to the conflict between control information and data information transmission resources. R17 will further discuss the two-step access mechanism in inactive state. For 6G services, it is necessary to guarantee the mixed transmission delay of multi-dimensional data. Usually, this kind of service has a clear task context, so the traffic has a priori behavior characteristics, such as message size, sending cycle, life cycle and moving trajectory. Using ML, BS can reserve and optimize wireless resources according to these characteristics.

3GPP R15 improves reliability by simplifying DCI process, introducing multi-antenna single stream diversity, multi-TRP spatial diversity and multi-channel frequency diversity with PDCP replication. R16 further improves the number of logical channels for PDCP replication, increases the redundancy transmission diversity ability of TRP with frequency division and time slot division, and proposes a dual-connection transmission scheme through multiple user planes and multiple routings. R17 further enhances the feedback mechanism of physical layer, specifies uplink multiplexing scheme for UCI and data to solve the compatibility problem with unauthorized spectrum. The diversity technology based on multi-connection can achieve better reliability performance. In theory, multi-connection scheme can be implemented at any layer of the protocol stack, such as physical layer, PDCP layer or routing layer. The end-to-end reliability can be guaranteed by network slicing and multi-slice transmission and non-public network. Furthermore, multiple routing channels can be established with non-3GPP networks. Finally, the sensing ability of millimeter wave radar and camera can be used to assist wireless transmission to improve transmission reliability.

Terahertz communication and visible light communication can be introduced into the short-range scenarios. These two communication technologies have rich spectrum resources, can provide higher data rates and form multiple connections with low frequency bands to effectively guarantee low delay and reliability.

6G is expected to provide wide-area three-dimensional coverage, and realize ubiquitous connections in diverse scenarios such as sky, ocean, remote areas, human body and micro-space through rich connection technologies such as space-air-ground integrated communication, and molecular communication. 6G is expected to support the dynamic coverage capabilities of target areas, users, and applications and meet the energy-saving requirements through coverage expansion.

### 4.2.2 Native sensing

6G should provide a multidimensional ubiquitous sensing capability for information acquisition at both network and terminals. Information acquisition is an essential prerequisite to information processing and services. Generally, it refers to the behavior of information collection from sensing objects by using sensing devices, data interface, and/or the ability of data analysis. Generally, sensing includes positioning, tracking, imaging, synchronization, detection, recognition, etc. It mainly collects the attributes and states of target services, users, network, terminals, and environment.

Information acquisition aims to provide data as service content, or big data for model training and reasoning. It can also be an underlying function to provide the parameters to enable transmission and computing. For example, channel state information estimation using reference signal and terminal positioning using positioning reference signal are actually the native sensing capabilities for 5G. Sensing can also provide connection function to replace or enhance wireless transmission in certain scenarios.

All the network entities and terminals should be embedded the sensing capabilities through data sharing interface, or by being equipped with sensing devices, such as radars, camera, detection devices, positioning modules, and other kinds of sensors.

#### 4.2.3 Native computing

6G should embed computing capabilities into network to meet the requirements of 6G services on ubiquitous computing. In a broad sense, computing refers to the calculation behavior for a specific task through special or general hardware and software. In addition to the computing work related to sensing and transmission, computing mainly includes application layer processing, data storage, big data analysis, machine learning with modeling, reasoning and decision-making, etc.

Native computing means the computing resources can be scheduled in a way similar to network resources and can be jointly scheduled with network resources. Abundant network resources and computing resources will continue to integrate and complement each other, providing the ultimate user experience for new services and computing services. Namely, computing is the basic resource, capability and service of 6G.

Cloud computing, edge computing, terminal computing, and fog computing are common computing paradigms. 6G should support distributed cooperative computing and address the problems of heterogeneous computing environment. Computing-aware network is a framework solution on how to realize native computing and provide computing services. Through the API call mode, it provides real-time calculation service with ultra-low delay at the nearest edge node, and non-real-time calculation service at cloud node. Ubiquitous field-level edge computing provides users with intelligent access and real-time data processing, and network-side edge computing provides users with rich computing power.

