5G-Advanced Technology Evolution from a Network Perspective 2.0(2022)

——Towards a New Era of Intelligent Connect X

Abstract

The commercialization of 5G networks is accelerating globally. From the perspective of industry development drivers, 5G communications are considered the key to personal consumption experience upgrades and digital industrial transformation. Major economies around the world require 5G to be an essential part of long-term industrial development. 5G will enter thousands of industries in terms of business, and technically, 5G needs to integrate DOICT (Data Technology, Operation Technology, Information technology and Communication Technology) and other technologies further. Therefore, this white paper proposes that continuous research on the follow-up evolution of 5G networks— 5G-Advanced [1] is required, and full consideration of architecture evolution and function enhancement is needed.

This white paper first analyzes the network evolution architecture of 5G-Advanced and expounds on the technical development direction of 5G-Advanced from the three characteristics of Artificial Intelligence, Convergence, and Enablement. Artificial Intelligence represents network AI, including full use of machine learning, digital twins, recognition and intention network, which can enhance the capabilities of network's intelligent operation and maintenance. Convergence includes 5G and industry network convergence, home network convergence and space-air-ground network convergence, in order to realize the integration development. Enablement provides for the enhancement of 5G interactive communication and deterministic communication capabilities. It enhances existing technologies such as network slicing and positioning to better help the digital transformation of the industry. In Dec 2021, 3GPP SA plenary meeting confirmed the content of release 18 studies in SA2. Therefore, this white paper is updated to 2.0 accordingly to include the latest technical study progress.

Source Companies

China Mobile, China Telecom, China Unicom, China Broadcasting Network, SK Telecom, CAICT, Etisalat UAE, du UAE, Omantel, STC KW, Zain
Huawei, Ericsson (China), Nokia Shanghai Bell, ZTE, CICT, Samsung, Asia Info, vivo, Lenovo, IPLOOK, UNISOC, OPPO, Tencent, Xiaomi,

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01 5G Development

1.1 Progress

The global commercial deployment of 5G networks is in full swing. By end of 2021, 200 5G networks in 78 countries and regions have been commercially released [2]. On top of this, over a thousand industry-specific applications have been projected to benefit from the advantages offered by 5G, such as high bandwidth, low latency, and strong connectivity. In terms of connectivity specifically, GSMA predicts that 5G will boost the massive number of connections from 200 million in 2020 to 1.8 billion in 2025[3].

Overall, the global 5G industry is still in the early stages of network construction. The industry generally believes that "the future 6G technology" will not be applied until 2030. Therefore, whether in terms of business scenarios, network technology, industrial progress, deployment pace, etc., the next 3 to 5 years will still be critical for 5G development.

For this reason, 3GPP initially determined 5G-Advanced as the concept of 5G network evolution at the PCG #46[1] meeting held in April 2021. In the future, all aspects of the telecommunications industry will gradually improve the framework and enrich the content for 5G-Advanced starting from R18.

In the process of end-to-end 5G-Advanced network evolution, the evolution of the core network plays a pivotal role. On the one hand, the core network is connected to various services and applications, which is the convergence point and hub of the entire network business and the assistor of future business development. On the other hand, the core network is connected to various standard terminals and access networks, the whole network topology. The center moves the entire body. Therefore, promoting 5G core network technology and architecture evolution based on actual business needs will help operators improve return on investment and help industry users better use 5G networks to achieve digital transformation.

At the 3GPP SA plenary meeting in December, 28 2021, study/work items for release 18 in SA2 were determined by voting. The participants included operators, network equipment vendors, terminal and chip suppliers. This fully reflects the industry's extensive participation in and attention to 5G-Advanced core networks. The release 18 contents include XR and media services, edge computing, AI-based service and network automation respectively represent expectations for new 5G services, network architecture, and network digital transformation.

According to the follow-up work plan of 3GPP, stage-3 of R18 will be frozen at the end of 2023.Therefore, it is expected that early commercial deployment of networks with 5G-Advanced capabilities may begin in 2024/25.

1.2 Driving Forces

1.2.1 Industries Requirement

Unlike previous generations of communication networks, 5G is considered the cornerstone of the industry's digital transformation. The world's major economies have requested 5G as an essential part of long-term industrial development.

For example, the European Union proposed the 2030 Digital Compass plan, which formulated outlines for commercial digital transformation and public service digitalization. It adopted 5G as the basis for Industry 4.0. As the first country to deploy 5G, South Korea has further strengthened the construction of a 5G+ converged ecosystem and promoted 5G united services. Japan continues to promote the value of B5G (Beyond 5G) to people's livelihood and society. China has also put forward a long-term goal for 2035 driven by insisting on scientific and technological innovation and deepening the "5G + Industrial Internet" as its important current goal.

Therefore, 5G-Advanced needs to fully consider the evolution of the architecture and enhance functions, from the current consumer-centric mobile broadband (MBB) network to the core of the real industrial Internet. However, it is currently possible to use network slicing, edge computing, and NPN (Non-Public Network) to serve the industry. Whether it is network deployment status, business SLA (Service Level Agreement) guarantee capabilities, easy operation and maintenance capabilities, and some auxiliary functions needed by the industry, the current capabilities of the 5G network are still insufficient. Thus it needs continued to be enhancements in 3GPP R18 and subsequent versions.

First of all, in the future, XR (Extended Reality) will become the main body of business carried by the network. Not only will the definition of XR be upgraded from 8K to 16K/32K or even higher, AR (Augmented Reality) business scenarios for industry applications will also evolve from single-terminal communication to multi-XR collaborative interaction and it will develop rapidly beyond 2025. Due to the impact of business traffic and business characteristics, XR services will put forward higher requirements for SLA guarantees such as network capacity, low-bounded delay, and bandwidth. At the same time, essential communication services still have a lot of room for development. Multi-party video calls and virtual meetings represented by telecommuting will become the norm. The current conference mode of fixed access and video call will transform into a multi-party remote collaboration of mobile access and rich media and real-time interaction in business. For example, corporate employees can access the corporate office environment with virtual images at any time at home and communicate with them. Colleagues communicate efficiently. Therefore, 5G-Advanced needs to provide an upgraded network architecture and enhanced interactive communication capabilities to meet the business development needs of the existing clear voice-based communication methods evolving to full-aware, interactive, and immersive communication methods. It should also enable consumer experience upgrade.

Second, industry digitization has brought about a much more complex business environment than consumer networks. Businesses in different industries, such as the Industrial Internet, Energy Internet, Mines, Ports, Medical Health, and Transportation, need the network to provide them with a differentiated business experience and provide deterministic SLA guarantees for business results. For example, the Industrial Internet requires deterministic communication, with upper and lower bounded delays. Intelligent grids need high-precision clock synchronization, high isolation, and high security. Mines need to provide precise positioning under the surface.Ports need remote gantry crane control.Medical health needs realtime diagnosis and treatment information, synchronization and support of remote diagnosis with ultra-low latency.Transportation needs low latency network to support remote driving and vehicle platooning. Therefore, 5G-Advanced needs to fully consider the deterministic experience guarantee for industry services, including real-time service perception, measurement, scheduling, and finally forming an overall closed control loop. For different industries, 5G needs to adopt public networks, local private networks, and various hybrid networking modes to meet the industry's business isolation and data security requirements. Therefore, 5G-Advanced should focus on the network architecture, networking scheme, equipment form, and service support capability that matches the diverse and complex business environment.

