6G Network Architecture

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Introduction

In October 2020, vivo communications research institute (VCRI) first released two whitepapers, "Digital Life 2030+" and "6G Vision, Requirements and Challenges"[1][2]. We have proposed the 6G vision and use cases for building a the freely connected physical and digital integrated world in the two whitepapers. After that, in July 2022, VCRI further released a whitepaper to consolidated our 6G vision, "6G Services, Capabilities and Enabling Technologies"[5], which illustrates that three major categories of services will be provided by 6G, namely super communication service, basic information service and converged computing service. We have also elaborated the capabilities and potential enabling technologies to support those services in that whitepaper.

With the systematic research of 6G, the industry expects to gradually reach a consensus over the overall views of 6G network architecture. Based on the consensus, the research of each technical direction will be conducted concretely, all of which finally constitute the systematic solution to the future 6G standards. VCRI, in collaboration with our partners, has been actively researching the 6G network architecture and the key technologies, and been continuously evaluating and validating these key technologies. In this whitepaper, we reveal vivo's initial perspectives and our latest results of 6G network architecture, including the design principles, overview, and key technologies, hopefully contributing to the 6G development.

02

Design Principles of 6G Network Architecture

6G is a brand-new generation of network systems. Thus, the architecture design of 6G shall follow three fundamental principles: inheriting the advantages of 5G; meeting the requirements of new scenarios, services and technologies; continuously enhancing the basic capabilities.

2.1 Inheriting the advantages of 5G

In the history of mobile network developments, the network architectures between two successive generations of networks typically exhibit strong correlations. Therefore, the 6G network architecture shall also maintain the successful and valuable features of the 5G network. In this way, network performance and quality of service can be further enhanced. These valuable features include the following aspects:

Service based architecture (SBA)

- Service based architecture aims at converting a monolithic application into a set of services that can be independently constructed, tested, deployed, and operated. In 5G SBA, different services can be combined and deployed on demand. SBA can also prevent duplicate development of functions and promote rapid innovation of services. Therefore, 5G SBA has been widely implemented in commercial networks, owing to the high flexibility and reusability. However, the granularity of the network service defined by 5G is coarse and the scope of network services is limited to the control plane of core network (CN). In other words, the service based interfaces are only available in the control plane of CN. The traditional interfaces, which are non-service-based, are used in the user plane and the interactions between different entities, such as between radio access network (RAN) and CN. The current status of service-based interface may lead to high complexity and low efficiency.
- Therefore, 6G network architecture should keep the design principle of SBA. Moreover, the granularity and the scope of the network function can be further extended, such as defining atomized network services, and employing service based architecture to the user-plane or RAN.
- The optimization of transport protocols is another potential extension in 6G, for example, introducing quick UDP internet connections (QUIC), segment routing over IPv6 (SRv6).

Control Plane and User Plane Separation Design

- The separation of control plane (C) and user plane (U) is adopted in 5G. Both C and U have independent network function nodes.
- The separation of C/U allows for the independent deployment, management, and upgrading of the control plane and user plane. Furthermore, the low-latency requirements of application function can be met through on-demand deployment of user plane functions.
- The design principle of C/U separation should be maintained in 6G network. On this basis, network function splitting and atomization can be further explored to adapt to the deployment of distributed network architectures. For instance, some network functions can be distributively deployed in edge nodes while others can be kept in the central node. As such, the balance between mobility and network performance can be achieved.

The guarantee of high quality of service (QoS)

The guarantee of high QoS is a crucial feature of mobile networks. Compared to 4G, the minimum granularity of QoS control in 5G is refined from evolved packet system (EPS) to QoS flow, leading to finer network resource scheduling. Besides, 5G introduces delay-critical guaranteed bit rate (GBR) type to better allocate the different types of resource for different services, ensuring the QoS.

Based on the 5G QoS mechanism, 6G network is expected to further support the multi-connectivity (e.g., concurrent co-operation of multiple streams), QoS control of new services (e.g., QoS enhancement of converged computing services), and so on.

Exposure of Network Capabilities

In 5G, events provided by network function can be exposed to external systems through the network exposure function (NEF) or common API framework (CAPIF) of the control plane, facilitating the convergence and innovation of network and application functions. This approach provides both exposure and security for the mobile network.

However, the information exposed by 5G networks only includes limited information, such as positioning and communication data. Due to privacy concerns, the exposure functions of network capabilities standardized in 5G, such as NEF and CAPIF, have not been widely deployed.

In 6G, the exposure of network information should be further enhanced. The potential enhancements target to further improve the efficiency of network data collection and strengthen the protection of data privacy. Additionally, more efficient ways can be explored to expose information to external parties to provide more widespread data and information services. For instance, application servers can directly obtain network information through the user-plane function.

The 5G standard has introduced many new features during its evolution. For instance, network intelligence and multi-Access edge computing (MEC) help to improve the network efficiency and performance; non-terrestrial networks (NTN) provide larger network coverage; positioning, integrated sensing and communication (ISAC), and ambient power-enabled internet of things (AIoT) support more services and applications with relatively low overheads. 6G network will keep these key features, and support them natively in the first release. In order to reuse the upfront investment and operation of the existing network, 6G network also needs to support the compatibility and interoperability with 5G network, enabling a smooth evolution.

2.2 Meeting The New Requirements of 6G

2.2.1Meeting the requirements of new scenarios and services

The "Typical Scenarios and Key Capabilities of 6G" whitepaper [3], released by IMT-2030 (6G) promotion group, proposes five typical scenarios: further enhanced mobile broadband, ubiquitous massive connection, superlative ultra-reliable and low-latency communication, quality guaranteed network artificial intelligent (AI) service, and integrated communication and sensing. The " Framework and overall objectives of the future development of IMT for 2030 and beyond" [4], released by International Telecommunication Union-Radio Communication Sector (ITU-R), proposes six major scenarios, including immersive communication, massive communication, hyper reliable and low-latency communication, integrated artificial intelligence and communication, integrated sensing and communication, and ubiquitous connectivity.

To meet the requirements of new scenarios, 6G network architecture needs to support sensing services, AI services, and computing services, in addition to the enhanced communication services. The whitepaper [5] divides the new services required by the new scenarios into three categories. The first one is super communication services that enhance 5G communications. The second one is basic information services that provide positioning, sensing, network exposure information as well as industry common information. The third one is converged computing services that include AI. In addition to these new services, lots of new scenarios raise specific requirements for 6G network. The ultra-low power or even zero-power internet of things (IoT) device access is required via simplified air interface technologies and network architectures. Ubiquitous connectivity requirements are proposed beyond 5G coverage through native convergence of terrestrial and non-terrestrial networks. Therefore, new functions and procedures shall be introduced to support the new 6G scenarios and services, including:

New sensing functions and new computing functions

Sensing functions and computing functions are required to control and execute related services, in order to meet the requirements of sensing and computing service.

New data functions

Data are the basic element and common requirement for ISAC AI model training. Thus, data function is required by 6G network architecture. Rather than case-by-case standardization, the requirements of all services and use cases should be comprehensively considered to support efficient network data collection and transmission.

Efficient organization and collaboration

New services require the efficient organization, real-time interaction and collaboration of network functions in 6G network architecture.

2.2.2Meeting the requirements of introducing new technologies

AI technology, wireless sensing technology, passive IoT technology and satellite mobile communication technology will be important enabling technologies for 6G design. 6G network architecture should meet the requirements of new technology introduction and integration.

AI technology

AI refers to a set of technologies that are based on machine learning and deep learning, used for data analysis, prediction, object categorization, natural language processing, recommendations, and intelligent data retrieval [6]. Currently, AI has successfully solved a series of problems that were previously difficult to deal with. These problems include image recognition and natural language processing in the field of computer science, as well as motion control and trajectory planning in the field of robotics.

There are many problems in communication systems that cannot be accurately modeled, such as the variation patterns of wireless channels and the nonlinear effects of the power amplifier. However, with the integration of AI and mobile networks, implicit relationships, features, or knowledge can be extracted from a large amount of wireless communication data. Therefore, AI capabilities can help to achieve more accurate modeling of complex problems. In a data-driven manner, AI can map the relationship between the input information (e.g., state, conditions, historical results, etc.) and potential solutions. AI is also applicable to many problems in communication systems of which closed-form solutions are not easily available or even not available (e.g., user equipment (UE) trajectory prediction). AI-based solutions can directly give solutions or approximate solutions to these problems. Using AI, a neural network can model multiple correlated functional modules as a joint optimization problem (e.g., cross-layer optimization) for a communication system. In this way, a complex multi-module correlation problem is converted into a simple data fitting or regression problem. Then a near optimal solution can be obtained.

From the perspective of network architecture design, the integration of native AI capabilities needs to be supported from the beginning of 6G design. Common requirements and functions, which are collected multiple use cases of network intelligence, should be supported through unified architecture design. Therefore, 6G can avoid duplicate research and “patch”-style standardization.

Wireless sensing technology

Wireless sensing technology is a wireless signal-based data acquisition, processing and analysis technology. Wireless sensing technology utilizes wireless sensors, intelligent algorithms and other means to achieve the real-time sensing and monitoring of targets in the physical environment.

The wireless communication signal in the mobile network is affected by the surrounding environment in the process of propagation. These effects are reflected in changes of signal amplitude, phase and other characteristics. The receiver is not only able to get the communication information, but also able to extract the sensing information. Sensing information refers to the characteristics of the propagation environment that are of interest to users. The integration of sensing and mobile network can reuse the large bandwidth spectrum resources and large-scale antennas of mobile communication system. Moreover, the network infrastructure can also be reused with a small overhead to provide sensing functions and services.

The 6G network architecture needs to cope with the changing demands of sensing services. From the perspective of the functional and interface design, the 6G network architecture is expected to support all the sensing modes in [7] and multi-node collaborative sensing [8]. At the same time, it is also expected to improve the sensing performance by AI capability.

Passive Internet of Things Technology

Passive IoT technology uses backscatter communication and wireless energy harvesting to realize passive low-cost terminal devices that communicate with readers. The passive IoT system is now widely used in various scenarios such as item identification, warehouse logistics, and so on. Radio frequency identification (RFID) is a typical passive IoT technology. However, RFID systems achieve poor performance in terms of coverage, communication rate, connection number, and security authentication. Therefore, RFID cannot well meet the requirements of ubiquitous IoT.

Taking advantage of 6G network, the requirements of ubiquitous IoT can be met. The passive IoT technology-enabled 6G network can support low-rate data transmission and high-accuracy positioning with meter or even smaller granularity. Therefore, the access requirements can be met in industrial manufacturing, smart transportation, smart agriculture, smart home, and other fields. In terms of access technology, by simplifying 6G air interface functions, protocols and processes, the complexity of the terminal is greatly reduced. Therefore, the passive IoT terminals in a wide area can access the network through the 6G air interface with almost zero power consumption.

From the perspective of network architecture design, multiple topologies need to be supported. The massive access requirements of various almost zero power IoT terminals need to be satisfied considering the widely distributed base stations and terminals in 6G network. In terms of functional design, the integration of 6G network and multiple network functions can be consider. For instance, the control, management, and high-accuracy positioning of almost zero power IoT terminals, as well as small and medium bandwidth business data transmission. In 6G, it is expected to realize a wide-area almost zero power IoT (AZP-IoT) communication network with minimal terminal complexity and low network costs.

Satellite mobile communication technology

Satellite communication is a communication method that uses artificial satellites as relays to transmit information. Satellites are positioned at high orbits with wide coverage, making them an effective complement to terrestrial cellular communication. In recent years, high-throughput satellites (HTS) emerge and inter-satellite link (ISL) technology develops quickly. Moreover, the middle earth orbit (MEO) and low earth orbit (LEO) constellations are continuously investigated. In the future satellite communication systems, it is expected to significantly reduce operating costs, enhance access capacity, and reduce the communication delays.

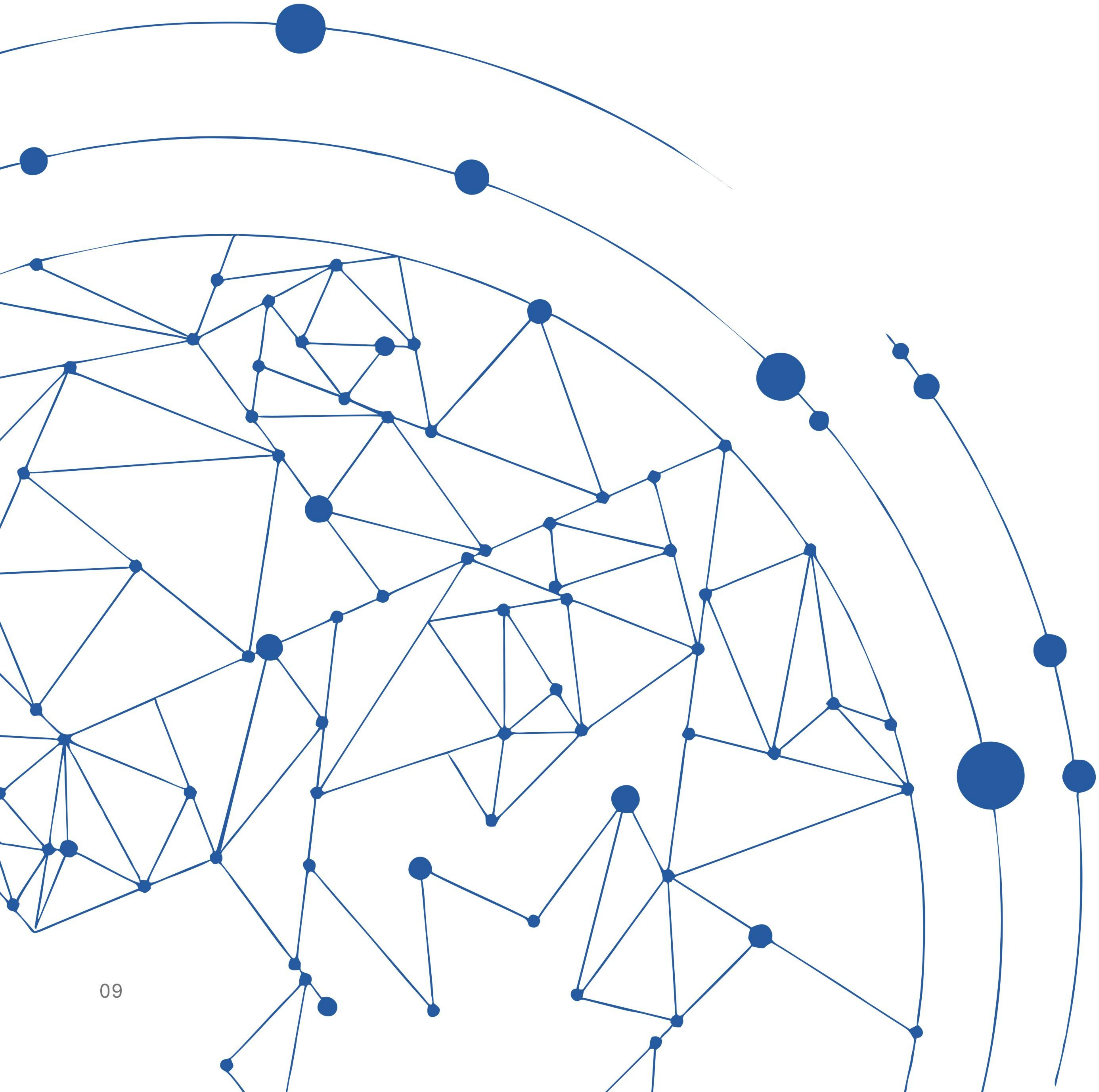
Compared to cellular networks, existing satellite communication still relies mainly on specialized user terminals. Due to the high cost of specified terminals, satellite communication technology is difficult to popularize. The comprehensive integration of terrestrial cellular networks and satellite communication systems will change this situation. The satellite communication industry can fully utilize the rapid development and economies of scale of the cellular network industry. Therefore, the terminal costs and service prices can be reduced to a more attractive level. With a globally unified standard of terrestrial and non-terrestrial integration, it will also overcome the differences between various satellite systems. Then the users can freely roam within different ground and satellite networks of different operators, achieving global three-dimensional coverage.