#### 4.2.4 Native AI

6G should provide a native AI capability to support intelligent information processing and services and network self-X. Native AI refers to the capabilities of data collection and sharing, and machine learning (ML) within the network. The key factors of ML are data, computing power and algorithm. So, native AI means each network nodes and terminal will have abundant or partial resources of sensing, communication and computing to perform complete or partial functions of data collection, model training, reasoning, and decision-making.

The basic ML architecture used in B5G/6G network includes two parts as illustrated in Fig. 5: training part which inputs with training data and generates trained model, and inference part which inputs new data from real network and make decision with trained model.

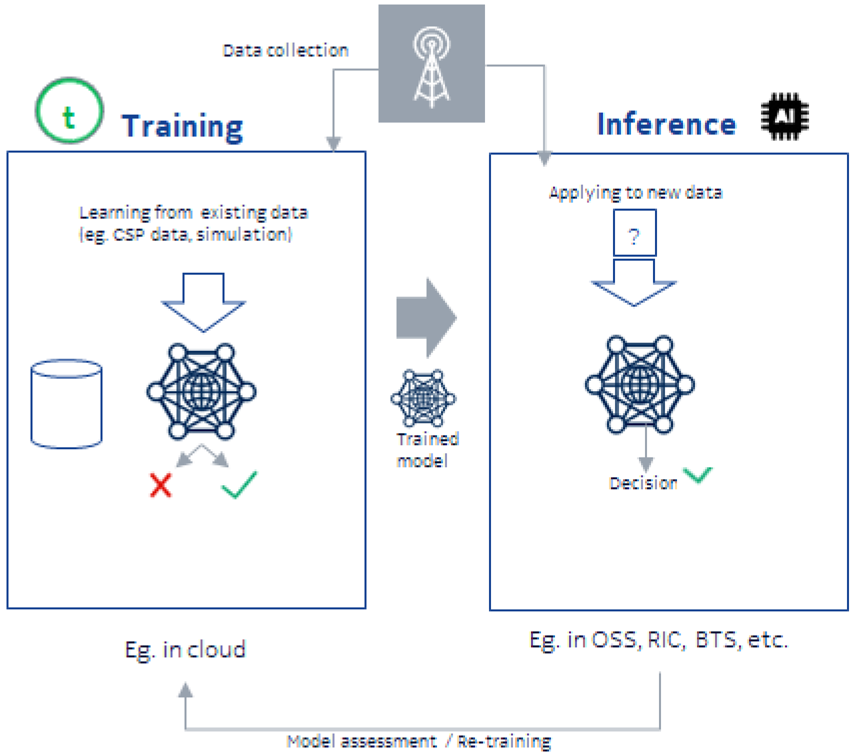


Fig. 5; Typical ML architecture in 6G

The availability of data is crucial for both inference (using the model) and training (creating the model). The requirements for data collection depend on the choice of algorithm, as well as the platform on which it is run. For example, for short latency applications, the data must be available when the application needs it. On the other hand, in high-performance parallelized training environments, ensuring an adequate volume of data is just as important as timing.

Furthermore, a unified framework is needed to manage models in training and inference. Fig. 6 shows a typical example. In this framework, Inference is performed within the endpoints. Training of models can take place either online (continuous training) or offline (discrete training). The continuity of the inference model needs to be balanced with the processing needs of training.

Normally, Training part needs a dedicated infrastructure which have huge processing power, storage capability and can be off-line. Re-training may be required to update the ML models. Eventually the dynamic training will enable to do re-train the models every time.

The inference is the execution environment. It may occur is different layers: OSS, Edge/RIC, BTS according to latency targets.