1.2.2 Network Technology Evolution

The 5G-Advanced evolution is technologically presented as a comprehensive integration of ICT technology, industrial field network technology, and data technology.

The communication network after 4G fully introduces IT technology, and the telecom cloud is generally used as the infrastructure. In the actual telecom cloud landing process, technologies such as NFV (Network Functions Virtualization), containers, SDN (Software Defined Network), and API (Application Programming Interface)-based system capability exposure have all received actual commercial verification.

On the other hand, the network edge is the center of future business development. Still, its business model, deployment model, operation and maintenance model, especially resource availability and resource efficiency, are pretty different from the centralized deployment of cloud computing. The Linux Foundation proposed that after introducing the concept of Cloud Native to the edge, it also needs to combine the various features of the border to form an edge native (Edge Native) application form [4]. Therefore, the evolution of 5G-Advanced needs to integrate the characteristics of cloud-native and edgenative, achieve a balance between the two through the same network architecture, and finally move towards the long-term evolution direction of and cloud-network integration.

For ICT technology itself, 5G-Advanced needs to exert its network convergence capabilities further. These integrations include the integration of different generations and different models of NSA/ SA, as well as the integration of individual consumers, family access, and industry networks. In addition, with the evolution of satellite communications, the 5G-Advanced core network will also prepare for a fully converged network architecture oriented to the integration of ground, sea, air, and space.

In addition to ICT technology, there will be more demand from production and operation in the future, and OT (Operational Technology) will bring new genes to mobile networks. For example, the Industrial Internet for industrial manufacturing is different from the traditional consumer Internet. It has more stringent requirements for network quality. It is necessary to consider the introduction of 5G while supporting minimal networking. Quality inspection scenarios based on machine vision require the network to keep both large bandwidth and low latency capabilities. Remote mechanical control requires the network to support deterministic transmission, guarantees the number of connections and bandwidth that can be promised, and the intelligent production line for flexible manufacturing also needs to be provided by the precise network positioning, data collection, and other capabilities. For this reason, wireless access networks need to have the reliability, availability, determinism, and real-time performance comparable to wired access. Introducing IT, DT and AI into CT's OT to realize the integration of CT's OT with IT, DT and AI will become an important direction for the development of mobile networks. 5G-Advanced networks will become the critical infrastructure for the comprehensive interconnection of people, machines, materials, methods, and the environment in an industrial environment, realizing industrial design, R&D, production, and management. The ubiquitous interconnection of all industries, such as services, etc., is an important driving force for the digital transformation of the industry.

In addition, DT (Data Technology) technology will also inject new impetus into network evolution. The development foundation of the digital economy is a massive connection, digital extraction, data modeling, and analysis and judgment. Combining 5G network with big data, AI (Artificial Intelligence), and other technologies can achieve more accurate digital extraction and build data models based on rich algorithms and business features. It can also make the most appropriate analysis and judgments based on digital twin technology and give full play to the digital impact which will further promote the evolution of the network.

In summary, the full integration of DOICT will jointly drive network changes and capacity upgrades and help the digital development of the entire society in all fields.

02 5G-Advanced Architecture and Technical Trends

To meet the needs of personal consumer experience upgrades and digital transformation of the industry. 5G-Advanced networks need to continue to evolve from the architectural and technical levels to meet diversified business demands and enhance network capabilities.

At the architectural level, the 5G-Advanced network needs to fully consider the concept of cloud-native, edge network, mobile computing fabric network, network as a service, and continue to enhance network capabilities and eventually move toward cloud-network integration and computing-network integration.

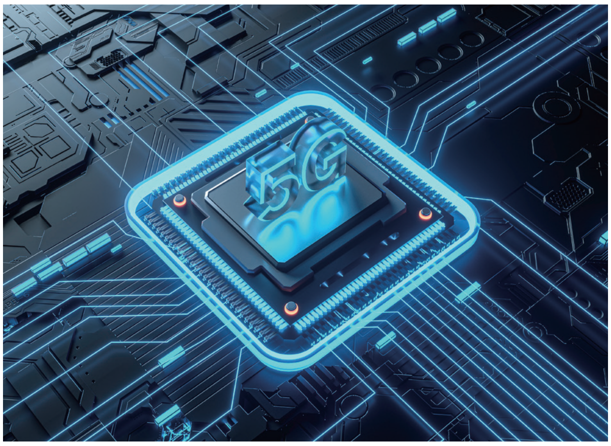
- Cloud-native is a further cloud enhancement based on the telecom cloud NFV to realize the flexible deployment of 5G networks and the flexible development and testing of functions more quickly. Cloud-native needs optimized software to improve the utilization efficiency of hardware resources, a cloud-based security mechanism to achieve internal security of the infrastructure, and manageability and maintainability of telecom cloud resources to ensure the robustness of telecom cloud.

- Edge network is an efficient deployment form that combines distributed network architecture and edge services.

- Mobile computing power awareness and scheduling network enhances computing awareness in 5G network to achieve the collaboration between 5G network and edge computing and also between MEC, dynamically provides optimal service paths and better experience for users and services. It finally forms integrated network and compute services.- The Network-as-a-Service model makes 5G systems highly flexible and can adapt to various customized solutions for vertical industry needs. The specific implementation form can be 5G network slicing or independently deployed networks. The SBA service-oriented architecture design of the 5G core network goes deep into the network logic, helping operators fully control the network and conform to the 5G network development goal of "network as a service."

This is because SBA is designed so that 5G network functions (NFs) could be developed stateless. It allows the NFs to be modularized, flexible and more application-focused for efficient communication. One of SBA' s important role is to manage and control various communications between NF services efficiently, by using request/response and subscription/notification based methods. SBA' s framework also allows robust scaling, monitoring and load-balancing of NF services.

Operators use SBA as the network foundation, network slicing as the service framework, network platform as the core, and key network function APIs as the starting point to build agile and customized 5G capabilities to help users deeply participate in the definition and design of network services. Operators need an increasing number of network features accessible via APIs so that together with slicing they can provide possibilities for automated differentiated business experience and higher business efficiency for the users and makes the connection and computing a powerful booster for developing the 5G service industry.