In the design of 6G, the integrated design of terrestrial mobile networks and satellite networks should be fully considered from the beginning. In this way, the differences in terminal characteristics can be minimized and the advantages of satellite communication can be fully taken.

2.3 Continuously enhancing the basic capabilities

ITU has set higher performance requirements for each generation of mobile communication systems compared to the previous one [4]. In the design of 6G network architecture, it is expected to improve basic network capabilities; achieve better user experience, better security performance and lower costs of deployment and operation; and realize more flexibility and shorter time-to-market for services.

In the design of 6G network architecture, it is expected to enhance basic network capabilities. The aim is to achieve better user experience, better security performance and lower costs of deployment and operation. Additionally, this endeavor seeks to enable greater flexibility and expedite the time-to-market for services.



Continuous improvement of user experience

The design of 6G network architecture needs to take the user-centric concept into account to ensure consistency of user experience. Traditional mobile networks focus on network-centric data collection, problem recognition and solving. A network-centric approach helps to improve the average user experience from a system perspective. In addition to this, it needs to consider supporting user-centric data collection, problem identification and solving in 6G network architecture design. The UE can quickly recognize problems based on the real-time and accurate local user experience information. These recognized problems can be solved through UE local optimization or end-to-end collaboration. The combination of network-centric and user-centric can elevate the lower bounds of user experience levels.

Native security

As the network evolves to 6G, the demand for network intelligence, ISAC, and integration of terrestrial and non- terrestrial will bring new security challenges. New technologies are required to provide stronger security capabilities for the 6G network. To address more complex and uncertain security forms, AI technology can be applied to 6G network security. AI technology can help the network to identify or predict possible security threats and risks. The future form of 6G UE will become more diverse, such as almost zero power IoT devices, AR and VR terminals, portable terminals, etc. The related security requirements will also become diverse and complex. Therefore, 6G network is required to support more flexible security access mechanisms. New technologies, algorithms, and even new security process designs can be adopted to meet the requirements of network security, such as diversity, flexibility, massive access. The 6G network will also bring some new businesses or more advanced capabilities, including ISAC. These capabilities bring users a better experience but also trigger higher demands for privacy protection.

Continuous cost reduction and flexibility improvement

The design of the 6G network architecture needs to balance the needs of centralized and distributed deployment. Moreover, on-demand flexible deployment, and costs reduction of network deployment and construction are also important. Secondly, the design of the 6G network architecture also needs to consider continuously improving the efficiency of network data collection, transmission and analytics. Network data collection, transmission and analytics provide a foundation for network automation operations, maintenance and energy saving. Finally, 6G network needs to continuously improve its scalability, including the scalability of network architecture, protocols, and technologies. The scalability of 6G enables the support of new applications and services, while also preserving the investment and use of existing networks.

03

Overview of 6G Network Architecture

Drawing an analogy with control plane and user plane in the existing standard, the plane usually has the following characteristics:

- **End-to-end connectivity:** UE, wireless access network, and CN supports the end-to-end interaction through the peer-to-peer protocol layer.
- **Isolation:** The functions of different planes are isolated. Each plane focuses on a class of functions and procedures.
- **Collaboration:** Different planes collaborate with each other to implement complete functions and services, such as communication service.

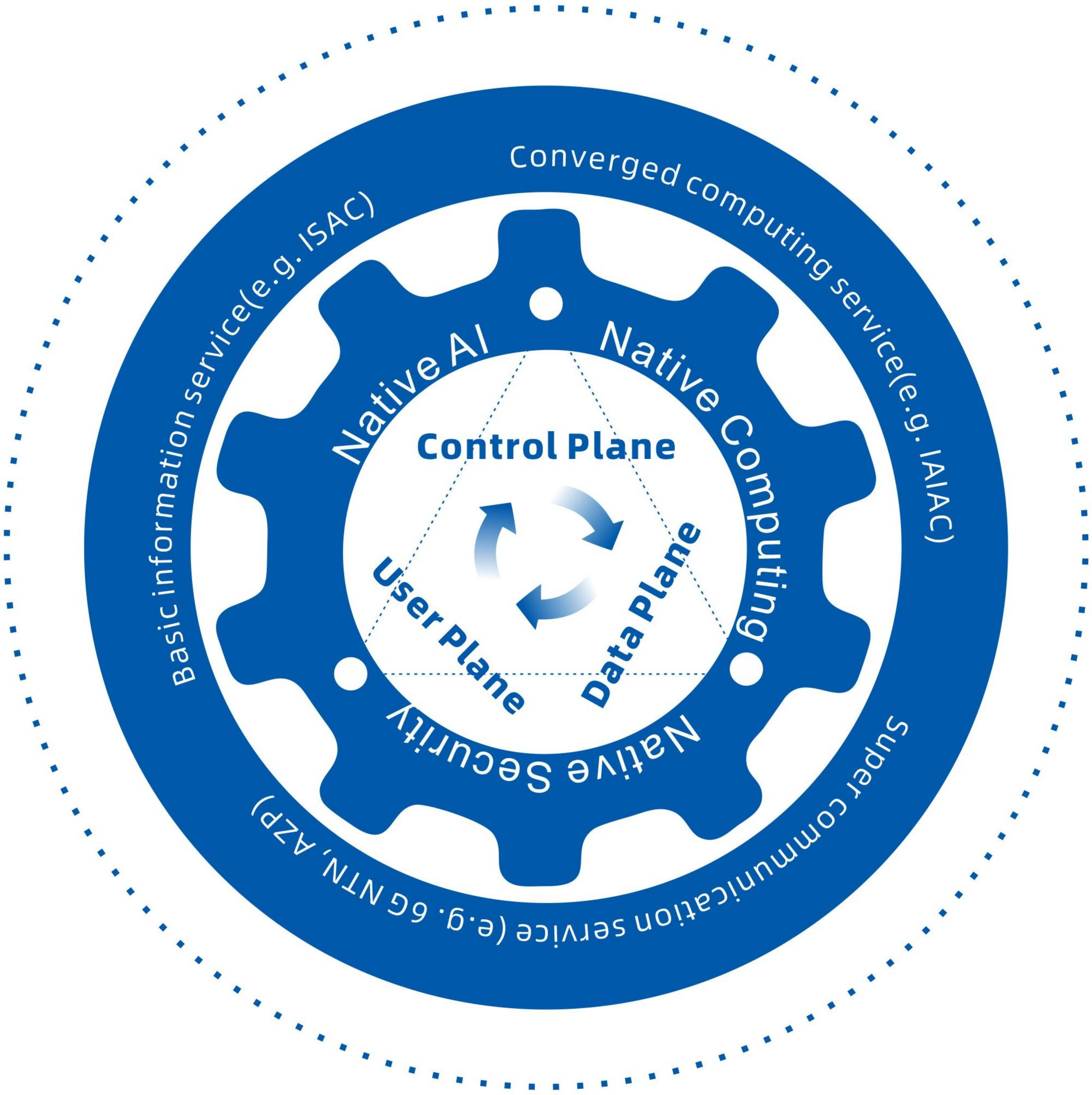


Figure 3-1. 6G system diagram

From the perspective of air interface, different planes may share several protocol layers. However, the configurations of protocol layer of each plane are different. Therefore, protocol layers can be reused among different planes. Meanwhile, the differentiated requirements of each plane also can be met. From the perspective of CN, each plane includes different network functions with their respective responsibilities. As shown in Figure 3-1, based on the characteristics of plane and function, 6G may introduce data plane and other planes on the basis of the control plane and user plane. The planes collaborate to support the key native characteristics, including native intelligence, native computing, and native security. This enables the services to the users.For example,it supports super communication services including 6G NTN and AZP-IoT.It also supports basic information services including ISAC, and converged computing services including integrated AI and communication (IAIAC).

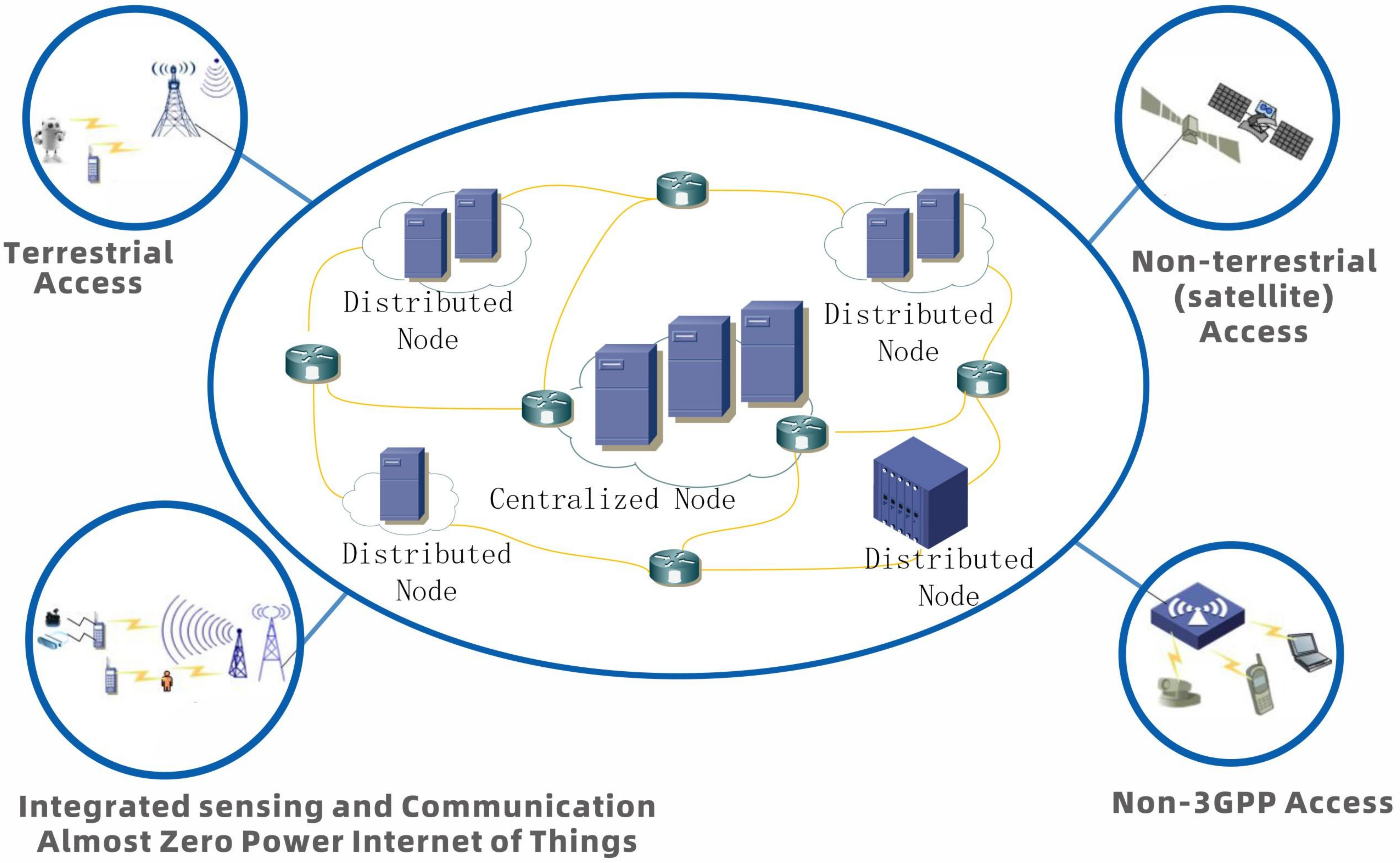


Figure 3-2. 6G system topology

For the overall topology of 6G, as shown in Figure 3-2, the 6G network architecture will be able to adapt to various topologies without loss of performance, including:

Combination of centralized and distributed network:

Centralized network function nodes are used to centrally process complex functions, such as security authentication. The centralized network functions can not only improve the overall network performance, but also reduce network costs by reducing the number of maintenance nodes. Distributed network function nodes can avoid network interruptions or degradation of service quality caused by single node failures. The distributed network functions also can be flexibly configured and adjusted according to application scenario requirements. Therefore, distributed network function nodes can improve network reliability and enhance network flexibility.