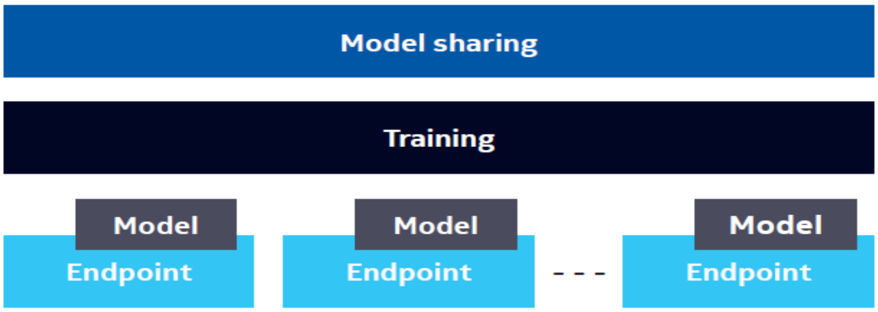


Fig. 6; Typical ML framework in 6G

6G native AI supports model sharing in a distributed inference environment consisting of multiple endpoints. Model sharing targets to improve efficiency for training. The simplest way of using ML is based on inference combined with offline training. In this approach, the model used in inference is trained (or re-trained) with data representative of real-world use.

Models can be trained only on data relevant to a single endpoint or the data encountered by other endpoints. For the latter, transfer learning can be used to share models across sufficiently similar contexts. Transfer learning can be used to improve training performance, using a model pre-trained with either simulations or a sufficiently similar context. If the two contexts are similar enough, the inference model from one context may be used directly in another context, without training. Another option is federated learning, which combines distributed on-line learning with global combining of model updates.

On-line learning can be used to continuously update the inference model with input data. Ideally, federated learning would allow locally learned models to be shared with other inference contexts. The limited size of hard real-time inference models restricts how complex the model can be, limiting the use of federated learning in constrained environments.

Computer simulations can be used to aid model training. A coarse-grained simulation model can be used to train the lowest layers of a feed-forward network, corresponding to the major phenomena that a DL model could encounter in real life. A more advanced approach is a digital twin for a part of a network, which simulates advanced features such as propagation models and mobility patterns. Such a simulation can be used to give the DL model more detailed training.

ML and DL benefit from hardware acceleration. In inference, specialized edge inference accelerators allow the use of low-latency ML based control loops. For offline training, general-purpose hardware accelerators such as parallelized Graphics Processing Units (GPUs) help train models with relatively large data volumes.

Network virtualization and service-based architecture (SBA) introduced in 5G NR provides the opportunity with AI to diagnose and analyze the operation states of network and services with the finer granularities optimize the operation in a more effective manner.

Due to near exhaustion of sub-6GHz spectrum bands, new spectrum and new methods to use them are required in 6G. With the AI capabilities, autonomous spectrum sharing and reuse can be achieved with advanced multiband operation, beamforming and densification. This allows various forms of coexistence among cognitive sharing systems.

6G native AI is expected to provide zero-teach O&M. This means 6G network is self-X: self-organization, self-deployment, self-learning, self-evolution, self-immunity, etc. In these cases, AI/ML will be a much more integral part of the B5G/6G network as well as the management architecture. Thus, e.g., ML models and their respective training need to be managed as part of network operational procedures, and their use with location and time has to be orchestrated/coordinated in a multi-vendor way.

### 4.2.5 Deterministic information processing

6G should provide a deterministic information processing capability to ensure the requirements of mission-critical services on determinacy. Determinacy mainly refers to the bounded delay and higher reliability. To meet the E2E latency and reliability requirements of a target task, information processing must take into account the processing delay of transmission, as well as sensing and computing. So, deterministic information processing includes deterministic sensing, deterministic transmission, and deterministic computing. This implies the network transformation from resource- based to task-based.

Sensing is a typical field-level information acquisition processing, no matter for the internal sensors and external sensors which are equipped within ATs and BSs. 6G services depends on these sensors with sensing on time and in time. Compared with the E2E information delivery and distributed information computing, the main performance of deterministic sensing is the sensing response time with a certain sensing accuracy and range. In cooperative sensing for cooperative ML, deterministic sensing also means the time synchronization among ATs and among the internal sensors.