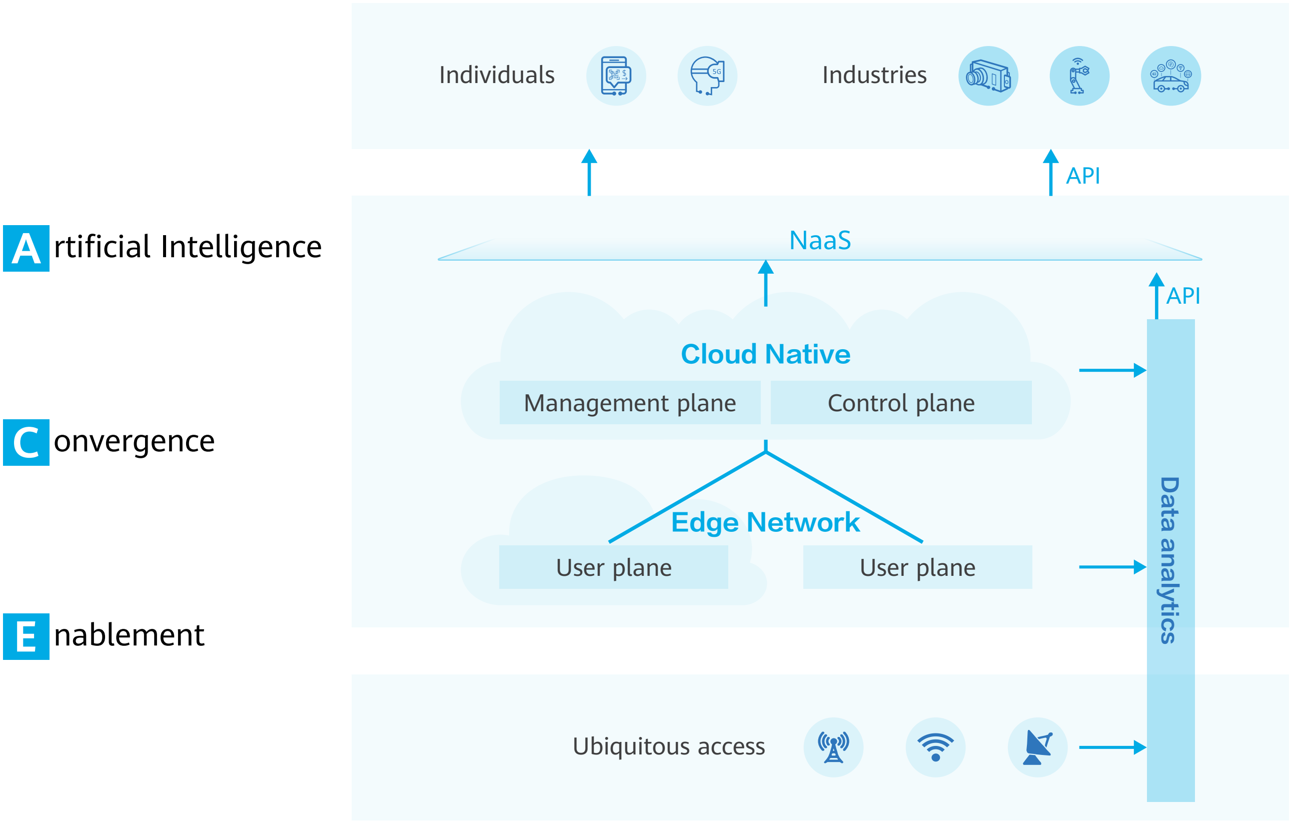


Figure 2-1: 5G-Advanced network architecture

Based on requirements that will be raised in the future, 5G-Advanced networks need to have the characteristics of an ACE: AI, convergence, and enablement.

• AI

As 5G develops, its applications and services are varying among industries. This leads to related network functions, management, and user behavior also becoming variable as well as complex. The network scale is continuously growing, but the conventional network needs heavy manual configuration, which is labor-intensive and prone to errors. Therefore, high management overhead has been added. It is necessary to introduce intelligent assistance to improve the capabilities and quality of services at all levels, from network functions to network management.

• Convergence

The convergence of different access modes and networks is the development trend of 5G-Advanced. Prior to the 5G era, various industries built independent networks, which were used for long periods, and diverse terminals, access modes, and transmission approaches emerged. However, the networks' low versatility led to the long iteration time of new functions, high cost of equipment, and slow development of technology. Therefore, the next-generation network, which should connect the air and ground and accommodate the IIoT, Wi-Fi, fixed networks, and other multi-industry and multiprotocol services, has become essential.

• Enablement

With 5G being used in industries, network capabilities continue to improve and gradually evolve from an infrastructure to enable services. Introducing new capabilities, such as deterministic networking, customization, high reliability, global control and management, and self-evolution to meet industry requirements, will facilitate the application of NaaS. This will enable 5G-Advanced to provide industries with customized networks featuring proactivity, flexibility, and resource isolation.

03 Key 5G-Advanced Technologies

3.1 Intelligent network

3.1.1 Key Technologies of network intelligence

The introduction of network resource virtualization, 5G service-oriented architecture, diversified services, and new 5G capabilities such as slicing and edge computing have brought challenges to 5G operations and commercial use. The application and integration of intelligent technology in telecommunication networks can improve network efficiency, reduce operation and maintenance costs, and improve the level of intelligent network operation.

Starting from 3GPP Rel-16, to promote network intelligence, continuous advancement has been carried out on the technical standardization of network infrastructure (SA2) and network management (SA5). NWDAF is a standard network element introduced by 3GPP SA2 in 5G. It is an AI+ big data engine. It has the characteristics of standardization of capabilities, aggregation of network data, higher real-time performance, and support for closed-loop controllability. 3GPP defines the location of NWDAF in the network and the interaction and coordination with other network functions and defines the flexibility of NWDAF deployment. NWDAF can be deployed within specific network functions through function embedding, and can also be deployed independently in which case intrinsic intelligence of the network functions and intelligence of the independent NWDAF collaborates to complete the closed-loop operation of network intelligence. Meanwhile, a self-evaluation and self-optimization mechanism for AI model performance in a mobile communication network will be available, which will contribute to the deep integration of AI and network. 3GPP SA5 defined Management Data Analytics System (MDAS), which, combined with AI and machine learning, enables automation and cognition of the management and orchestration of networks and services. The MDAS can mine data value in network management by processing and analyzing network management data. It can also generate analysis reports and provide suggestions on network management and operations to promote the intelligence and automation of closed-loop network management and orchestration. NWDAF and MDAS can cooperate with each other, especially to deal with cross-domain problems. NWDAF can provide MDAS with data and localized analysis results, to help MDAS make an intelligent decision for end-to-endnetwork management.

The evolution of 5G networks has increased the networks' complexity and, in turn, their O&M. Networks are required to be highly intelligent, automated, and autonomous. The networks need to automatically adjust to meet the rapidly changing service requirements according to changes in themselves and the environment. They also need to automatically perform the required network updates and management based on service and O&M requirements. To fulfill these requirements, the following AI technologies can provide reference for the intelligent development of 5G-Advanced network.

• **Machine learning**
As a basic network intelligence technology, machine learning can be widely used in various nodes and network control and management systems in 5G networks. Based on the large amount of subscriber and network data in the 5G system, combined with professional knowledge in mobile communications, a flexible machine learning framework has been adopted to build a network intelligent processing system that will be widely used and support distributed and centralized deployment.

• **Cognitive network**
Cognitive network technology uses algorithms empowered with mobile communications expertise and fully utilizes the big data analytics generated by the 5G network, enhance the intelligence of network operations to enable complex and diverse services.

• **Intent-based network**
Intent-based network technology enables operators to define their network goals, which the system can automatically convert into real-time network operations. The network is continuously monitored and adjusted to ensure network operations remain consistent with the service intent.

In the future, a company can introduce advanced frameworks such as federated learning to support the joint learning and training of multiple network functions. This can effectively enhance the training effect and protect data privacy. In addition, NWDAF can be deployed in layers, flexibly build a distributed intelligent network system, that responds better to different needs.

In addition, from the architectural enhancement, the 5G-Advanced network can further optimize data analysis framework of 5G network, specifically by supporting the following enhancements:

- Distributed and trusted AI architecture, such as federated learning to support joint learning and training between multiple network functions, between terminals, between network functions and terminals, and between networks and 3rd party AIML servers. This can effectively enhance the training performance and protect data privacy. This also enables NWDAF to flexibly build a distributed intelligent network system to fulfill different business requirements.

- Analytics framework at the enablement layer, besides the data analysis in the core network, the data analysis framework could analyze big data of the management domain and application domain to facilitate the realization of business goals.