Terrestrial and non-terrestrial access complement each other

Terrestrial and non-terrestrial access can simultaneously meet the comprehensive demands of users for high bandwidth, low latency, and ubiquitous connectivity. 3rd Generation Partnership Project (3GPP) Satellite-integrated access technologies such as 6G and 5G, support mobile devices (e.g., smartphones) to access and communicate anytime and anywhere. 3GPP satellite integrated networks provide multidimensional services, such as high-speed data transmission with QoS guarantee, low-latency computing services, and sensing services, etc.

Integrated sensing and communication

One of the important areas of 6G is ISAC. ISAC is used for environment sensing through 6G wireless signal reception and transmission .

Almost zero power internet of things

Traditional high-performance internet for people is still one of the important areas of 6G. On this basis, AZP-IoT with low power consumption and simplified air interface is also one of the important areas that 6G needs to consider.

Multi-RAT integration

Although 3GPP access technologies, such as 6G and 5G, are important means of mobile access and high-rate data transmission. Non-3GPP access technologies, such as wireless fidelity (WiFi), can also provide lower-cost coverage and data transmission for indoor scenario and so on.

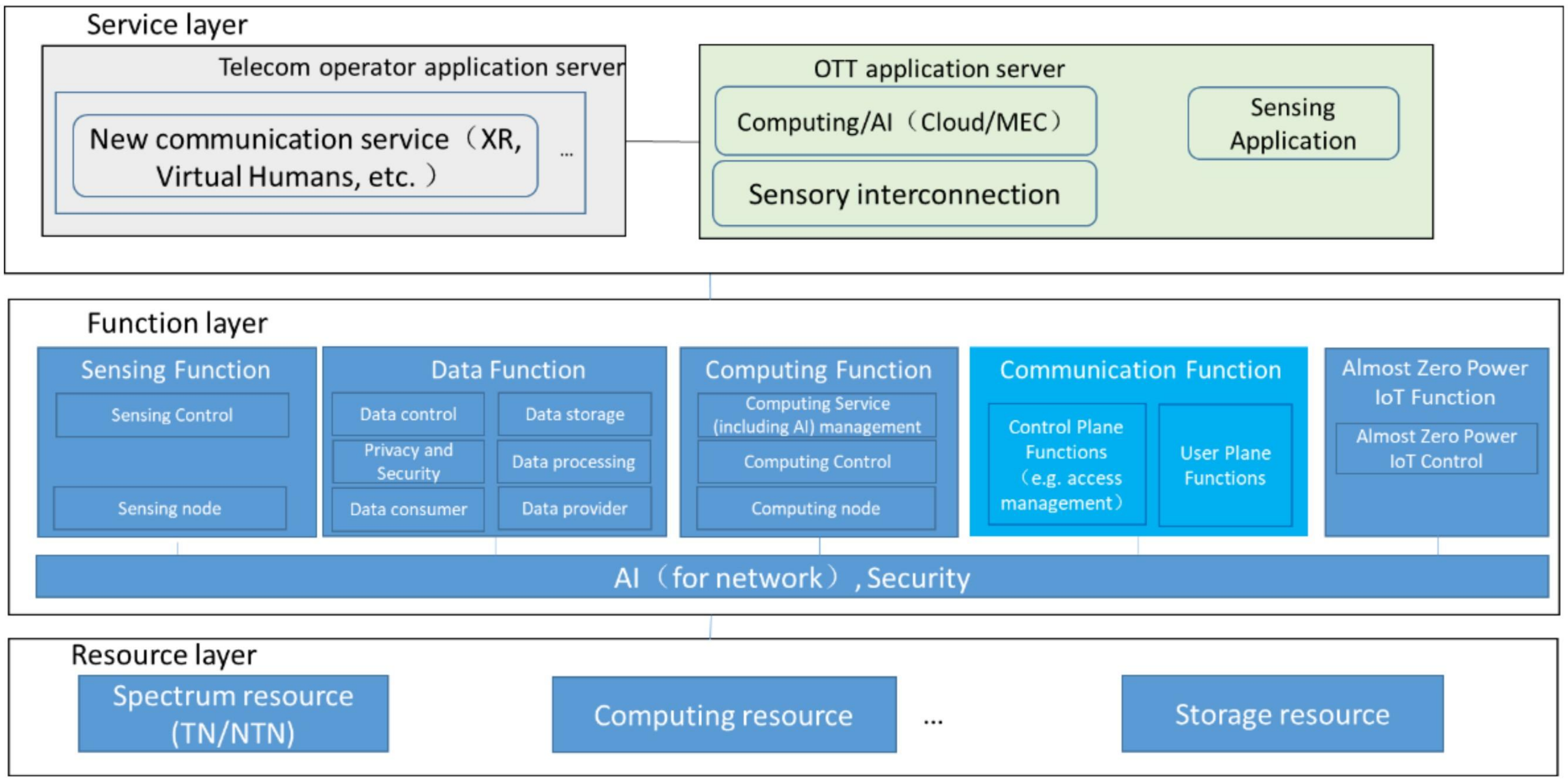


Figure 3-3. The functional architecture of 6G network

Furthermore, as shown in Figure 3-3, the functional architecture of the 6G network can be explained from the perspectives of service layer, function layer, and resource layer.

Service layer

It includes the service subsystems defined by 3GPP. For instance, similar to 5G IP multimedia subsystem (IMS). It also includes external network services. For instance, over-the-top (OTT) services. For the service layer, 6G will further enhance the existing IMS communication services to support new businesses such as immersive XR, digital humans, and multi-sensory interconnection. Correspondingly, OTT application servers will also expand the aforementioned new businesses, which demand higher transmission, sensing, and computing requirements on the 6G network.

Function layer

It mainly includes the function definition and procedures of the CN, RAN, and UE. Corresponding to 6G services, the existing communication functions, such as access management, mobility management, session management, policy control, and user plane data transmission, will be enhanced. Meanwhile, new network functions will be introduced, such as sensing, computing, data, AZP-IoT security, and intelligence functions. These functions enable ISAC, convergence of mobile network and computing, cross-domain data interaction, native intelligence, and AZP-IoT.

Resource layer

In addition to traditional spectrum resources, the resource layer also needs to include computing resources and storage resources.

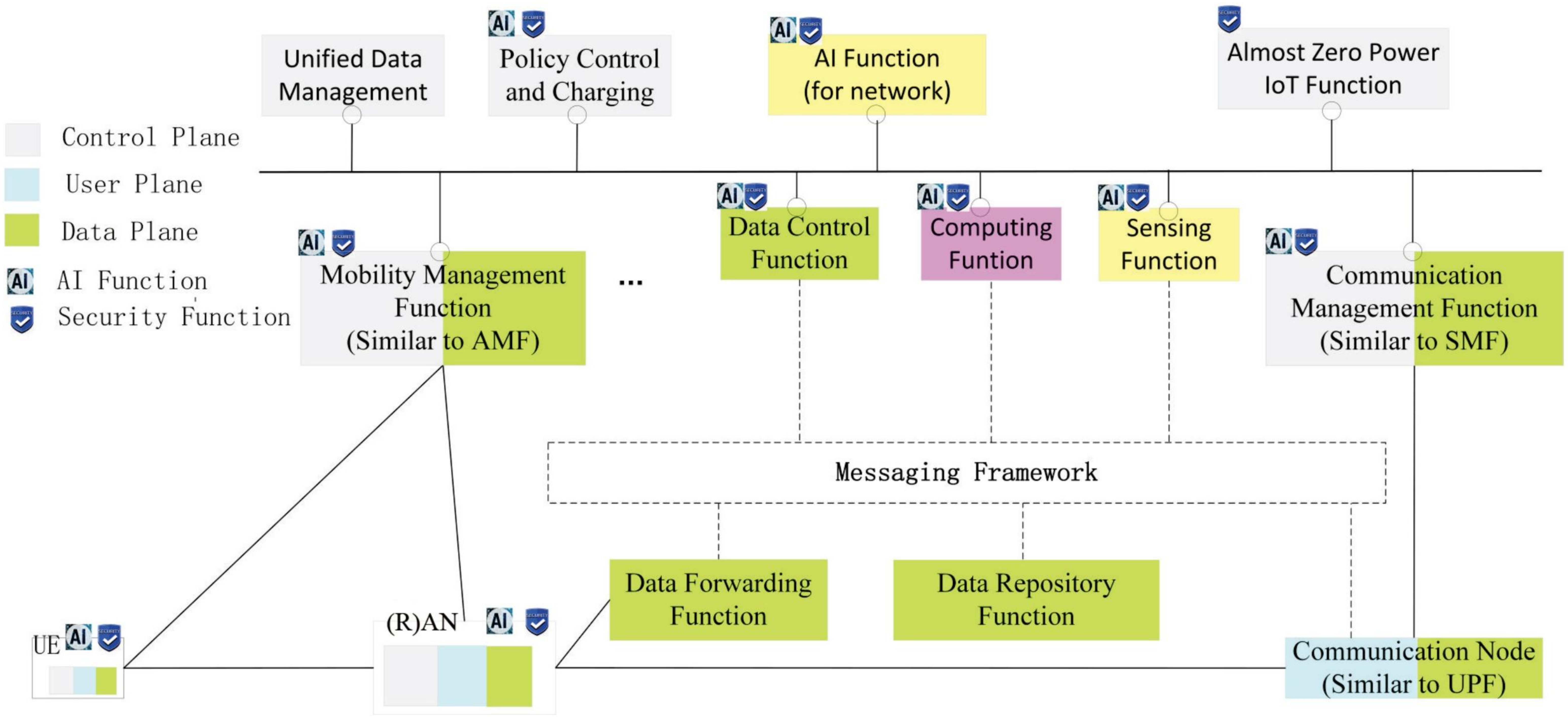


Figure 3-4. An example of 6G network architecture

In order to present the overall 6G network architecture in a visual way, we attempt to provide a 6G network architecture example based on a series of assumptions, as shown in Figure 3-4. For communication functions, we have assumed the adoption of current 5G standards without reflecting the further enhancement that will be brought by 6G, because many different potential evolution options are still under discussion. Data functions, sensing functions, AZP-IoT functions, computing functions, security functions, and intelligence functions are shown in the SBA.

Data functions: CN data plane functions include data control function, data plane transmission function, data storage function, etc. 6G data plane consists of the aforementioned CN data plane functions and the peer-to-peer protocol functions of RAN and UE.

Sensing functions: Used for sensing control, as well as the acquisition and processing of sensing data, etc.

Almost zero power IoT functions: Used for management of AZP-IoT devices, task decomposition and control of AZP-IoT services, data forwarding control, and small data forwarding based on the control plane, etc.

Computing functions: Used for control and management of computing resources in the mobile network when providing computing services (including external AI services) to external functions.

-Security functions: Used to provide stronger security capabilities for 6G.

Intelligence functions (for network): Used for supporting AI model training, model inference, network control operation recommendations, and other functions when providing AI capacities for network functions.

New messaging framework: In the 5G standard, the existing SBA is mainly used in control plane functions. Considering the efficiency of data transfer, the messaging framework is one of the potential options to support a large amount of data transfer in CN.

Corresponding to the functions of CN, RAN and UE also need to introduce peer-to-peer functions to support the enhancements of communication and new features of 6G. Considering the difficulties of presenting multiple options of development in one example diagram, Figure 3-4 is only an example of the 6G system functional architecture. The purpose of the example is to help readers understand the association and differences between 6G and 5G in a more concrete way.

04

Key Technologies of 6G Network Architecture

4.1 Convergence of mobile network and computing

Based on the overview of 6G architecture, key technologies of 6G network architecture are further elaborated in this chapter. It includes convergence of mobile network and computing, ISAC, AZP-IoT, AI-enabled network, data service and data plane, distributed network, 6G-satellite integrated network, etc.

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As described in Chapter 2, 6G system will natively support converged computing functions and provide converged computing services. The converged computing service includes AI service. When the latency of cloud computing service can not meet the computing service requirements, the converged computing service can solve the challenges of insufficient resource on the UE side, such as computing, storage, AI, etc. The convergence of mobile network and computing can provide lower latency and higher performance. Therefore, it is suitable for the scenarios with high real-time interaction requirements, as well as scenarios that require mobile network-assisted data computation.

The deep integration and unified design of computing and communication in 6G can meet the comprehensive service requirements of diverse services. At the same time, it also can realize the efficient and energy-saving utilization of network resources. Considering the service level agreement (SLA) demand, network load, computing power distribution and other factors, the mobile network with natively converged computing function can realize the full-domain awareness and the real-time cross-domain scheduling of network resources. It relies on the optimal collaborative scheduling strategy to realize efficient and energy-saving utilization of various types of network resources, such as computing, communication, data and etc. By offloading the computing demand to the mobile network, the mobile network with natively converged computing function can reduce the processing burden and power consumption of user equipment. The computing service provided by 6G also can improve the response speed and performance of user service, and extend the lifetime of user equipment. Therefore, the converged computing service could support more types of terminals such as headset and cell phone. The converged computing service will improve the user experience and benefit the various types of new application business forms in a wider range of commercial fields.