Deterministic transmission has been discussed preliminarily in 3GPP with focus on latency and jitter control. IEEE began to study TSN network since 2006, and has been expanding from audio and video field to industrial field, IoV field and MNO's transport network. The key issues for TSN are time synchronization, traffic scheduling, and network control. 3GPP R16 defined integration architecture of TSN and 5G network to provide key industrial IoT functionality.

DetNet is the generalized TSN applied into the IP and MPLS networks. It is composed of terminal node, edge node and forward node that jointly provide DetNet services. These nodes are interconnected through transport nodes (i.e., routers) as an endpoint, and connected to the subnets. These subnets, such as TSN and OTN, support DetNet flows. Multi-layer DetNet is possible, where one underlying DetNet appears as a subnet and provides services for higher-level DetNet. In DetNet, critical data streams with extraordinarily low packet loss ratios and E2E latency are guaranteed though resource reservation (node buffers, node schedulers, and link bandwidth) via configuration, management and protocol action. Critical data streams and other best-effort streams can co-exist within a single network if the former do not take up too much network resources.

TSN is also introduced into 5G network for the deterministic fronthual. Moreover, the work item "deterministic mobile networking" has been set up in ETSI to identify the requirements of 3GPP mobile network towards deterministic networking capabilities for URLLC applications. Its target is to provide holistic architecture including functions, interface and protocol to realize E2E deterministic transmission across RAN, core network, backhaul or transport and virtual networks within data center. Base on this, 6G is expected to be a deterministic network.

Deterministic computing refers to the information computing on time and in time within a task process. An integration of cloud, edge and network, as well as computing task assignment and computing resource allocation algorithms are needed to ensure deterministic computing.

The features of deterministic sensing, deterministic transmission and deterministic computing are respectively field-level processing, E2E processing and distributed processing.

4.2.6 Native capability exposure

6G should support capability exposure to provide essential capabilities and information to/from the third-party application and service providers. Capability exposure enables highly efficient resource utilization, tight coordination between networks and services, more optimized customer experience and more service models.

In 3GPP R15, network exposure function (NEF) has been defined to provide standard services for application function (AF), such as QoS capability, event monitoring, parameter configuration, device triggering, traffic guidance, etc. R16 specification further enhances these services At the same time, it also adds some new services such as non IP data delivery, data analysis, network status, IPTV configuration, etc. Besides, more network capabilities are abstracted out for application layer including network slicing service, edge computing service, location service, 5G voice and message, data analysis service, and AI service. These service capabilities will have a wide range of vertical application scenarios.

In addition to these capabilities, the integration of sensing, communication and computing will introduce sensing services, synchronization services, 3D positioning services, ML services, as well as the information and data services, such as the attribute and states of users, service, network, and terminals.

The capability exposure architecture contains three layers: application layer, capability layer and resource layer. Application layer is the demander of network capacities, and an API interface is used to bridge the demand and the open capacities. The demand on the capability exposure in terms of sensing, computing, positioning and synchronization is triggered by the 6G emerging services.

The capability layer interworks with the application layer through northbound interface and connects with the resource layer through southbound interface. It is the core layer of capability exposure and primarily responsible for capability modeling and encapsulation, capability orchestration and O&M, and capability announcement.

Resource layer completes the abstract definition of the underlying network resources, gathers the information and data on control plane, user plane and AI plane, as well as the information about the attribute and status of users, network, cloud, edge, and terminals, performs parameter configuration and resource scheduling according to the call logic and strategy of resource and capability from the upper layer.

### 4.2.7 Native Security

6G will meet the security challenges of multifold interconnections and cooperation among massive heterogeneous nodes and terminals. To address this, 6G should provide native security capabilities for trusted information processing and services. Native security means zero trust, active defense and self-immunity. Its features include trusted nodes, terminals and users, expected relationships, and authentic connections. Trusted information processing includes trusted sensing, trusted transmission and trusted computing.