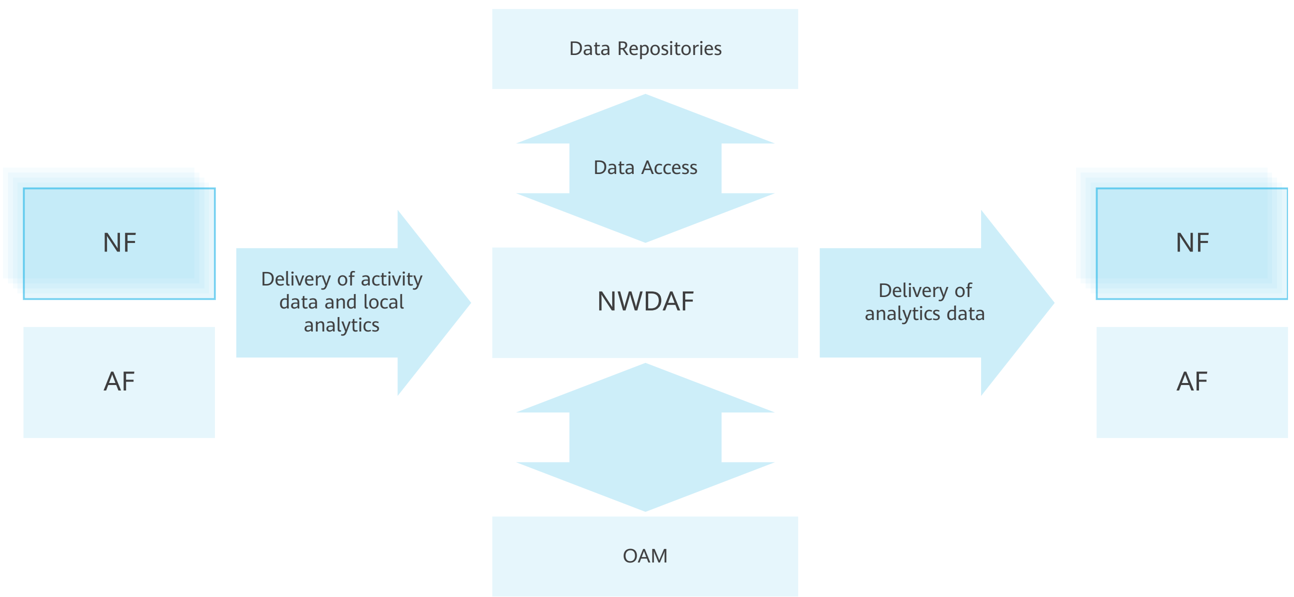


Figure 2.2.2-1: General framework for 5G network automation[5]

3.1.2 Support for AI/ML service

The use of AI/ML technology to realize application layer services such as autonomous driving, health monitoring, voice interaction, media enhancement, etc. is the future trend. 5G-Advanced networks not only need to provide good pipeline capabilities, but also need to provide on-demand information opening capabilities. High-quality information sharing can help third parties with effective operational decision-making, speed up the training process and improve training accuracy.

The 5G-Advanced network can provide AI/ML services with pipeline capabilities and information opening capabilities to achieve efficient model inference, model training and download, and distributed/federated learning services. Specifically, 1) For AI model reasoning, due to computing power and privacy constraints at mobile terminals, 5G-Advanced networks and AI/ML applications can interact through effective negotiation to achieve the purpose of not affecting AI/ML service experience. 2) For model training and download, when large number of AI models are adapted to various scenarios, the terminal needs to obtain the AI model adapted to the current scenario on demand. It can evaluate on-demand requests from terminals, providing high-value information to assist the rapid completion of application-layer model training, helps applications sense terminal behavior in time, and adapt to the model with the scene is sent to the terminal for use. 3) For distributed/federated learning, in order to break the terminal data island problem, make full use of a large number of terminal local data to form an effective global data set, and efficiently complete the model training. The 5G-Advanced network supports distributed/federated learning at the application layer, which helps in many aspects, such as computing power sharing, privacy security, and efficient use of wireless resources.

The 5G-Advanced network will help break the resource isolation between the communication network and top-level application, form complementary advantages, and effectively contribute to improving the efficiency of AI/ML services.

3.1.3 Intelligent Network Application Scenario

To realize the construction of intelligent network, empower the digital intelligence transformation of the industry, 5G networks require the continuous introduction of AI Internally, it can better support connections, security, and management and utilize AI algorithms to transform cloud-based big data resources into intelligent planning, analysis, fault diagnosis, and adaptive optimization capabilities.

AI can help 5G networks realize closed-loop optimization of service experiences. First, user experience is intelligently monitored and then evaluated. Then, the optimal strategies are recommended through intelligent comprehensive analysis based on service requirements and network capabilities. Finally, policy adjustment and closed-loop tracking are implemented through the service experience feedback mechanism, including steering the user to access the network via the appropriate access technology and access frequency band, to balance network costs and service experience. For example, a relationship model between user experience indicators and QoS indicators is built through intelligent data analysis and, based on this model, user experience of current services is monitored and evaluated in real time. In addition, differentiated QoS parameters that best match users, services, and networks are generated by analyzing and mining users' communication habits and intelligently identifies the services that users are using. Moreover, network slicing resources and services are intelligently scheduled and optimized through reinforcement learning and other optimization algorithms to ensure premium experience of services delivered by network slices. What' s more, AI-based multi-access collaboration can ensure that multi-access resource is fully utilized with improving user experience.

Externally, the network intelligence technology can fully support various types of AI/ML services such as autonomous driving, VR/AR, intelligent positioning and perception. By opening the intelligent QoS prediction capability, the application can adjust the operation mode in time to better adapt to the network status changes. For example, for V2X applications, when the predicted QoS received from the network cannot meet the requirements of automatic driving, it can be adjusted to assisted driving in time. Meanwhile, the intelligent 5G Advanced network makes full use of the computing power, data and scene advantages of the telecom industry to redefine the end-tube cloud ecology and build a new business model of the telecom industry. Many 5G applications require the cloud, the edge, and end devices to work together to implement and orchestrate services with the assistance of data collection, model training, and intelligent inference. To better use the available and everchanging computing and networking capabilities, AI needs to be introduced to predict the computing and network loads, as well as optimally schedule the computing, storage, and network resources across the cloud, the edge, and devices. Domain twin models can be used to simplify multi domain orchestration problems which would ensure that services can be practically and flexibly deployed and migrated on heterogeneous cloud-edge-device resources to provide the required service quality with optimal resource utilization.

3.2 Industry-Specific Networks

The integration of 5G and industry networks will become a key scenario for 5G-Advanced networks for vertical industry customers. In the industry network, 5G network can bring more business value, such as personnel protection, production flexibility, and advantages in wireless and mobility. From the perspective of networking, it can not only greatly reduce the complexity and labor cost of wired networking but also help industry customers realize the ideal of "one network at the end." For example, in the field and workshop networking in the industrial manufacturing field, 5G can simplify the multilevel wired network level at the vertical level to achieve network flattening. Based on the differentiated guarantee of 5G deterministic capabilities, 5G can realize the IT network of the field network (Such as equipment operation and maintenance data collection) and OT network (such as PLC control) into one.