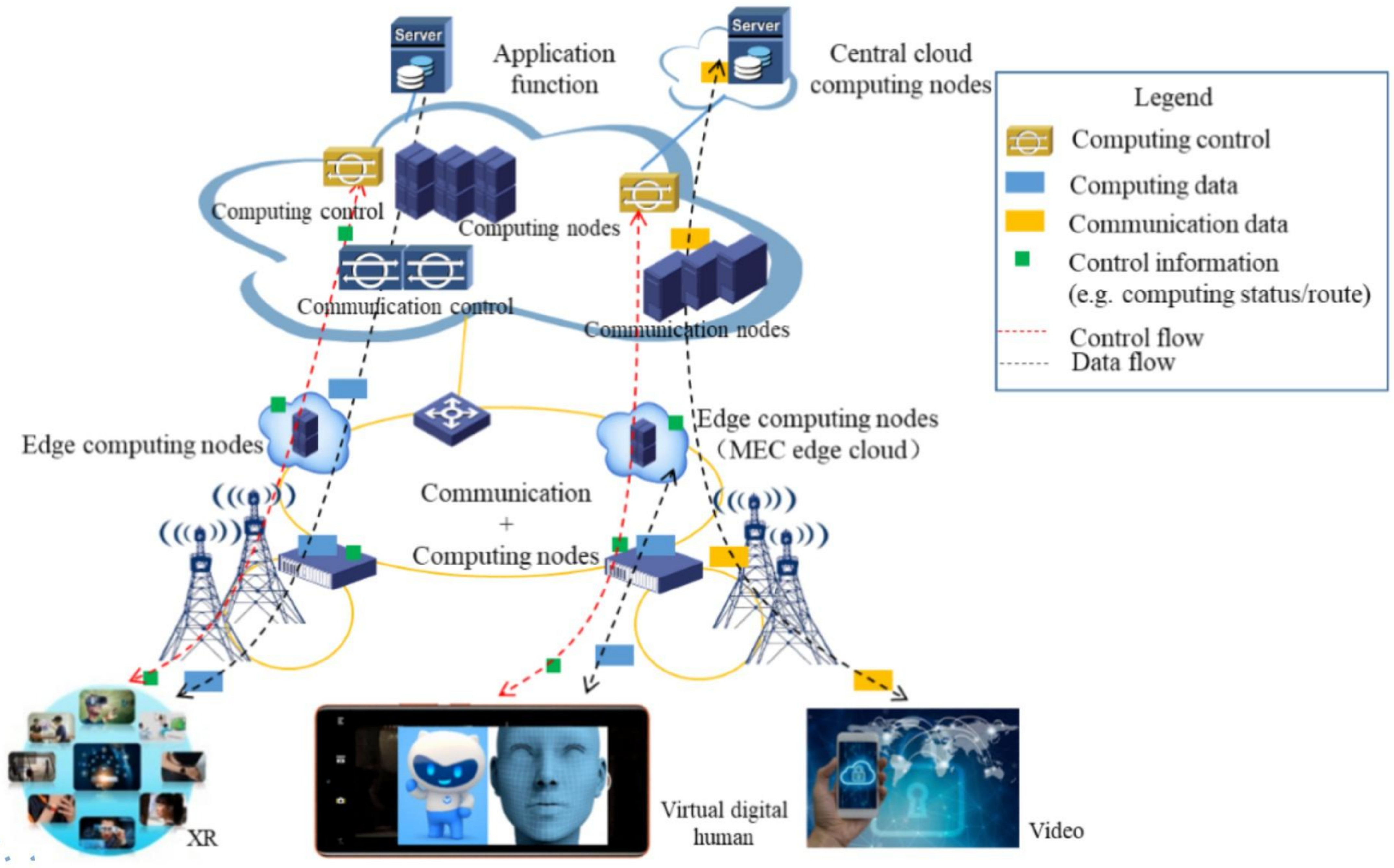


Figure 4-1: The architecture of convergence of mobile network and computing

The key to the convergence of mobile network and computing lies in how to break the boundaries between layers and merge the underlying computing resources and the computing requirements of upper layer applications, which is exactly the main task for the computing control function. A type of convergence routes is add-on convergence architectures, e.g., computing convergence enhancements based on the MEC architecture or the IMS architecture. These enhancements do not require a new control plane function, and may only be considered the computing aspects in the decision-making process (such as, the selection process of the service servers or the establishment procedure of the data channels). Another type of convergence route is the native convergence architecture of computing and communication, which introduces the computing control function into the control plane of the mobile communication network. Under the guidance of a unified policy, the computing control function is synergized with the communication control function to achieve collaboratively scheduling computing and communication resources.

As shown in Figure 4-1, the computing resources are not only in the EDGE or the cloud, but can be distributed to the user-plane function within the network, or even the base station. The computing control function compatible with the SBA architecture can be further divided into multiple service function to provide the computing service management function, on-demand allocation function, co-scheduling function and etc. The computing control function can support an end-to-end computing control protocol layer to the UE, to support the interaction of computing control information, including computing demands, computing resource allocation and updates.

The mobile network with natively converged computing function provides users with not only communication services, but also comprehensive data services. Therefore, the QoS mechanism should be enhanced to consider both communication aspects and computation aspects to ensure the user's service experience. Correspondingly, the session concept of the 6G system can be further enhanced to computing bearer/computing session, so as to better coordinate the allocation and scheduling of communication and computation resources and to ensure a unified quality of experience（QoE）.

In order to serve the AI computing service, the computing control function can be further devided into the following sub-functions: computing service (including AI) management function, computing control node (responsible for the AI model management function and etc.), and computing resource node. A feasible interaction process between the UE and the computing service management function can be as follows:

When requesting an AI computing service, the UE provides the network with the AI service identification, the QoS demand information, whether it needs network internal data and the data source information, and optionally, the UE can also provide model related information.

After receiving the AI service request from the UE, the policy management function derives communication processing policy/communication QoS and AI processing policy/AI processing QoS based on the QoS demand information.

The computation service management function can determine the AI model information by interacting with the computing control node, determine the data source information by interacting the data plane management function, allocate the computation resource node for the UE and configure the model parameters, data source address, and computing power information.

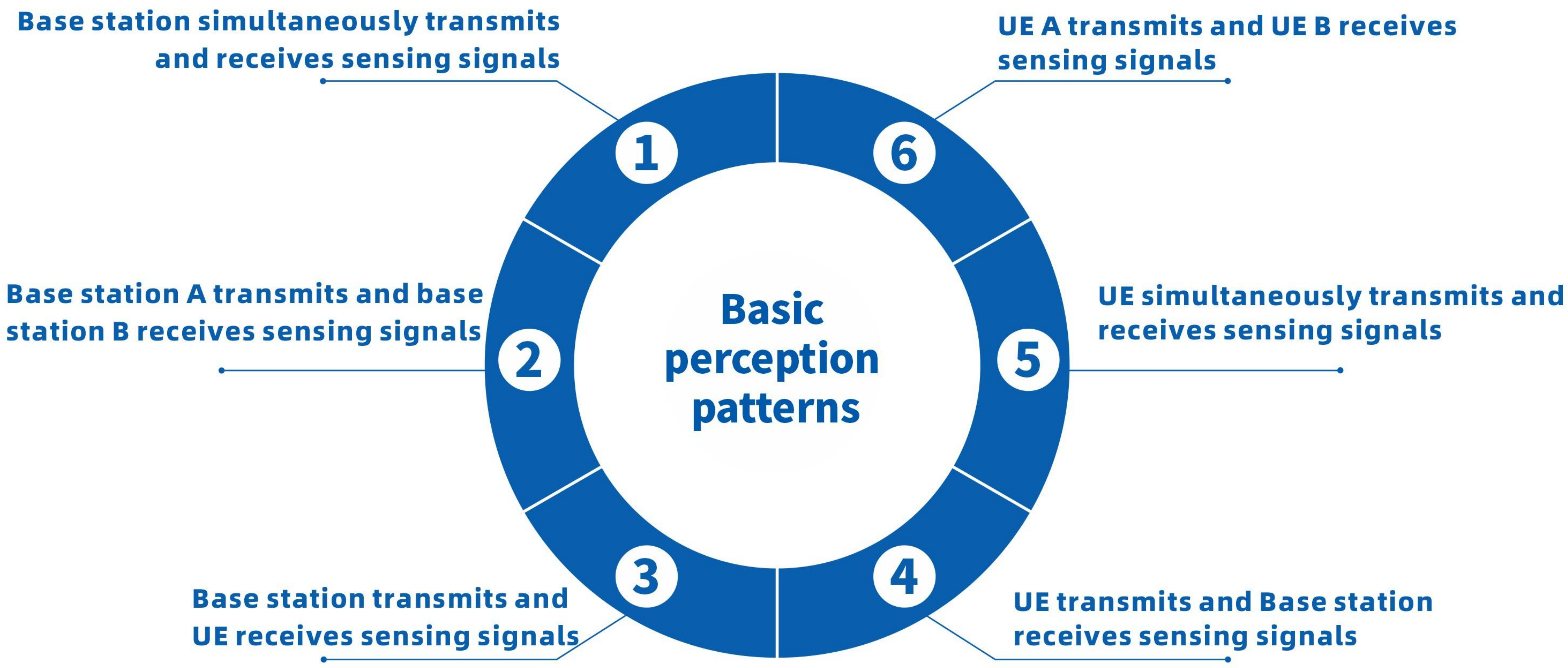
With the collaboration of the communication control function, the network establishes a communication session of the UE to the computing resource node/application server, and subsequently the UE can obtain AI services based on the process result of both communication resources and computational resources.

4.2 Integrated Sensing and Communication

As described in Chapter 2, sensing provides new means of acquiring information for mobile communication networks. ISAC will bring new business opportunities for 6G. Currently, 3GPP is discussing whether and how 5GS introduces sensing services. Some typical use cases and basic sensing functions are initially identified [9]. 6G is expected to have rich spectrum resources. For instance, Millimeter-wave and Terahertz bands, which have higher frequency and larger bandwidth. The rich spectrum resources provide possibilities for higher performance sensing services. From the perspective of network architecture, 6G sensing will have the following characteristics.

Full sensing modes

Considering that each sensing mode has advantages in different scenarios, 6G sensing should support full sensing modes. There are six basic sensing modes, including (1) Base station simultaneously transmits and receives sensing signals; (2) Base station A transmits and base station B receives sensing signals; (3) Base station transmits and UE receives sensing signals; (4) UE transmits and Base station receives sensing signals; (5) UE simultaneously transmits and receives sensing signals; (6) UE A transmits and UE B receives sensing signals. The full sensing modes also include the non-3GPP sensing mode, which refers to the use of the IoT devices in the communication network to capture massive sensing data, such as sensors, cameras, radar devices, etc. It can be fused with the 3GPP sensing measurement to improve the dimensionality and accuracy of the sensing results.



Common Sensing framework

To save deployment and operation costs, 6G network needs to design a generic sensing architecture to adapt to rich and variable sensing services and provide common sensing data or results. Specifically, the generalization is reflected in the following two aspects:

Common sensing measurements quantities: Considering different sensing scenarios, it is necessary to design common sensing measurement quantities. Different combinations of sensing measurement quantities can be used for the calculation of multiple sensing results, and even one measurement can serve multiple sensing services.

Common sensing intermediate results: To meet different services requirements from different consumers, it is necessary to expose common sensing intermediate results, e.g., velocity and position of the target objects. The consumers will process the sensing intermediate results according to their own service logic to generate the final sensing results, such as weather results, human health results, etc.

Different levels of sensing information are given in Table 4-1, in which the received signals or the original channel information are the most primitive sensing information. The raw sensing information has a large amount of data and needs to be further processed and analyzed in order to obtain the sensing measurements quantities and sensing results.

Sensing information	Contents of sensing information
received signal or raw channel information	Complex results of the received signal or channel response
sensing measurement quantities	Delay, Doppler, angle, strength, and their multi-dimensional combined representation
sensing results/ sensing intermediate results	Presence or absence of target, distance, velocity, orientation, acceleration, position, trajectory, movement, expression, respiration rate/heart rate, imaging results, weather, air quality, material and composition, etc.

Table 4 -1: Sensing information at different levels

Coordination between sensing and AI

In the 6G era, it can be expected that sensing services are rich and varied with different needs. So it is urgent to utilize 6G native AI capability to handle massive sensing service data. Specifically, AI can be used to assist the network in sensing data processing, analysis, computation, privacy protection and other aspects.

Multi-devices sensing coordination

6G can utilize a large number of sensing devices in the communication network for distributed collaborative sensing. For example, by collecting environmental data from different angles and locations, sensing the environment more comprehensively and improving the sensing coverage; through the joint judgment of multiple sensing links, the accuracy of detection or identification of sensing targets can be improved; through the balancing and backup switching between multiple nodes can improve the robustness of the system, interference resistance, and the efficiency of data transmission and processing, as well as the continuity of the sensing service.