Identity authentication and authorization are the enablers for trusted user and terminal to realize trusted interconnection and cooperation among sensors, ATs, base stations, routers, edge servers, cloud servers and other heterogeneous nodes. It specifies how resources can be accessed by trusted users.

6G should introduce software defined security (SDE) to achieve security function reconfiguration and resilient network. Based on SDN, SDE can quickly build logical, sliced, virtual and spatial boundaries for diverse services and traffic according to their requirements. In this way, user/tenant-centric network security and multi-service security isolation on the same terminal can be realized.

When the attack and disaster occur, SDE will isolate the logical or spatial "epidemic area" and "disaster area" to block the spread of attack and disaster, ensure the normal operation of basic functions, and also meet the emergency communication needs. Furthermore, based on AI and big data technology, and the ubiquitous collaboration across terminal, edge, network, and cloud, active defense can precisely reconfigure the security functions and optimize security strategies to achieve highly reliable attack detection and perception, and automatic and intelligent security response and defense. In the white-box attack environment, the white-box cryptography is presented to protect the key information.

6G native security supports privacy protection and digital asset protection and fast transaction security. This will bring the development of new data business models.

### 4.2.8 Resource sharing and multi-party cooperation

6G should introduce blockchain technology to promote trusted resource sharing and service cooperation among multiple parties. The resource sharing of sensing, communication, computing and data, as well as the generated new capabilities such as cooperative sensing, cooperative communication and cooperative computing, are crucial for improving the 6G service quality and capability and expanding the 6G service scenarios and modes.

For AI services, Blockchain technology can build an open AI platform to share and trade data, algorithms and computing power. Users can complete the transaction of data usage right with the data demander through smart contract, so as to ensure data privacy and obtain benefits. Users can process data by calling functions and return the results to the demander, or provide encrypted data to the demander through trusted computing. Some new AI services can collect more high-quality user data through crowdsourcing and incentive. Based on abundant data, AI service providers can develop algorithms and models for trading. The challenge arena mechanism can be introduced into the smart contract to develop the algorithm with better performance. At the same time, users can share their idle computing and storage resources to support AI services. Through the incentive mechanism, AI service providers can obtain better data, better models and more powerful computing power, thus can provide richer AI services and applications. Furthermore, AI service terminals (i.e. ATs) will also gain the ability of evolution, form more powerful ATs, and even form AI organizations through task division and cooperation.

For digital twin services, blockchain can provide reliable data storage. In fact, many blockchain-based applications have the characteristics of digital twin. For example, both supply chain and food traceability applications based on blockchain record the status from all aspects of production, storage, transportation and sales. The identity and status of assets on the chain are equivalent to the digital twins of data off the chain. For another example, blockchain can be used to save patient's case data and daily physical characteristics data in different hospitals. Doctors can build digital twins of whole or part of their organs for patients to make diagnosis or treatment plans based on these data. In some scenarios, the digital twin itself has the attribute of digital assets, and its value can be realized through blockchain transactions. The transaction of ownership or use right of physical entity may also be accompanied by the transaction of its digital twin.

Furthermore, in addition to individual resource sharing, there are also a large number of multi-party cooperation and resource sharing scenarios, especially the resource sharing of spectrum, BS, backbone network, cloud computing/edge computing, sensors among different asset operators, as well as the resource sharing of sensing, computing and communication between terminals. Based on the blockchain trading platform, more asset operators or individuals join in the multi-party collaborative services and resource sharing, thus stimulating new 6G services and applications.

## 4.3 Requirements on key performance

### 4.3.1 Peak/ User experience data rate

6G networks will face the challenges of higher peak/user experience data rate from AI services, digital twin services and immersive services.

In the future, XR devices will bring richer experiences and achieve more complex services, which put higher requirements on communication. To meet such requirements, more advanced technologies are needed. The frame image format in the rendering process is RGBA. In order to provide a higher fidelity VR image, the picture resolution is 24k for both eyes and the frame rate is 120fps, 18 bits per pixel according to YUV color coding. With the development of coding standards, the compression ratio is expected to be 500. According to above parameters and time delay in each process, the user experience data rate is calculated to be 1.6Gbps.