The characteristic of the private industry network is to provide third-party customers with a flexible and on-demand customized network within the scope of their operation and management. The 5G industry private network can integrate the enterprise's network system with the 5G network to build unified management and seamlessly integrated industry networks.

Convergent industry-specific networks have been enhanced in the following three aspects:

1)Enhancement of network intercommunication:
5G-LAN technology can use 5G networks to replace local area networks in the current industrial field. Solve cable mobility limitations and high optical fiber laying costs in existing industrial networks, and provide industry users with the ability to quickly and flexibly build private mobile networks. 5G-LAN defines a virtual network through the concept of a group and supports point-to-point and point-to-multipoint communication within the group. The 5G-LAN group can deploy one UPF or multiple UPFs and supports local exchanges within UPFs and intra-group communication across UPFs. The open API interface enables third parties to create or modify communication groups flexibly, thereby realizing dynamic group management. 5G Advance can enhance 5G-LAN technology in the following aspects:

- Further study the new requirements in industrial networks, enhance the layer 2 data transmission of mobile networks and expand the application scenarios of 5G-LAN in industrial networks. For example, factory complex scenarios require group communications with service continuity among networks, dynamic group communications in 5G LAN, and 5G LAN group QoS support.

- At present, 5G-LAN only supports one group to be served by a single SMF. In the future, it will be expanded to one group spanning multiple SMFs, thus realizing wide-area interconnection.

- Convergence of fixed network and mobile network, 5G-LAN needs to communicate and converge with traditional industrial wired LAN.

In addition, in the 5G industry private network networking, enterprises can conduct unified management and plan for terminal addresses. Constructing the N3IWF network function can also support the integration and switching of the industry's existing networks and 5G private networks.

2)Management
A central network management monitoring system replaces the siloed management systems, simplifying network management.

3)Security
The networks will meet enterprises' requirements for security and reliability. The network for enterprise can be deployed isolated on-demand from the public network and one possible way is to support industry-specific network (e.g. PNI-NPN). In terms of security, they will further support the network topology hidden. An enterprise can also incorporate a firewall to filter all data in its private network to ensure that confidential data remains in the campus. The reliability of access, on-demand resources, and connections is also improved.

3.3 Home Networks

Home networks will be a focus for developing 5G-Advanced. Already now, many operators see a peak in mobile data traffic when people are at home. This is likely to be even more so with new services for consumers (e.g. mobile gaming, or high definition mobile TV) that require every higher data rates.

High data rate services such as interactive applications are best served at higher frequency bands, where more capacity is available. However, these higher frequency bands make providing indoor coverage a challenge. It may not be possible to provide enough indoor capacity with outdoor base stations, relaying or indoor base stations may be needed to give consumers a ubiquitous coverage experience.

Unlike other areas where networks are deployed, there are more devices of different types in home networks, though they move around in much smaller areas. In addition, home network users do not require extremely high reliability, but have stringent requirements on protocol conversion and bandwidth.

In the future home intelligent IoT network, there will be various devices and types of collected data. Finding the optimal way to synchronously transmit this data, use AI algorithms to pre-judge user behavior accurately, predict device status, and implement intelligent adjustment will become the focus for the next generation home network.

3.4 Space-Air-Ground Networks

The 5G network was built not only to provide high network speeds, but also ubiquitous mobile network access. However, in remote areas such as mountainous areas, deserts, and the ocean, building and maintaining a 5G terrestrial network is extremely expensive, which makes it impossible to provide 5G network coverage in those areas. Fortunately, the development of aerospace technology enables the satellite-based broadband communication system to provide radio coverage to large or even global areas at a much lower cost. As such, the 5G network will deeply integrate with the satellite communication system to constitute a convergent communication network that provides seamless coverage on the planet, meeting various service requirements anywhere in the world.

Current 5G networks supports the base station to adopt 5G NR system, allowing terminals to access the unified 5G core network through the satellite base station, and satellite base stations working in transparent mode, but there are some limitations on the support of voice service and transmission delay. In the future, the 5G-Advanced network will comprehensively integrate with satellites and provide the following features:

- Support for the integration of the terrestrial 5G network with satellite networks in orbit at different altitudes, for example, different mobility management strategies for low, medium and high orbit.

- When providing wireless access, the satellite can work in bent-pipe or re-generative modes to forward data transparently and process on-board data, respectively. The 5G-Advanced network can support networking for satellite-ground and satellite-satellite, in order to support terminals to use both satellite access and ground access to optimize data transmission no matter whether the satellite access and terrestrial access belong to a single operator or different operators. The 5G network can support enhanced mobility management mechanisms for terminals connecting via satellite access, such as access control based on terminal location, terminal seamless switching between satellite access and ground access, policy and QoS control based on the type of satellite access, discontinuous satellite coverage for paging enhancement and power saving optimizations, and network-based positioning to enable positioning of non-GNSS terminals and to fulfill reliable UE location requirements.

- When the base station uses the back-haul service provided by the satellite network or satellite enabled NG RAN, the core network shall be able to perceive the status of the satellite network (such as time delay, bandwidth, etc.) to facilitate policy and QoS control considering the movement of satellites and the entire constellation. This can also help to expose the back-haul capability to the application layer to assist the application adaptation.

- Support of deploying UPF on the satellite in the case that the main business application is on the satellite, which can either enable satellite edge computing services to reduce data transmission latency and minimize the backhaul resources consumption; or enable local traffic switch for UEs served by UPF on-board to reduce end-to-end packet delivery latency and improve communication efficiency.

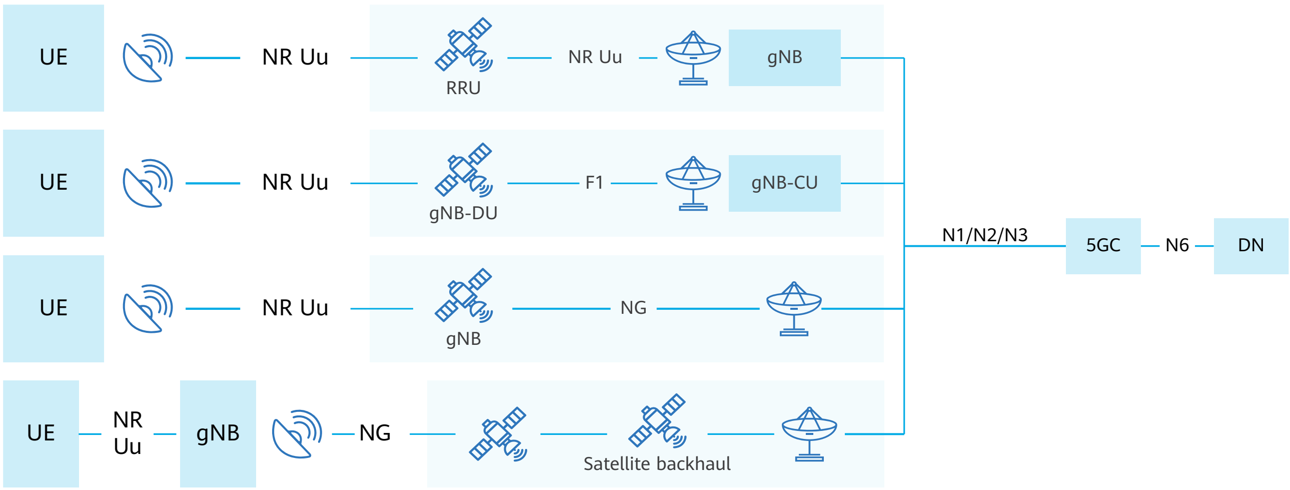


Figure 3.4-1: 5G network integrated with a satellite system

3.5 Interactive Communications

As 5G coverage expands, the screens of smart terminals increase in size, and AR/VR/XR devices develop rapidly. Consumers expect more than the conventional voice and video services and are increasingly anxious to experience digital, highly interactive, and multisensory experiences [6].