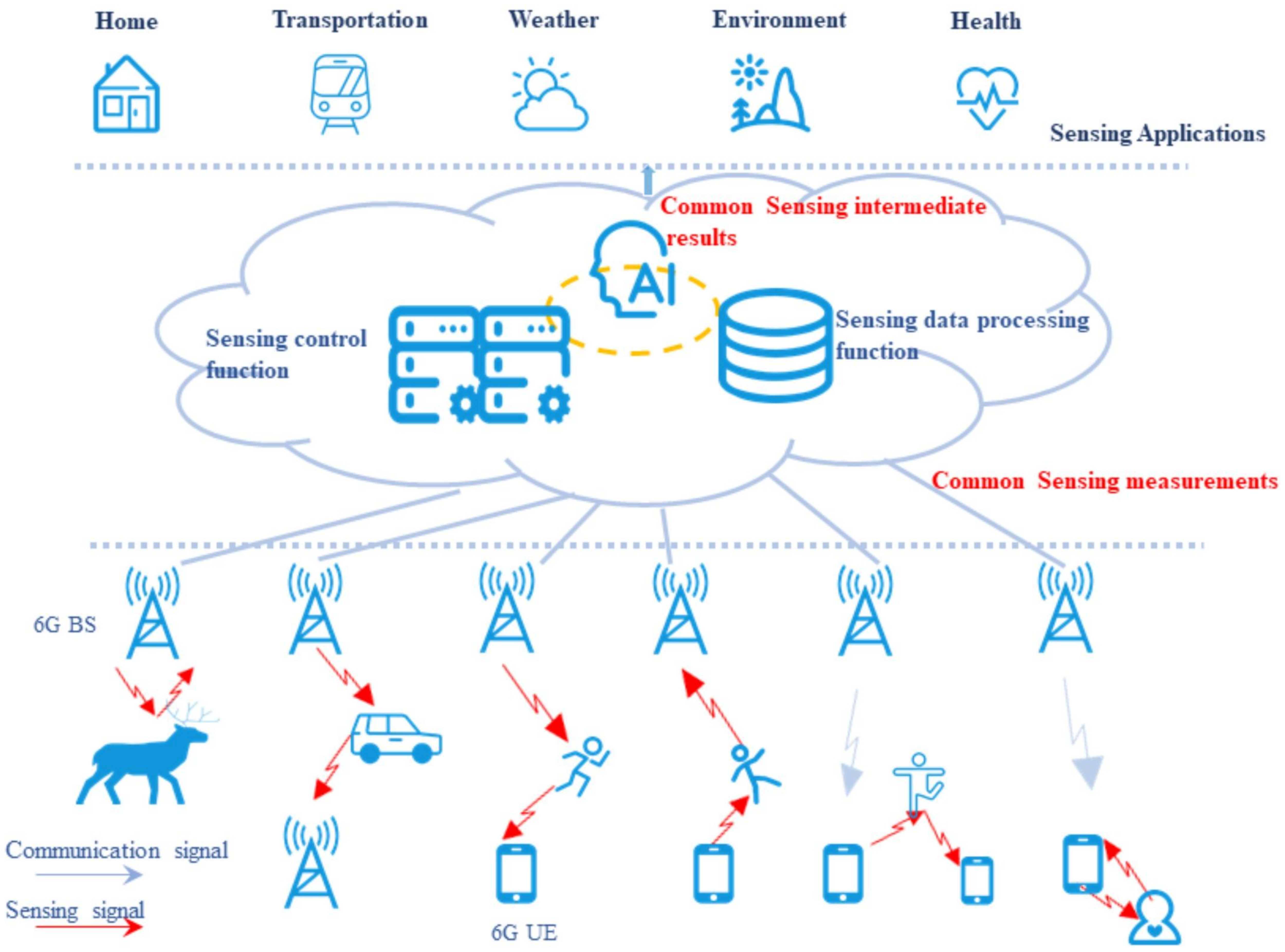


Figure 4-2. The architecture of Integrated Sensing and Communication

Sensing related entities in 6G network include sensing control function, sensing data processing function, and sensing signal transmitting and receiving devices. The sensing control function is in charge of signaling and policy control of the sensing service. The sensing data processing function is used to process and analyze sensing data to obtain sensing results or intermediate results. The sensing signal transmitting and receiving devices are used to transmit and receive sensing signals correspondingly. In addition, they are used to measure the sensing signals to obtain information about the environment or the target object.

Based on Figure 4-2, an example of sensing service process is described as follows:

Sensing service triggering

When a consumer requests a sensing service from the network, the sensing control function first needs to trigger the sensing authorization and security verification process to confirm that the consumer can access the sensing target related information. In addition, the sensing control function also needs to assign the corresponding sensing service PCC policy, which can provide differentiated sensing service guarantee for consumers.

Selection of sensing transmitting and receiving devices

The sensing control function determines the appropriate sensing mode(s) from the full sensing modes according to the service requirements. In addition, it determines the appropriate sensing transmitter and receiver. The adapted sensing mode can be a mixture of multiple modes.

Sensing Measurement Execution

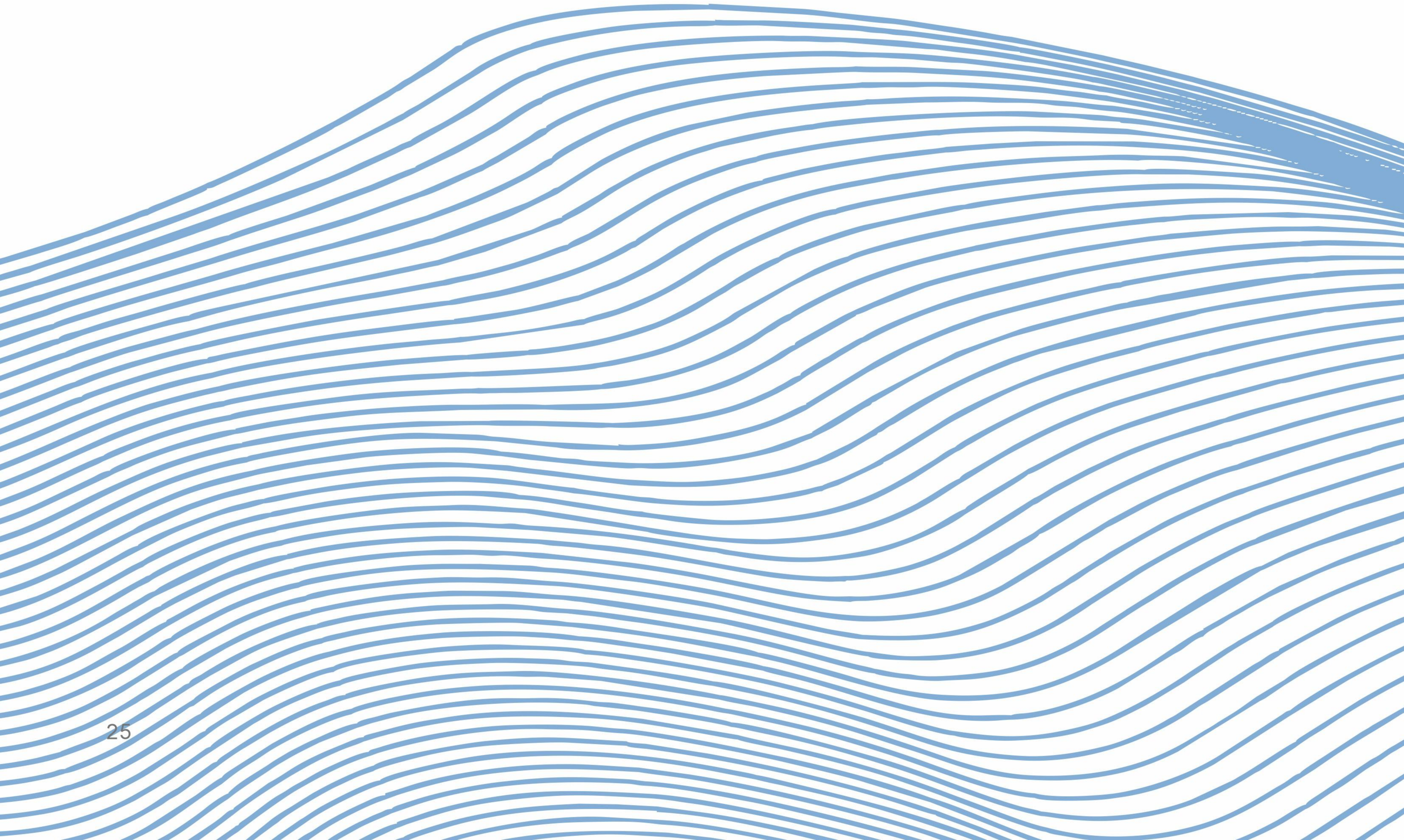
The sensing control function triggers the sensing signal transmission, reception and measurement according to the corresponding sensing modes, in which multiple sensing transmitting and receiving devices can perform multiple sensing modes. Besides, the PCC policy needs to ensure the cooperation not only between different sensing transmitting and receiving devices, but also between the communication and sensing services.

Sensing Result Generation

Sensing transmitting and receiving devices report common sensing data to the sensing data processing device. It will analyze the sensing data to obtain the common sensing intermediate results, and the process can be considered to incorporate AI capabilities. The sensing data processing device exposes the sensing intermediate results to the consumers, which will be processed by the consumers according to their own service logic to generate the final sensing results.

4.3 Almost Zero Power Internet of Things

As described in Chapter 2, the convergence of mobile networks with passive IoT technologies can take advantage of the strengths of mobile networks. In the 5G era, 3GPP starts the discussion of use cases for AIoT technology. Requirements to the mobile system are discussed to support the reduction of the complexity of AIoT devices, enabling AIoT devices to work with very low power consumption [12][13] in the usage scenarios. AIoT devices are devices that can obtain energy from the environment (e.g., solar energy, radio waves, vibration, etc.) for communication. They can be classified into three categories based on whether or not there is an energy storage as well as the communication method: Device A does not have energy storage, and can only use backscatter technology for communication; Device B has energy storage, and can only use backscatter technology for communication; Device C has energy storage and can generate carriers for communication independently. AIoT devices can communicate with the 5G system through a UE or base station. The uplink or downlink data can be forwarded through a 5G relay node or an assistant node. Among the use cases of AIoT devices, there are four typical scenarios including inventory, sensor data collection, location acquisition, and actuator control. In these scenarios, AIoT devices transmit small amounts of data and the transmission latency demand is not stringent [12].



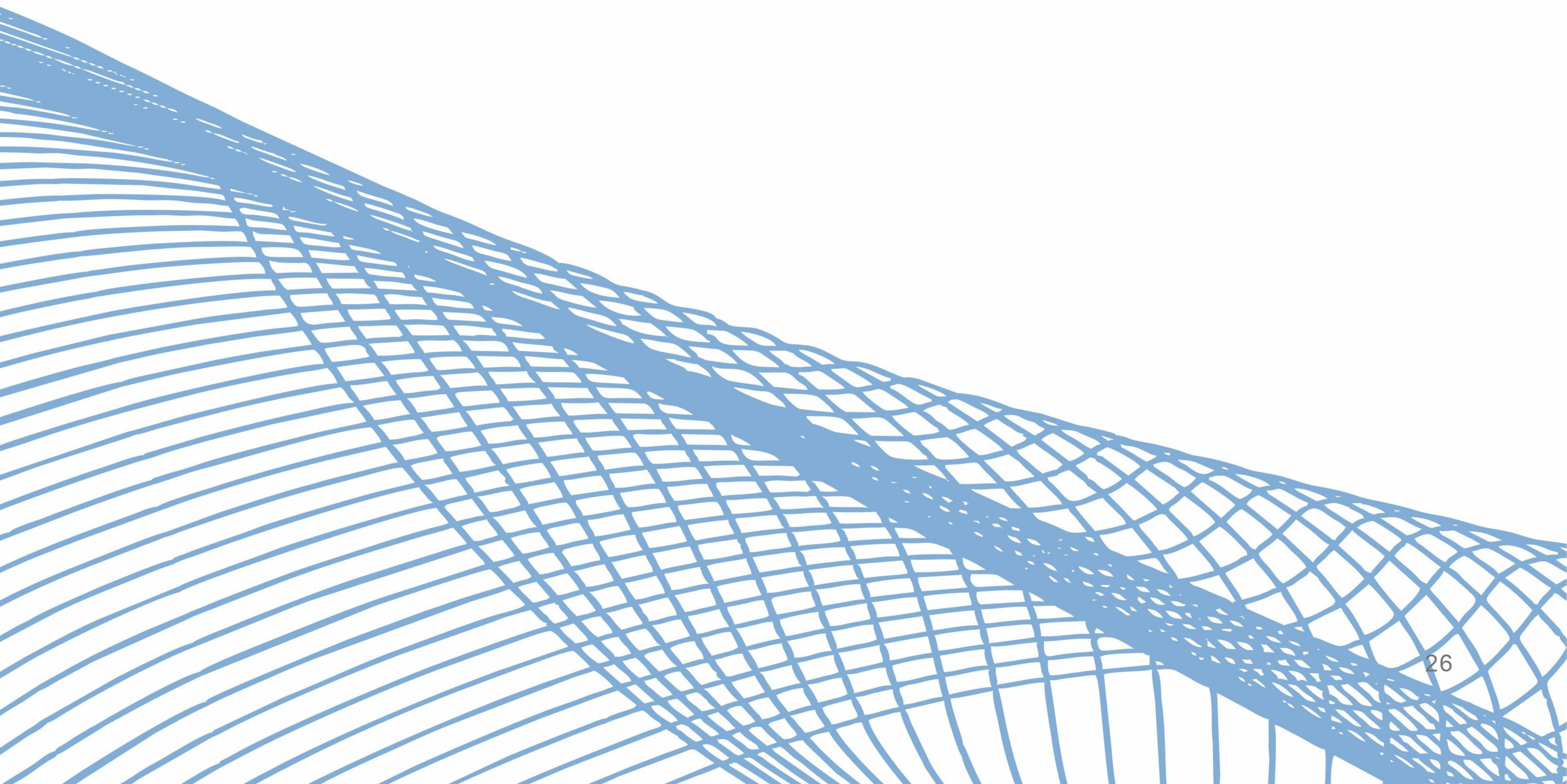
As described in Chapter 2, AZP-IoT is an important part of the 6G network architecture. 6G AZP-IoT network architecture is a brand-new network architecture, which does not need to be constrained and limited by existing network architectures. For functional design, an independent network element function can be set up in order to support the Almost Zero Power IoT technology. With this, the network architecture natively adapts to the needs of ultra-large-scale, low-complexity, and almost-zero-power IoT. In addition to fully supporting the above AIoT scenarios and requirements, the 6G AZP-IoT network architecture needs to further consider the following two points:

AZP-IoT full-rate scenarios

In addition to the aforementioned scenarios where the data volume is small and insensitive to transmission delay, AZP-IoT devices can also be used in some medium-rate scenarios, for example, loading small-volume AZP-IoT devices on implantable medical devices such as endoscopic capsules, which can record images of the inside of the gastrointestinal tract, realizing fine inspection while eliminating patient pain. In this scenario, the AZP-IoT devices need to support larger bandwidth data transmission. Therefore, the 6G AZP-IoT network architecture should be able to meet the access and data transmission requirements of AZP-IoT devices in multiple data-volume scenarios.

High-accuracy positioning support

In addition to indoor stationary scenarios, the 6G network architecture needs to satisfy the demand for high-accuracy positioning with meter or even smaller granularity and tracking of AZP-IoT devices, so as to better satisfy the scenarios of logistic tracking, herding, and personal asset finding.



As shown in Figure 4-3, the 6G AZP-IoT network architecture should consider to use the widely distributed base stations and terminals to support a variety of topologies to enable access to 6G network for a large number of diverse AZP-IoT devices. The connection between AZP-IoT devices and the 6G network can be conducted in a variety of topologies: (1) A 6G terminal acts as a reader, allowing 6G UEs to perform offline operations in certain scenarios; (2) A 6G base station acts as a reader; (3) An AZP-IoT device accesses the 6G network through a 6G relay node and a 6G base station; (4) The downlink of an AZP-IoT device is directly connected to the 6G base station, while the uplink is connected to the 6G base station through an assistant node and (5) The uplink of an AZP-IoT device is directly connected to the 6G base station, while the downlink is connected to the 6G base station through an assistant node.