Digital twin city is a typical application scenario of digital twins, in which the real-world data will be extracted and utilized. And the whole process includes data extraction, simulation modeling, visual presentation and computing platform, where the extracted data will be summarized to the computing platform. Then user experience data rate will be evaluated according to the amount and frequency of extracted data. For an example, Shenzhen, with area of 1953 square kilometers, currently is covered by 400,000 cameras. By 2030, the camera resolution is predicted to be 16K*16K. And the acquisition frequency and coding compression ratio are expected to be 120 fps and 500, respectively. Finally, based on the above parameters, the user experience data rate is estimated to be 2.38Gpbs.

In digital twin body, the device density will be far greater than 100 per person, and it will increase by thousands of times in subsequent process. Limited by transmission power and equipment manufacturing difficulty, the user experience rate of twin body area network is difficult to reach terabit. However, the user experience rate should be no less than 1 Gbps so as to support various applications in digital twin body.

Holographic type communication (HTC) reconstructs the original 3D image by reformatting, storing, transmitting, receiving and calculating. Taking the 3D image with original pixel size of 1920×1080×50 as an example, RGB data is 24 bit and refresh rate is 60 fps. After processing with a compression ratio of 500, the user experience rate is about 167 Gbps.

To sum up, the user experience rate requirements of four typical services have been analyzed. On the basis of 5G communication, the peak rate is considered to be an order of magnitude higher than the user experience rate. Then the user experience rate and peak rate data rate are summarized in Table 1.

| | Cloud VR | Digital twin city | Digital twin body | HTC |
|---|---|---|---|---|
| User experience rate | DL:1.6Gbps | UL:2.38Gbps | UL:1Gbps | DL:167Gbps |
| Peak rate | DL:16Gbps | 23.8Gbps | UL:10Gbps | DL:1670Gbps |

Table 1. User experience rate and Peak rate

In addition, ultra-high-definition (UHD) video is a new round of major technological innovation after video digitization and high definition. China Media Group officially launched the 4K UHD TV channel named "CCTV-4K" on October 1, 2018, which transmits 4K UHD TV signals through satellite distribution and cable transmission. The video format is 3840x2160, 50fps, 10bit, BT.2020 color gamut and HLG conversion curve. Encoding adopts AVS2, and the video encoding rate is 36Mbps. The technical parameters and transmission requirements of UHD TV are shown in Table 2.

| **Classification** | **Technical Parameters** | **Coding Standard** | **Encoding Rate** |
|---|---|---|---|
| 4K UHD TV | 3840x2160,50p, 10bit, BT.2020 color gamut, PQ/HLG | H.265/AVS2 | 36Mbps |
| 8K UHD TV | 7680x4320, 50p, 10bit, BT.2020 color gamut, PQ/HLG | H.265/AVS2 | 85Mbps |
| | | H.266/AVS3 | 60Mbps |

Table 2. The technical parameters and transmission requirements of UHD TV

### 4.3.2 Synchronization

Synchronization is the primary condition to achieve low latency, high reliability and deterministic transmission. It is inevitable that 6G networks will require more and more synchronization accuracy in the future. Some special services may require higher precision for time synchronization, reaching several hundred ns or even tens of ns. In order to support immersive services, multiple transmission paths or data streams with diverse geo-locations are expected to be synchronized appropriately with limited arrival time differences, usually at the level of ms time interval.

Additionally, many machine control applications are multi-axis applications requiring time synchronization to manage the complex position relationships between axes and permit cooperation between various devices. For the real-time feedback from hybrid sensory inputs, which possibly arise from different locations, must be strictly synchronized. In case of unmanned manufacturing, synchronization accuracy between machine tools should meet the requirements of 1us.