In this context, real-time communications are becoming more immersive, represented by HD video, AR/VR, and other emerging technologies. This shift not only enhances individual services, such as personalized calling, remote collaboration, AR social media, and VR communications, but also helps enterprises establish their image and carry out marketing more efficiently. For example, enterprise information can be displayed to consumers in calls from enterprises, improving the call connection rate, and interactive menus can replace audio instructions in customer services, helping customers select service options. Moreover, exposing network capabilities help enable a new wave of application innovation. Applications like ride-hailing, enterprise campus communications, and remote education have been influencing people's work and lives.

3GPP Rel-17 defines new requirements, 5QI and other QoS parameters for cloud games and XR and other interactive services. In the 5G-Advanced stage, interactive communication also needs the following key technical support:

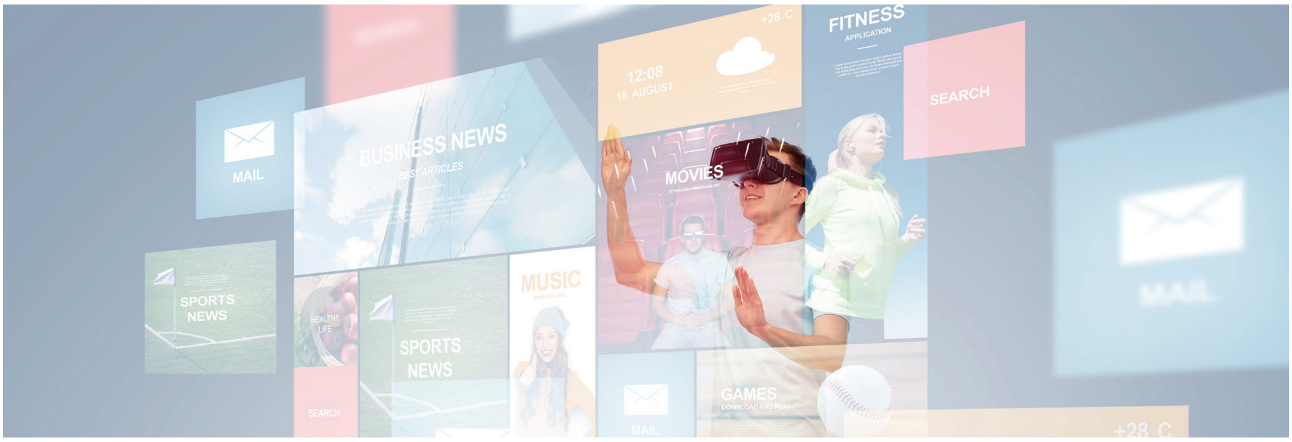
• IMS data channels
Existing real-time communications networks are overlaid with IMS data channels, which enable screen sharing, AR effects, and enhanced interactions with environments and things in them.

• Distributed service-based convergent media
A unified convergent media plane is established to upgrade basic audio and video services and facilitate new media services like collaborative activities and AR/VR. The media plane is deployed in a distributed manner, so that the nearest media resources can be scheduled for services to ensure the lowest possible latency and largest uplink bandwidth. Service-based media control interfaces can flexibly meet diversified requirements of different services, such as transcoding, playing announcement, and data channel, it also can improve media resource assignment efficiency and reduce the TTM of new services.

• Trusted access of third-party IDs: Enterprise business calls are often rejected as nuisance calls, which resulted low communication efficiency. A joint authentication mechanism between carrier and enterprise should be defined that the authenticated caller identity and call intent information can be carried during call connection. This ensures the enterprise business calls are trusted and increases the call completion rate.

• Programmable call applications
Terminals are enhanced so that their web browser engine can process service data in the IMS data channels in real time and display the results on terminal UIs. This increases the flexibility of services to an unprecedented level.

• Enhanced QoS
Multi-flow services are coded and transferred at different layers, and the QoS of each layer is assured based on a specific 5QI. Moreover, QoS control is implemented for different data packets at a finer granularity, such as latencyor reliability-based control. In addition, new QoS parameters, including latency, reliability, and bandwidth, are introduced to help ensure that all types of data, including that from tactile sensors, is efficiently transmitted. Supports QoS mechanism that is aware of media service features and provides differentiated QoS scheduling for different packets of service flows based on service feature information. End-to-end latency and jitter also need to be guaranteed for the XR services.



• Collaboration of enhanced multimedia communication data flows
All data representing service features is collected, facilitating smooth coordination and central scheduling of different service flows. This ensures that data packets synchronously arrive at servers or terminals.

• Enhanced network capability exposure mechanism
For strong interactive business scenarios such as AR/VR, the 5G system and AF directly support better user experience and more efficient use of network resources by exposing more and more real-time information.

• Enhanced mobility and power-saving mechanisms
In order to better enable the immersive service experience for the mobility scenario, mobility and power-saving enhancements need to be considered to improve the service experience and the device battery life.

• Resource allocation to guarantee XR experience
In order to guarantee the XR service experience, the resource for specific XR services should be guaranteed e.g. dedicated resource allocation, or high priority of QoS.

3.6 Deterministic Communications

3GPP has defined deterministic communication capabilities since Release 15. In Release 16, the deterministic capabilities were further enhanced for the air interface, CN, networking and integration, SLA assurance and URLLC. 3GPP Release 16 defined a 5G system as one or more bridges which can be integrated transparently into an TSN architecture. On top of this, 3GPP Release 17 sketched the deterministic communication architecture for independent 5G TSN to adapt to more networking scenarios. That being said, an overarching architecture buttressing deterministic SLA fulfillment and QoS from end to end has not been ready yet. This architecture must be enhanced in the following aspects:

• Management and deployment
The management and deployment of deterministic network services rely on accurate requirement conversion — translating all service KQI requirements from industry players into network KPI requirements and splitting all the KPI requirements among different network domains and mapping these KPIs to deterministic network capabilities.

Operators can utilize modeling and simulation to predict and verify whether the conversion results can satisfy the service requirements on a specific network. In this way, they can adjust the network deployment and configurations in advance to facilitate service rollout and mitigate the risks of service losses.

• Measurement and assurance

Applications that deliver deterministic performance need to send packets at millisecond-level intervals, and thusly network resources need to be scheduled highly flexibly and efficiently. To ensure this, the KPIs related to latency, bandwidth, and jitter cannot only be measured based on average values, but also must be accurately guaranteed on the 5G-Advanced network.

• Scheduling and coordination

To ensure predictable, attainable QoS and SLAs for deterministic services, every part of the transmission must be scheduled flexibly and coordinated collectively.

- Applications need to notify the network of their access; whereas the network needs to sense the formats and coding approaches of various application data and recognize the characteristics and priorities of related service flows, be it from periodic services or those featuring random bursts.

- Once an application has been sensed, the network needs to schedule resources on demand, at an intra-flow, inter-flow, or media granularity.