In terms of functional design, the 6G network architecture natively considers the needs and scenarios of the AZP-IoT, for example, designing an independent AZP-IoT control function for the AZP-IoT, which are isolated from the network functions serving 6G UEs, to provide more efficient management and coordination functions. Specifically, the following aspects may be included:

Device management

It includes management of AZP-IoT devices and management of readers. There are huge number and diverse types of AZP-IoT devices. AZP-IoT device management includes management of reachability and state machine of AZP-IoT devices. Reader management includes authorization of a reader, configuration, cooperation and coordination between readers.

Operation task control

It supports authorization of AZP-IoT service requests, generation of operation tasks, and selection of one or more readers for distribution. Especially in the case of multiple readers cooperating to perform the same task, the operation task control function serves as a task anchor point to manage the life cycle of the task and the continuity of the task.

High-accuracy positioning

It supports for invoking and acquiring high -accuracy location information of AZP-IoT devices. 6G network needs to support new measurement signals, measurement configurations, and process control based on the features and capabilities of AZP-IoT devices. However, this functionality should be defined in a converged location service function. This functionality supports more the invocation of positioning services to obtain a high -accuracy location information of the AZP-IoT device.

Data forwarding control

It controls the data forwarding mechanism which would be used, for example, small data can be forwarded through the control plane, and data for relatively large bandwidth services can be forwarded by establishing a user-plane channel using the user-plane resources in Figure 4-3. In the case of forwarding through the user-plane, further group operations can be used to improve data forwarding efficiency.

Small data forwarding function based on control plane

When the data forwarding control decision is based on the case of small data forwarding by control plane, the AZP-IoT control function is further required to support small data forwarding between the reader/ AZP-IoT device and the application server.

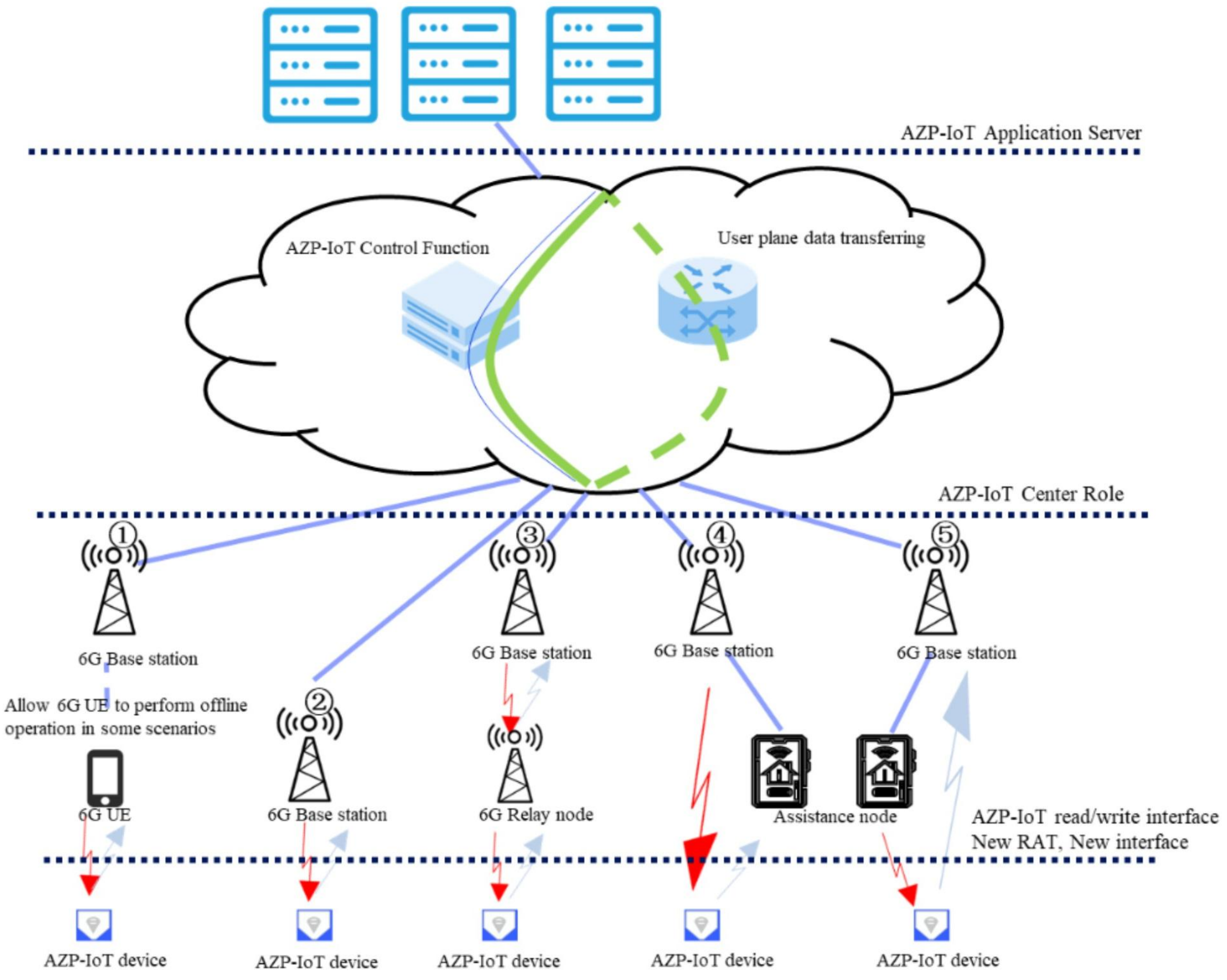


Figure 4-3. The architecture of AZP-IoT

Based on the network architecture in Figure 4-3, an example communication process of an AZP-IoT is as follows:

Inventory task triggering

The application server requests an inventory task from the 6G core network which is responsible for authorizing the task request.

Reader selection and task distribution

The AZP-IoT control function is responsible for selecting readers and decomposing the task and distributing it to one or a group of readers.

The reader discovers AZP-IoT devices and communicates with them

Secure communication mechanism is supported between the reader and AZP-IoT devices. The reader or the core network controls the information reading from the AZP-IoT devices and activates the security mechanism on demand for the read information to protect information privacy.

Returning inventory results to the application server

The 6G network returns the inventory results of single or a batch of AZP-IoT devices via the control plane or the user plane. After the task is completed, the AZP-IoT control function closes the loop of the task.

6G core network manages the AZP-IoT devices read by readers

The 6G core network manages the reachability, status of the read AZP-IoT devices for the next trigger of the AZP-IoT task.

4.4 AI enabled Network

Since 5G era, AI function has been introduced in the 3GPP standards sequentially in CN, network management system and RAN. After several versions of enhancement and evolution, AI function covers more and more scenarios, use cases and communication function entities. Taking NWDAF (Network Data Analytics Function) as an example, which is responsible for the AI function of the core network, there are more than 10 use cases and corresponding usages of AI defined in the current 3GPP standard. These use cases include statistics and predictions for user service experience, UE abnormal behavior, network performance, etc [10]. Since R18, RAN workgroups have also begun to study AI-based enhancement for air interface, some use cases are identified gainful including AI-based CSI control, AI-based beam management, and AI-based positioning [11].

Based on 5G AI, 6G AI enabled network architecture has the following characteristics:

Native AI

Native AI in 6G refers to the native integration of AI capabilities into the 6G network, where AI is considered in the architecture design at the beginning of 6G. The functions, interfaces, capabilities, and signaling structures required for various AI use cases are reserved to achieve deep integration with the mobile communication network.

Distributed cross-domain AI

To improve 6G performance overall, 6G should support both highly autonomous single-domain AI and highly efficient cross-domain AI. Thanks to distributed network computing resources, 6G can carry out end-to-end distributed AI function deployment. Adapting to different cloud, edge, and UE computing resource situation, 6G network differentially schedule or split AI tasks among different entities. In addition, the introduction of technologies such as federated learning to address data isolation between UE, base station, core network and OTT server is another driver for distributed AI.

AI performance can be verified

6G can make use of digital twin network technology to verify the performance of AI. In the model training phase, each round of AI outputs will be applied to the twin network to generate the network state, and then use reinforcement learning methods to train the model; in the model inference phase, the results of the inference will be verified in the twin network beforehand. Based on the state and gain of the twin network, it can be decided whether or not apply the inference results in the real network.

Advanced intelligent recommendation

With the assistance of technologies such as reinforcement learning, digital twin network, universal model, etc., 6G AI can ensure the global nature and accuracy of the AI model. Based on this, 6G AI can directly obtain recommendations of end-to-end control operations on the network for the target requirements of specific scenarios.

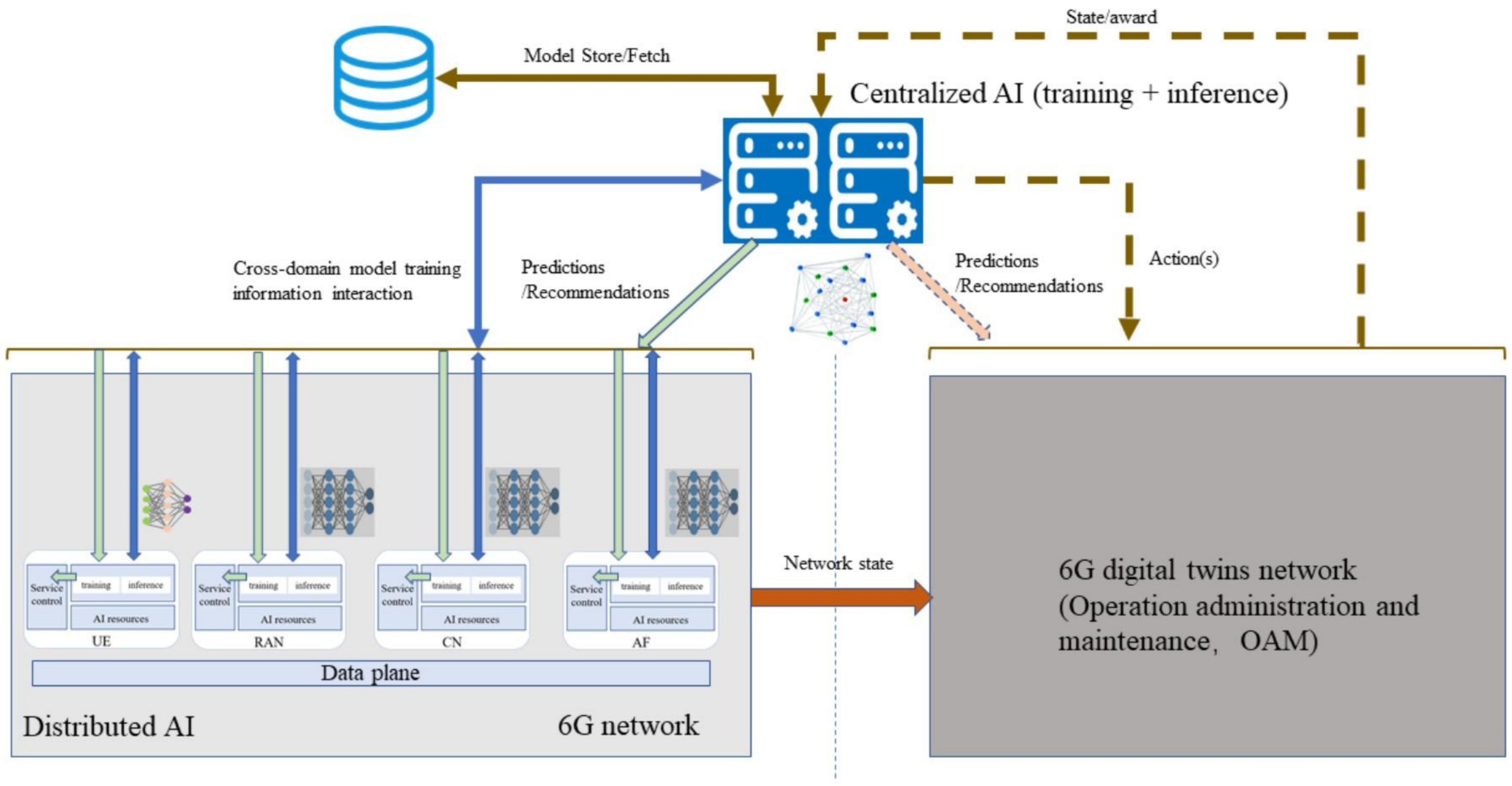


Figure 4-4. The architecture of AI enabled Network

Based on Figure 4-4, an example of a general procedure of AI enabled network is:

Model training

To protect data privacy, distributed cross-domain model training methods can be used for model training. Typical model training methods are horizontal federation learning and vertical federation learning. In these methods, distributed AI nodes interact with centralized AI nodes with intermediate models or intermediate data to jointly complete model training. The advantage of the distributed cross-domain model training method is that it can make full use of the data resources and computing resources of the distributed nodes, and thus avoid the data privacy problem while improving the efficiency of model training. In addition, considering that the state of the network will change with the model training processing, the model output may affect the state of the network in the next stage. Therefore, to train more accurate AI models, the model training process can also combine with reinforcement learning method by interacting the model output and network state with the 6G digital twin network.

Model inference and validation

For specific service requirements from network or users, the AI node performs the model inference based on the trained model, and produces the inference results. In addition, considering that the uncertainty of AI may have a negative impact on the existing network, 6G AI nodes can perform a pre-verification process of the inference results with the help of digital twin networks.

Recommendation for network control operations

Based on the verification results, the 6G AI node decides whether or not to send the AI model inference results to the 6G real network. In order to achieve more advanced network intelligence than 5G AI, 6G AI nodes can directly output recommendations for network control operations based on model inference, if the global nature and accuracy of the model can be guaranteed. For example, to protect the quality of service, 6G AI nodes can generate the inference results to recommend how to set QoS parameters for each node in the network.

4.5 Data service and data plane

As described in Chapter 2, data is the basic element and common requirement for ISAC AImodel training, and user experience enhancement.