#### 4.3.3 Positioning

Accurate localization is one of the most important features in the future mobile networks. With the growing demand of both vertical and horizontal localization services, the current solutions cannot solve the 3D-positioning problem. For instance, as the size of shopping malls is growing larger, the customers are facing increasing difficulties in finding shops, meeting people and locating vehicles. To address such issue, 3D-indoor positioning will play an important role, and the expected localization accuracy will reach sub-meter even centimeter level. Besides, with further development in autonomous driving, accurate and precise positioning services are required in such intelligent transport systems to improve transport efficiency. Regarding ultra-high-speed scenarios, ultra-high-precision positioning with sharp response is required for protecting passenger's and pedestrian's safety. In order to support aforementioned features, the outdoor positioning needs to reach meter and later sub-meter accuracy. Furthermore, in order to achieve robots-enabled activities such as remote surgery and intelligent manufacturing, sub-centimeter/millimeter accuracy will be inevitable needed. With these scenarios in mind, a few enabling technologies need to be developed, including very large-scale antennas, terahertz communication and visible light communication, as well as the enhancement of autonomous things (ATs) sensing technology.

#### 4.3.4 Deterministic latency and reliability

6G should support E2E information processing latency reduction and ensure bounded latency to achieve deterministic latency. Deterministic latency here takes into account sensing latency, transmission latency and computation latency with multiple parameters relative to fixed timing.

Sensing is a typical field-level information acquisition processing, no matter for the internal sensors and external sensors. The main performance of deterministic sensing is the sensing response time at 1ms level with a certain sensing accuracy and range. The transmission latency is anticipated to be below 1ms as one of 6G KPIs to help deterministic transmission. Deterministic computing refers to the information computing on time and in time within a task process. The computing latency depends on application computing and computing resource allocation algorithms.

Unmanned services and applications typically demand low E2E latency ranging from sub-ms to 10 ms, and small jitter at 1µs level to meet the critical closed loop control requirements. Regarding unmanned manufacturing, the deterministic transmission between machine tools should meet 100us requirement. In terms of XR services, the E2E latency is anticipated to be at 40ms level, with transmission latency below 10ms, and the computing latency at 10ms level, which mainly consists of video coding/decoding latency, rendering latency and displaying latency.

3GPP R15, R16 and R17 respectively target to support 99.999%, 99.9999% and 99.999999% air interface transmission reliability under given constraints. The transmission reliability is anticipated to achieve 99.9999999% as one of KPIs for 6G.

Regarding unmanned manufacturing, the deterministic transmission requirements with other KPI requirements are described for several user cases in Table 3.

| Use case | E2E latency | Jitter | Reliability | Clock synchronicity | Transfer Interval | Service area |
|---|---|---|---|---|---|---|
| Close-loop control | <10ms | 0.5ms | 99.999999% | <1us | 10ms | 100x100x50 m |
| Motion control | <0.5ms | 0.5 μs | 99.999999% | <1us | 0.5ms | 50x10 x10m |
| Mobile robot | <10ms | 2.5ms | 99.999999% | <1us | 10ms | <1km$^2$ |
| Mobile controller | 10ms | 2.5ms | 99.999999% | <1us | / | 50x10 x4 m |

Table 3. Requirements examples for unmanned manufacturing

#### 4.3.6 Mobility and service continuity

Service continuity refers to the service availability under a dynamic environment. Availability of 99.999% is expected as one of 6G KPIs. The continuity includes coverage continuity, sensing continuity, computation continuity and application continuity. Coverage continuity refers to the access point handover, sensing continuity refers to sensor handover or mobile sensing, computation continuity is for computing task reassignment, and application continuity is for application relocation.

Especially, 5G can support communication services with a user terminal movement speed of 500 km/h. Regarding airplane as terminal to access network, the movement speed can reach 1000km/h. Non-Terrestrial Networks (NTN), integrated space-air-ground network, as well as dual-connectivity mechanisms can expand the network coverage to reinforce the service availability.

Besides communication coverage enhancement, technologies to improve sensing coverage, computing power availability should be considered.