- The network quickly establishes a closed-loop service assurance approach based on the services' characteristics and priorities. With bidirectional interfaces, the network controls data packet exchanges and coordinates them harmoniously with the E2E resource scheduling. Meanwhile, the network influences the application, pushing it to adjust traffic to adapt to the network, and thereby avoiding congestion caused by concurrent services. With this mechanism, capacity of the air interface can be improved and latency for scheduling (e.g., for the UL traffic) can be reduced.

- End-to-end coordination is achieved based on the coordination between CN and AN, together with the coordination between CN and xHaul. 5GS end-to-end delay and jitter would be further reduced by means of N3 deterministic transmission and assistance for RAN to improve the scheduling accuracy.

- In addition, the exposure enhancement to 5GS enables the (3rd party) applications to explicitly provide reliability requirements. The network needs to better serve terminals by using its enhanced features, such as providing active/standby connections and supporting dual feeding and selective receiving to set up reliable transmission paths.

• Based on the vertical' s requirement, 5G-Advanced will enhance the bridge integration approach include:

- In addition to the centralized TSN deployment model stipulated by IEEE, 5G-Advanced shall support more models, such as distributed deployment, to make networking more flexible and deploy more new applications. and to make services highly controllable and scalable.

• Timing service： Currently, most industries that require precise time synchronization rely on the Global Navigation Satellite System (GNSS) to manage their system time. To address the problems of malicious attacks, electromagnetic interference, weak indoor signals, and high power consumption of receivers, the 5G system can expose the capability and needs to provide more flexible time services and serves as a backup or supplementary system for the GNSS to ensure continuous and accurate time synchronization for both individual users and industry players.

3.7 User Plane Customization

UPF should be able to support different kinds of 5G services from eMBB, URLLC, mMTC. As UPF is separated from control plane functions, the architecture is now more focused on for optimized packet-processing.

With the deployment of 5G networks, vertical industries have increasingly clear requirements for 5G in edge scenarios. 5G UPF can be deployed and expand capacity according to market demand, which requires 5G UPF to have flexible and exposure capabilities, support function customization on demand and be able to quickly go online.

Based on the SBA design, the invocation of user-plane capabilities by other network functions can be supported. Information such as precise location information, user planeload conditions, network delays, slice related information, billing, and additional specific information that industry customers are concerned about can be exposure by 5G UPF.

In order to support better integration of UPF into the 5GC SBA, the UPF event exposure service discovery and registration/deregistration is supported via the NRF. The UPF event exposure service can expose information which is originated from the UPF to other NFs if needed.

3.8 Network Slicing

Network slicing is a technology that enables networks to be deployed on demand. It isolates multiple virtual E2E networks above a unified infrastructure to meet various service requirements. It is one of the key features of 5G SA. Many standards organizations such as 3GPP, ITU-T, ETSI, and CCSA have conducted standardization related to network slicing, and the network slicing-related functions and technical specifications have essentially reached maturity. to enable network slicing to be commercially used in industries, the following areas need to be improved:

• Functionality evolution

The network slice functionalities need to be further involved to meet new requirements. For example when the existing network slice cannot meet the requirements of PDU sessions or the performance requirements of applications, how to ensure service continuity, how to support roaming users to select different VPLMNs according to requested network slices, how to enhance network based network slice control mechanism to meet new requirements, and how to enhance network slicing mechanism to support localized service deployment, etc.

• Intelligent configuration

Network slicing-related configuration has been gradually improved through standards. For example, 3GPP defines the parameters and interfaces related to the Network Slice Management Function (NSMF) and the Network Slice Subnet Management Function (NSSMF) of each subdomain. However, these parameters still need to be manually configured. Further work is required to find the optimal way to implement automatic, intelligent closed-loop control for these parameters to fulfill SLA requirements.

• SLA guarantee

Standards have defined the process for tenants to subscribe to their target network slices from network administrators. After subscribing to a slice, the tenant needs to be informed of QoS conditions and the slice resource usage.

• Integration with vertical industries

To better serve vertical industries with network slicing, vertical industries' typical requirements need to be considered, for example, industry customers wish to manage their slices themselves, such as self-service monitoring and data query. If a vertical industry has deployed a private network, industry users may need to access the 5G network slice for the industry and then be directed to the private network. To ensure smooth user experience, the 5G network slice and private network must be concertedly coordinated.

3.9 Positioning, Ranging and Perception Enhancement

5G positioning facilitates personnel and vehicle locating, logistics tracking, and asset management. As an increasing number of services are gravitating towards edge computing, positioning capabilities are increasingly important at the network edge and need to have ultra-low latency and high precision. For instance, Vehicle to Everything (V2X) requires positioning accurate to a centimeter level with a confidence of over 90%; scenarios from enterprise and industrial require that the location information does not leave the sites, and further reduce the end to end location service delay. Many companies have been carrying out extensive research on reducing the transmission delay of location information based on edge computing-based deployment of the location management function (LMF), gateway mobile location center (GMLC) and Network Exposure Function(NEF), as well as using reference UEs to eliminate timing deviation between base stations to improve the accuracy and confidence of the location information. In the indoor positioning scenario, to meet the requirements of terminal low-power consumption and high-accuracy positioning (LPHAP) at the same time, the battery replacement cycle of low complexity IoT terminal requiring positioning will be extended through the joint optimization method between the radio access network and core network. With the development of 5G network, new network capabilities based on ranging and Perception are emerging. For example, in some scenarios of smart home, smart city, smart transportation, smart retail and Industry 4.0, there are requirements of obtaining the relative position and angle between objects, as well as perceive the distance, speed and shape of the target object. 5G-Advanced network should be further enhanced to assist the wireless network in ranging and sensing capabilities by processing the information from service awareness. This can be the foundation for further steps of 5G-Advanced network' s digital and intelligent transformation.

In the next step, the network needs to enhance the independent perception and analysis capabilities of the core network, realize multi-dimensional and multi-granularity environment perception and target perception, meet the needs of target recognition, status monitoring, etc., and lay a solid foundation for the integration of communication perception for the 5G-Advanced network.

3.10 Multicast and Broadcast Services

5G multicast and broadcast services can transmit multimedia streams or data to various general 5G devices, which is conducive to improving the efficiency of wireless resources and the realization of innovative services. NR MBS is very important for the realization of ARVR broadcast and multicast, public safety local broadcast, V2X applications, transparent IPv4/IPv6 multicast transmission, IPTV, wireless software transmission, and Internet of Things applications.

5G networks need to consider the flexible and dynamic allocation of resources between unicast and broadcast/ multicast services through 5G NR-MBS, providing substantial improvements and new capabilities in terms of system efficiency and user experience. In addition, the use of artificial intelligence technology can achieve efficient resource allocation according to the actual user experience. The 5G network could further enhance the ability to support a flexible mechanism for the ability of terminals to access broadcast services.

Additionally, 5G multicast and broadcast services will also support the scenario in which the user equipment receives multicast MBS data, so as to strike a balance between transmission efficiency and energy efficiency and considering the support of multi-PLMN resource sharing.

3.11 Policy Control Enhancement

5G supports flexible policy adjustment by introducing UE policy and user-based AM (access and mobility) policy management functions. This function can already provide the UE with capabilities such as user routing selection and access network discovery, and provide the network with capabilities such as wireless access mode and radio frequency selection priority (RFSP Index), access area restriction, UE AMBR and slice MBR, SMF selection and etc.