Data services serve both external functions and network functions, which are called network for data service and data service for network. Exposure of network capabilities is an example of network for data service. The training data collection for network AI use case is an example of data service for network.

The requirements of data services include a large amount of data collection and transmission, flexible data termination at any network function node, data reuse, anonymous data collection, and data privacy and security.

In order to avoid control plane carrying a large amount of non-signaling data and to avoid user-plane transmission terminating inside the network, the data plane is introduced. The function design and parameter configuration of the 6G data plane can be optimized for the aforementioned requirements.

The 6G data plane can also provide a unified solution rather than many fragmented solutions to different use cases.

Taking positioning data as an example, the efficiency of data transmission can be improved by reducing duplicate ASN.1 encoding/decoding and encryption/decryption during data transmission process. Therefore, the introduction of the data plane can improve data transmission efficiency, achieve data reuse, enhance cross-domain data collaboration, and facilitate scalability to meet new requirements.

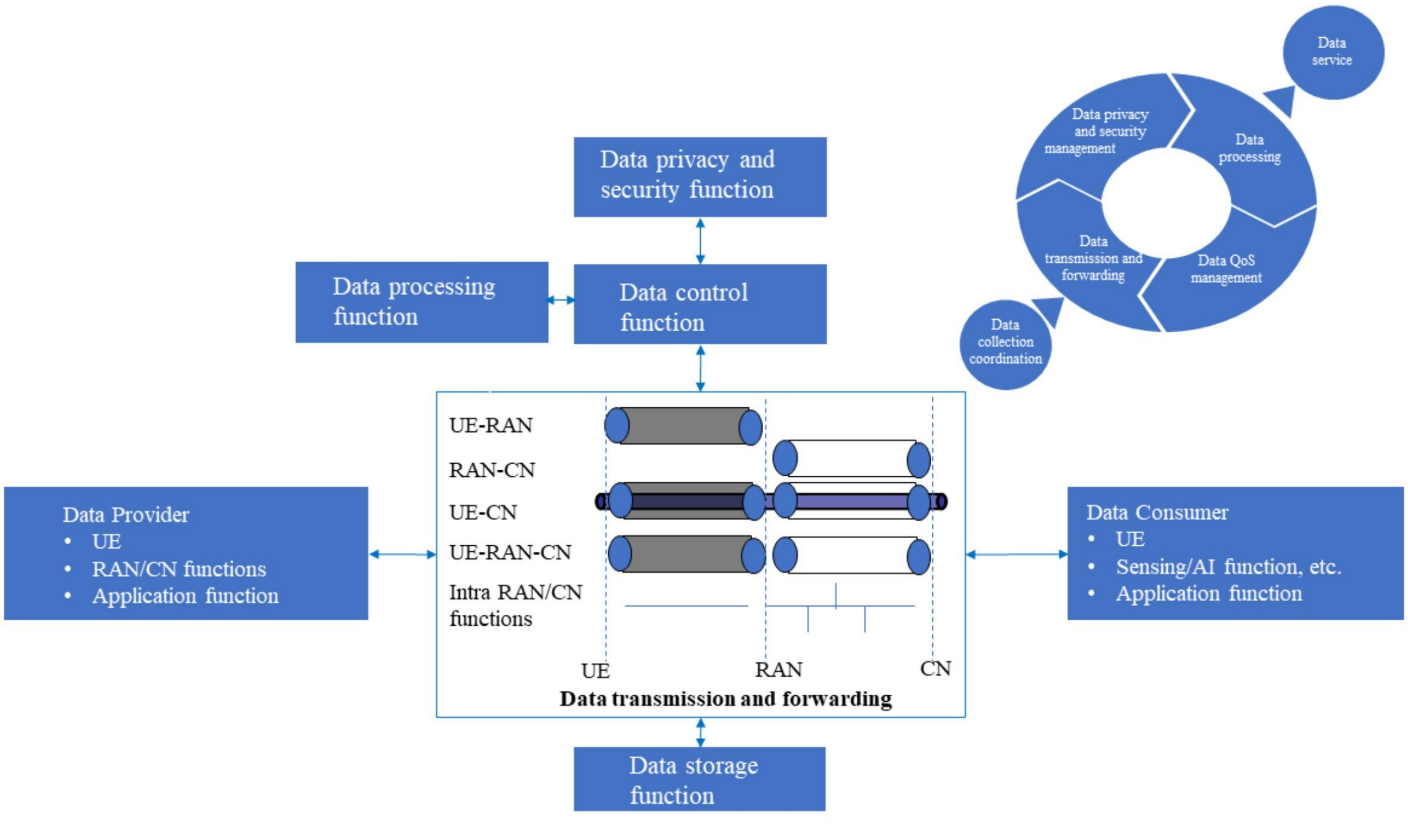


Figure 4-5. The architecture diagram of data service and data plane

The architecture diagram of data service and data plane is shown in Figure 4-5. The end-to-end data-plane functions include the following functions.

Data Control Function (DCF)

DCF is used to support data collection coordination, data service configuration (e.g., data packet size, interval, etc.), data transmission configuration (e.g., establishing / modifying / releasing data plane transmission channels), and data processing configuration (e.g., data pre-processing or data analysis configuration, etc.).

Data Privacy and Security Function (DPSF)

DPSF is used to support the mechanisms of privacy and security, such as authentication, authorization, access control, etc.

Data Repository Function (DRF)

DRF is used to support the persistent storage and retrieval of data collected by the data plane.

Data Transmission Function (DTF)

DTF is used to support the forwarding and transmission of data plane data based on the configuration from DCF. Depending on the termination node of data transmission, data plane transmission includes several data transmission protocols. For instance, the protocol between UE and RAN, RAN and CN, UE and CN, as well as the protocol of intra RAN functions or intra CN functions.

Data Processing Function (DProcF)

DProcF is used to pre-process data or provide data analysis according to the requirements of data service.

Data Provider (DPro)

DPro provides the required data according to the configuration from DCF.。

Data Consumer (DCons)

DCons sends data requests and receives data responses.

Based on Figure 4-5, an example procedure of a data consumer requesting data from the CN DCF is briefly described as follows.

- When one or more DCons request data from the CN DCF or subscribe to data, data privacy and security management is needed. One option is that DCF requests authorization information from the DPSF. Then DCF determines whether the DCons can access the required data and whether the DPro can provide the required data.
- If data collection is permitted, DCF performs data collection coordination. In other words, DCF removes duplicate data among different requests. It also means the collected data can be reused to avoid redundant data collection. Then, DCF configures the selected DPro via data plane protocol stacks between UE and CN, as well as data plane protocol stacks between RAN and CN.
- DPro transmits data through the bearer of data plane. The corresponding DTF forwards data based on the configuration from DCF. In the example, we assume UE serves as a DPro. the bearer of data plane includes the bear between UE and RAN and the bearer between RAN and CN, if the data is required by both RAN and CN. If the data is only required by CN, the bearer of data plane using peer-to-peer protocols between UE and CN is preferred. During this process, data plane functions such as DPro, DTF, and DCF also can process data on-demand, such as data cleaning, data integration, and data analytics.
- The DCF is also responsible for data QoS management. Data QoS management is used to guarantee the quality of data services.

4.6 Distributed Network Architecture

As described in Chapter 2, 6G network will introduce distributed network nodes to improve network flexibility and reliability.

First of all, for the computing service and data service, the nodes providing computing resource are distributed in network data centers, edge computing centers, and even end-users. The distributed network not only needs to integrate the computing resource scattered throughout the network and UEs, but also needs to customize the computing service according to the business requirements and computing status of different users. Data plane service assumes to have distributed data providers, data service consumers.

Moreover, data processing nodes are also distributed in different locations of the network. So 6G network architecture needs to provide distributed data collection and governance capabilities. At the same time 6G also needs to provide differentiated data service capabilities to external consumers.

In addition, 6G will support more complex and diversified scenarios. Facing the demand for differentiated user experience, the network user-plane and even part of the control-plane functions will be more distributed to provide the ultra-low latency. Facing the customized exposure demand of the local users, the user-plane nodes will also be further connected with the application servers to directly provide network exposure information in order to shorten the exposure information path.

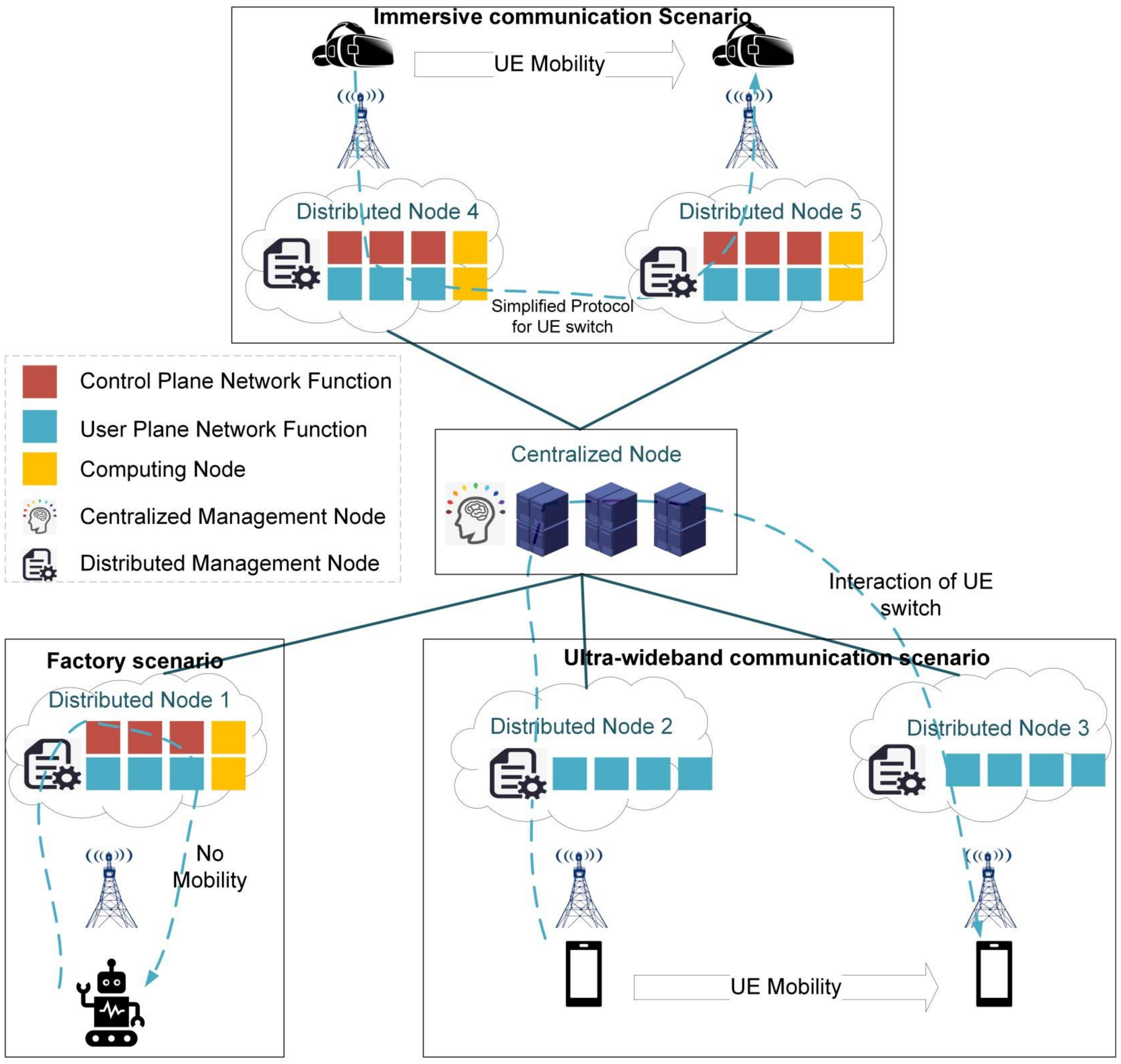


Figure 4-6 Schematic Diagram of Distributed Network Architecture

Figure 4-6 shows the schematic diagram of distributed network architecture. Taking the star topology as an example, the customized distributed nodes serve immersive communication scenarios, factory scenarios, and ultra-wideband communication scenarios, respectively, and the impact on the architecture is as follows:

Flexible combination of network functions:

Network functions are further atomized and split, centralized and distributed nodes collaborate to form a network, and network functions and network services are combined on-demand according to user service scenarios and business requirements, while the routing protocols, security and trust mechanisms, and resource isolation schemes of distributed nodes can be customized on-demand in consideration of the differentiated capabilities of the user side.

User friendly design:

In order to ensure the consistency of UE’s service experience, the distributed network can simplify the interconnection and intercommunication mechanism between centralized network nodes and distributed network nodes on demand, and simplify signaling interactions on the basis of ensuring network security and reliability, so as to avoid the degradation of network service experience caused by unsuccessful switching/migration.

Distributed autonomy:

Each distributed node has the capability to be autonomous, able to make decisions and manage its own functions and behavior independently, and at the same time be able to adapt to complex network environments and changes. This autonomous network architecture can not only improve the robustness and reliability of the network to avoid a single point of failure and network paralysis, but also improve the processing and response time of the network, reducing network latency and packet loss.

Based on Figure. 4-6, the immersive communication service for example is briefly described as follows:

- In order to meet the ultra-low latency transmission demand, the distributed node design can sink some of the network control plane functions and user plane functions as close as possible to the immersive UE side;
- In order to meet the image processing needs of immersive UEs, the computing nodes are also further sunk to the distributed node side to provide image rendering, AI image generation and other computing services in close proximity;
- Distribution may lead to high UE switching frequency, and UE switching will have a large impact on the immersive service experience, such as data interruption or instantaneous sharp drop in data rate. By optimizing the signaling protocol design to reduce the switching frequency, the service continuity/consistency experience of the UE is guaranteed to the maximum extent;
- For the exposure requirement of local users, the distributed network architecture will also introduce local exposure solutions, deploying local exposure functions near to the UE side, the local exposure functions can interact directly with external application services e.g. application server, and exchange externally exposure data through packet header information, etc., so as to reduce the transmission latency and response efficiency of network exposure.