4.3.7 Computing power level

6G should support heterogeneous computing environment in terms of FPGA, CPU, GPU, ASIC, etc. More peak computing power requirements usually come from accelerators. AI modeling and holographic display are the bigger demanders for computing power. For example, holographic meeting needs about 50TOPS, and holographic map needs about 200TOPS.

## 4.4 GAP analysis

6G will have great innovation in network architecture. The architecture gap is summarized in Fig. 7.

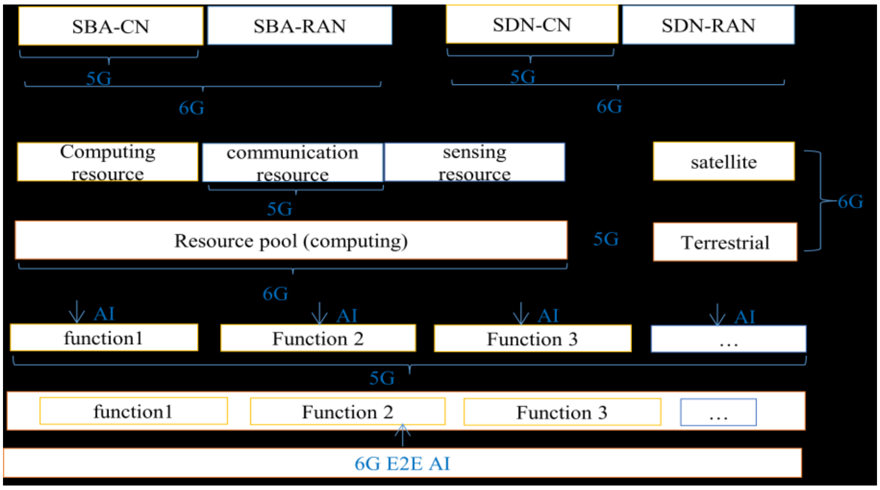


Fig. 7; The architecture gap between 5G and 6G network

6G will have more native capabilities as the enhanced wireless transmission capability, which are lacking in 5G network. The new capabilities, such as sensing, computing, AI, security will be designed in the same way as communication in terms of procedure and resource scheduling. All in all, the E2E information processing is the main capability gap between 5G network and 6G network.

6G will have tighter key performance, not only on the inherited function from 5G, but also on the new function to be introduced in 6G. Compared with 5G, the peak data rate will be improved 50 times. The E2E latency will reach ms level. The positioning will achieve sub-meter level and 3D positioning accuracy will reach millimeter level. The mobility will reach 1000km/h.

In summary, there is a clear gap between the 6G service requirements and the 5G network in terms of architecture and capabilities. This accelerates the research and development process of 6G new technologies.

## 5. Summary

This paper discusses the driving forces, trends and features of 6G services under the trend of deep integration of ICDT. AI services, immersive services and digital twin services, as well as typical vertical application scenarios and use cases are identified. The design suggestions of 6G network architecture and functions are proposed based on the common requirements of sensing, communication and computing. Some illustrative key performance indicators of 6G are listed according to the requirements of some representative services.

# References

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# List of Abbreviations

- **6G** The Sixth Generation Mobile Communications
- **AI** Artificial Intelligence
- **AR** Augmented Reality
- **ATs** Autonomous Things
- **BCI** Brain Computer Interaction
- **DL** Deep Learning
- **eMBB** Enhanced Mobile Broadband
- **eMTC** Enhanced Machine-Type Communication
- **ICDT** Information, Communication and Data technology
- **IoT** Internet of Things
- **HMI** Human-Machine Interface
- **ML** Machine Learning
- **MMI** Machine-to-Machine Interface
- **MR** Mixed Reality
- **NR** New Radio
- **QoE** Quality of Experience
- **RAN** Radio Access Network
- **RIC** RAN intelligence controller
- **RRM** Radio Resource Management
- **UAV** Unmanned Aerial Vehicles
- **UHD** Ultra High Definition

- **URLLC** Ultra-Reliable and Low Latency Communication
- **VR** Virtual Reality
- **XR** Extended Reality

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