In the follow-up 5G-Advanced research, operators need to further explore the market application prospects of UE and mobility management strategies. For example, UE policy and access and mobility policy control should be supported under roaming conditions, Policy Control can support a better QoS management by utilizing a fine-grained QoS Monitoring and operator-specific traffic categories in the traffic descriptorwhich effectively improves a service assurance of UE sessions. Per-slice specific QoS control helps efficient bandwidth management for supporting various network deployments such as B2B and B2C. There is also need to ensure user policy consistency between 4/5G systems under the current 4/5G interoperability situation. To better respond to requirements of high precision and low latency in industrial applications, the granularity and distribution process of existing policy management parameters need to be further optimized. Also, the operators care about how the network verifies the enforcement of delivered UE policy by the UE to take further optimization policy.

3.12 Proximity-based Services

Since business demands such as AR/VR and public safety are increasing day by day, 5G proximity-based services enables direct communication between UEs by using PC5-NR communication technology. 5G proximity-based services enables remote UE to access 5G network through relay UE(s). This not only reduces the latency of end-to-end communication, but also helps to provide a new method for operators to enhance 5G-Advanced network coverage, but also helps to enhance the 5G-Advanced network's control of remote UE access methods, thereby improving the service experience. Therefore, 5G proximity-based services can help realize AR/VR, public safety and other services, and promote the development and commercial use of related industries.

In order to better provide business services, 5G-Advanced networks need to further improve 5G proximity-based services. For example, it can be considered that the UE can access the 5G network through different paths (e.g. the UE is connecting to the gNodeB directly and via a relay UE), so that the 5G-Advanced network can effectively improve the reliability and data rate of the UE accessing the network.

3.13 Mobile Computing Power Awareness and Scheduling

The computing power awareness and scheduling are the main directions of computing-network convergence in the future. 5G-Advanced core network domains can build mobile computing network capabilities based on business use cases without major network architecture change. For example, 1) currently distributed edge computing mainly supports local deployment of video, cloud gaming, and some industry applications. However, the difference of local computing capabilities and resource utilizations from different local sites, as well as the resource complementarity between multiple edge sites are not considered for such deployment. To further enrich use cases, optimize service experience, and improve resource efficiency, in-depth network computing collaboration will become a potential solution to this problem. 5G network will provide flexible service scheduling based on computing power and resource awareness to achieve computing power mutual assistance among multiple sites. This will ensure the services obtain matching resources at proper sites. 2) Cloud mobile-phone scenario. Network will provide computing power expansion for cloud phones, further enhancing the processing capability, and reducing the power consumption of mobile phones for better performance. 3) Digital twin and intelligent processing will become the key native services of the network. Those services will generate massive data. And it requires high performance of service processing, lower latency during data transmission, and higher reliability of the network. Therefore, it is necessary to promote computing closer to data sources to form distributed computing resources in the network. Computing power orchestration is the core technology of computing resource management. It centrally schedules and manages the entire network and computing resources. It combines AI, digital twin, and big data processing technologies to implement unified resource orchestration, intelligent scheduling, precise configuration, and dynamic optimization for all services.

3.14 Passive IoT

Passive IoT uses technologies such as backscattering and energy harvesting to achieve efficient information transmission of target nodes without batteries and with extremely low complexity. It has the significant advantages of zero power consumption, low cost, and easy deployment. Passive IoT systems can be widely used in smart warehousing, smart logistics, smart agriculture, industrial wireless sensor networks, smart transportation, smart medical and other fields, and is expected to become the basic enabling technology for the Internet of Everything. However, traditional passive IoT technologies, such as RFID, have the problems of short coverage distance, low system efficiency, and difficulty in automatic management due to the interference of the system itself and only single-point communication.

For the evolution of 5G network, passive IoT technology is introduced into the 5G-Advanced system, and the combination of passive communication equipment and cellular communication equipment is promoted. Through the minimalist network architecture, minimalist network protocol, lightweight security certification and other technologies, it can not only achieve continuous indoor and outdoor coverage, but also achieve rapid networking through network management and coordination, improve network coverage, reduce system deployment costs, and meet physical needs. So as to meet the passive, extremely low-cost and ultra-large-scale access requirements of IoT terminals.

04 Conclusion

Mobile communication is always in a state of innovation and development. Today, with the first phase of 5G standards commercially deployed, the technology continues to evolve and 3GPP officially names the 5G evolution as "5G-Advanced" on April 27. The study/work items of release 18 for SA2 have been determined during the meeting on December 2021. 5G-Advanced network will define new goals and capabilities for the 5G evolution to enable the generation of greater social and economic value through network evolution and technological enhancements. At this point, industry partners jointly publish this white paper, hoping to provide reference for the development of 5G-Advanced network.

This white paper mainly introduces the 5G-Advanced oriented network architecture and key technologies and guides the next 5G network evolution stage. The network architecture will develop along with the concept of cloud-native, edge network, and network as a service to meet the demands of rapid deployment of network functions and on-demand iteration. In terms of network technology, the 5G-Advanced network capability will continue to be enhanced along the three aspects of "Artificial Intelligence, Convergence and Enablement". Artificial Intelligent will focus on improving the level of network intelligence, reducing the cost of operation and maintenance, further promoting the application and integration of intelligent technology in the telecom network, carrying out the research of distributed intelligent architecture, and the collaborative intelligence between terminals and networks. Convergence will promote the coordinated development of 5G network with industry network, home network and space-are-ground network. Enablement will support the 5G network serving the vertical industry. While improving the representative capabilities i.e. network slice and edge computing, 5G-Advanced network will also support interactive communication and broadcast communication to make network services "more diversified". The network will become "more certain" based on the end-to-end quality measurement and guarantee, and scheme simplification. The network capabilities can be "more open" in terms of time synchronization, location services, etc.

Based on the progress of 3GPP R18, 5G-Advanced will gradually shift from requirement and scenario definition phase to service design phase. This white paper is expected to provide reference scenarios, requirements and technical directions for the development of 5G-advanced network, in order to motivate the industrial consensus, and jointly promote the development of 5G network.

Acronyms and Abbreviations

Abbreviation	Full Spelling
AF	Application Function
AI	Artificial Intelligence
AM	Access and Mobility
AMBR	Aggregate Maximum Bit Rate
API	Application Programming Interface
AR	Augmented Reality
B5G	Beyond 5G
CT	Communication Technology
DOICT	DT, OT, IT, and CT
DT	Data Technology
E2E	End to End
GMLC	Gateway Mobile Location Center
GNSS	Global Navigation Satellite System
LMF	Location Management Function
LPHAP	Low-power Consumption and High-accuracy Positioning
MBB	Mobile Broadband
MBS	Multicast and Broadcast Services
MDAS	Management Data Analytics System
MEC	Multi-access Edge Computing

Abbreviation	Full Spelling
N3IWF	Non-3GPP Inter Working Function
NF	Network Functions
NFV	Network Functions Virtualization
NPN	Non-Public Network
NSMF	Network Slice Management Function
NSSMF	Network Slice Subnet Management Function
NWDAF	Network Data Analytics Function
O&M	Operation and Maintenance
OSS/BSS	Operation Support System/ Business Support System
OT	Operational Technology
PLC	Programmable Logic Controller
QoS	Quality of Service
RFSP	Radio Frequency Selection Priority
SBA	Service Based Architecture
SDN	Software Defined Network
SLA	Service Level Agreement
V2X	Vehicle to Everything
XR	Extended Reality
5G-LAN	5G Local Area Network

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