4.7 6G-Satellite Integrated Network

As described in Chapter 2, 6G will further integrate terrestrial networks and satellite networks to achieve global three-dimensional coverage, providing the possibility of ubiquitous network communication services.

From the perspective of satellite payload functionality

Satellite communication can be divided into transparent payload and regenerative payload. The advantage of transparent mode is that satellites require simpler processing, resulting in relatively lighter satellite weights. The advantage of regenerative mode is that satellites can handle modulation/demodulation, coding/decoding, switch and/or routing functionalities. Therefore, the regenerative mode can reduce the number of satellite-to-ground communications and latency. 3GPP began the research of integrated satellite communication with 5G New Radio (NR) technology from release 15 and named this integrated technology as NTN. 5G satellites primarily use transparent mode [14]. Considering the support for new scenarios and businesses in 6G, as well as the need for deeper integration, 6G is expected to primarily use regenerative mode to provide users with a better service experience.

From the perspective of network functionalities deployment

In 6G, it is possible to adopt a hierarchical control framework by deploying a lightweight 6G core network on board the satellite. This lightweight network may involve a minimized set of control plane NFs and/or user plane NFs. The lightweight 6G core network on the satellite can coordinate with the master 6G core network deployed on the ground. Such terrestrial -space coordinated 6G core networks can provide global network control with fewer ground stations, reduce signaling messages and user traffic traversed to ground stations with many hops, and further increase the network’s resilience and resistance to destruction.

From the terminal’s perspective

NTN is a new feature introduced after the standardization of the 5G basic network architecture. There are significant differences in how terminals connect to the 5G network via NTN compared to TN, e.g. terminals need to first detect whether they are accessing NTN or TN and then execute corresponding strategies based on the different access technologies, resulting in complex terminal design. In 6G, the design should focus on providing unified services with a single device. A unified protocol stack and a unified architecture allow terminals to access the network transparently without distinguishing access technologies between TN and NTN. For example, in LEO scenarios, terminals can seamlessly switch between TN and NTN without needing to differentiate whether they are connecting to a base station on a satellite or on the ground.

From the perspective of basic communication services

TNs are currently focusing on delivery of services to areas already being served by existing cellular technologies, however, there are still nearly 80% of terrestrial areas, and over 95% of marine areas are longing to be in coverage. With the advantage of GEO satellite’s large coverage and low deployment cost (in theory, 3 GEO satellites can provide global coverage), GEO satellites can be used to build a globally covered public basic communication network in 6G to natively support basic communication services such as voice and short message. However, GEO also introduces challenges in natively implementing IMS-based voice services, such as limited antenna gain and transmit power due to the long distance between the terminal and GEO. To meet the link budget and latency requirements, two possible solutions are proposed:

- **Push To Talk (PTT) approach:** Similar to walkie-talkie communication, both communicating terminals cannot talk simultaneously. In this approach, there are no strict latency requirements for voice communication, which can reduce the demands on data transfer rates and latency. However, the communication experience may be relatively weaker.
- **Low-bit-rate voice encoding approach:** Define a lower voice encoding rate, such as 0.6 kbps. This approach requires the definition of new voice encoding rates, and to ensure interoperability with non-satellite terminals, transcoding of voice encoding must be performed within the IMS network.

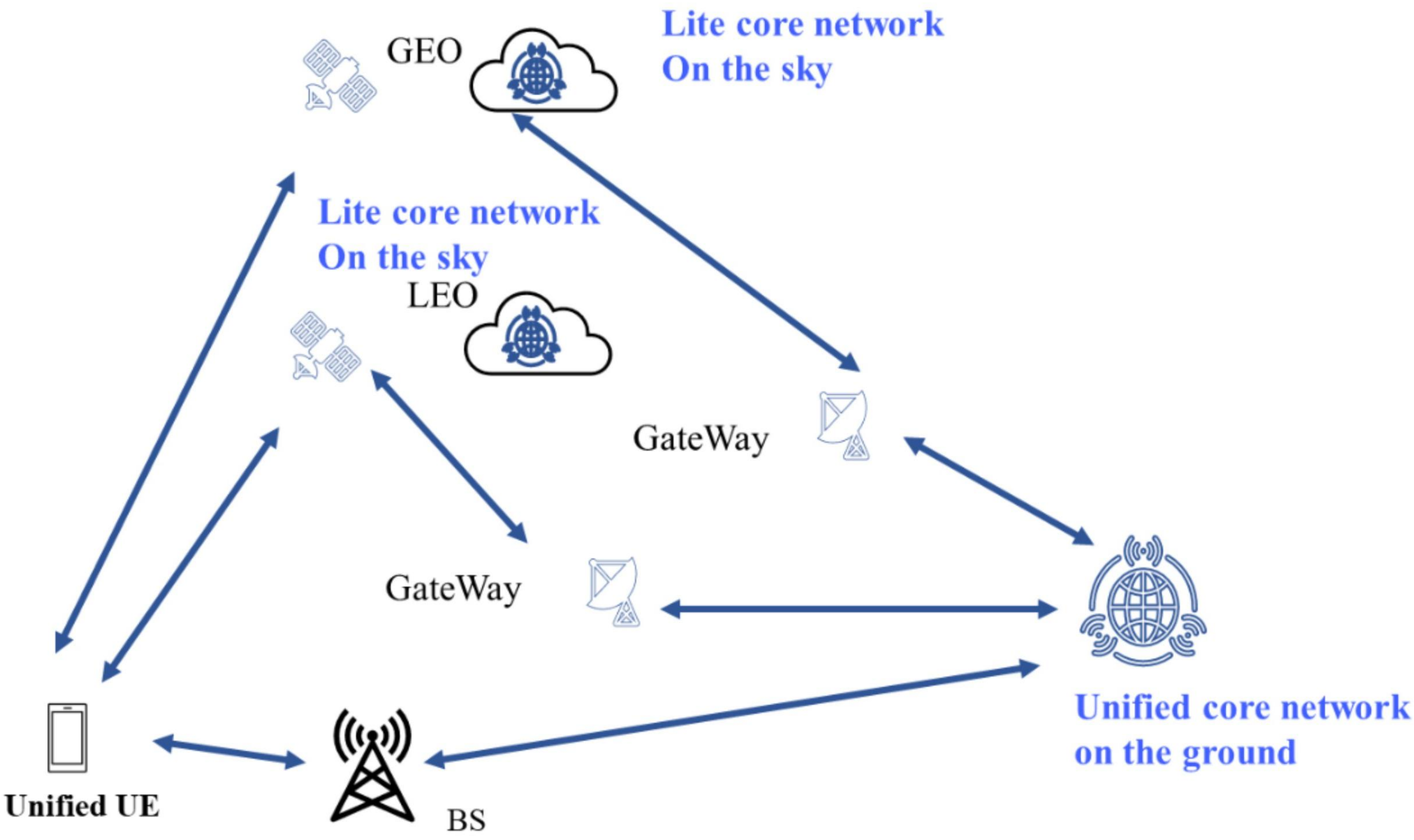


Figure 4-7. The architecture of Space-air-ground integrated network.

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Conclusion

Within the vision of building a freely connected physical and digital integrated world, the design principles of 6G network architecture are proposed. The principles include inheriting the advantages of 5G, meeting the new requirements of 6G, and continuously enhancing the basic capabilities. Based on the three design principles, the overview of 6G network architecture is introduced from the perspectives of topology and functional architecture. The planes, including control plane, user plane, and data plane, collaborate to support the key characteristics of native intelligence, native computing, and native security. This enables the super communication services, basic information services, and converged computing services to the users.

The research on the 6G network architecture and key technologies is still in the open discussion stage. Many issues are still under discussion, such as:

- How to achieve native security and trust through end-to-end design, including the necessity to introduce a security plane, etc.?
- How to design a simplified architecture for 6G new services and technologies to avoid a complex design that leads to a significant increase in complexity?
- How to support 6G and 5G compatibility and interoperability, achieving the easy deployment of network and reduced the cost of UE?
- How to continuously improve the energy efficiency of networks and UE, achieving the sustainable development goals of a green and low-carbon future?
- How to continuously improve network resilience, ensuring system availability and reliability?
- Whether and how to apply semantic communication to the 6G communication system, including scenarios, evaluation systems, and the impact and compatibility with the protocol system, etc.?

In the future, vivo will continue to collaborate with partners on the research of 6G network architecture and key technologies. The collaboration will cover the continuous evaluation and verification of the enabling technologies and architecture of 6G networks. The target is to deliver a comprehensive solution to the 6G standard architecture, which will hopefully provide better service experiences to mobile users.

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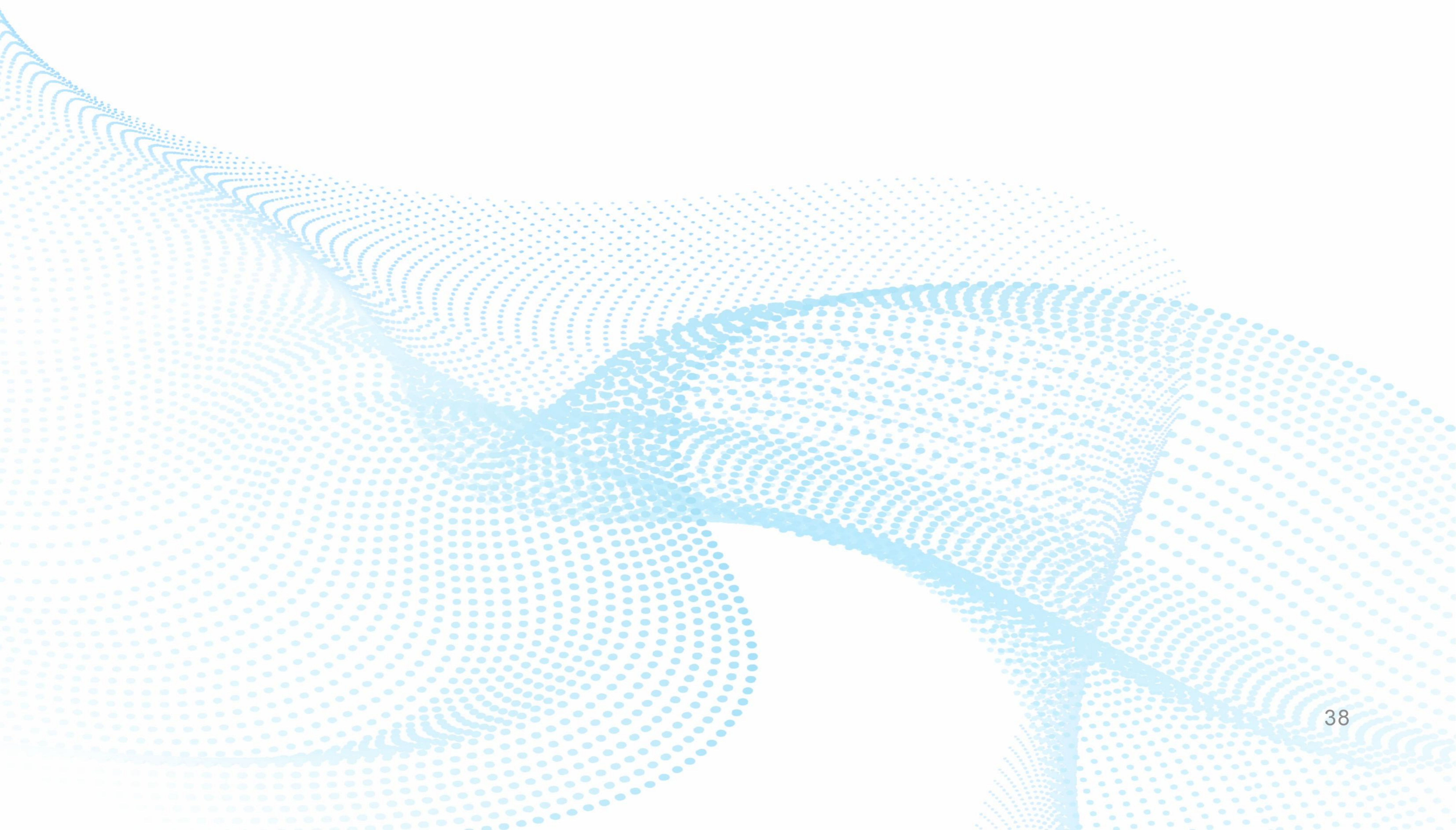

Abbreviations

3GPP	3rd Generation Partnership Project
5G	The fifth generation mobile communication systems
6G	The sixth generation mobile communication systems
AI	Artificial Intelligence
AIOT	Ambient power-enabled Internet of Things
AZP-IoT	Almost Zero Power IoT
BS	Base Station
CAPIF	Common API Framework
CN	Core Network
DCF	Data Control Function
DPSF	Data Privacy and Security Function
DProcF	Data Processing Function
DRF	Data Repository Function
DTF	Data Transmission Function
DProcF	Data Processing Function
DPro	Data Processing Function
DPro	Data Provider
DCons	Data Consumer
EPS	Evolved Packet System
GBR	Guaranteed Bit Rat
GEO	Geosynchronous Earth Orbit
GPT	Generative Pre-Trained Transformer
HTS	High-Throughput Satellite

IAIAC	Integrated AI And Communication
IoT	Internet of Things
ISAC	Integrated Sensing And Communication
ISL	Intersatellite link
IMS	IP Multimedia Subsystem
ITU-R	International Telecommunication Union -Radio communication Sector (ITU-R)
LEO	Low Earth Orbit
MEC	Multi-Access Edge Computing
MEO	Middle Earth Orbit
NEF	Network Exposure Function
NR	New Radio
NWDAF	Network Data Analytics Function
NTN	Non- Terrestrial Networks
OTT	Over-the-topQoEQuality of Exp
QoE	Quality of Experience
QoS	Quality of Service
QUIC	Quick UDP Internet Connections
QoS	Quality of Service
QUIC	Quick UDP Internet Connections
RAN	Radio Access Network
RFID	Radio Frequency Identification
SBA	Service Based Architecture
SLA	Service Level Agreement
Srv6	Segment Routing over Ipv6
UE	User Equipment
VCRI	vivo Communications Research Institute
XR	Extended Reality