A Versatile 6G with Minimized Kernel: To build the mobile world

OPPO 6G White Paper

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1.0 Concept of a versatile 6G with minimized kernel

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Task of 6G in mobile communication development

1.1

Every 10 years, mobile communication technology evolves to a new generation. After five generations (1G to 5G) of development, what historical role will the 6th generation (6G) play in the development process of mobile communication industry? We need to first answer this question.

Telecommunications is an applied science. Different from basic scientific research, its ultimate goal is not only to "explore and explain the laws of nature", but also to meet the needs of people and society for information exchange, then obtain reasonable market returns, and promote the sustainable and healthy development of the information technology industry. Therefore, only by determining the innovation direction of each generation driven by demand can the evolution of mobile communication technology continue to achieve success.

Reviewing the development process from 1G to 5G, it can be seen that **mobile communication does not actually achieve an industrial upgrading through every generation, but a major industrial upgrading goal every two generations of technology:**

- **1G and 2G have realized "mobile voice", that is, ubiquitous voice access;**
- **3G and 4G have realized "mobile data", that is, mobile Internet access;**
- **The goal of 5G and 6G is to realize the "mobile world", that is, all vertical industries are connected to and integrated via the mobile network.**

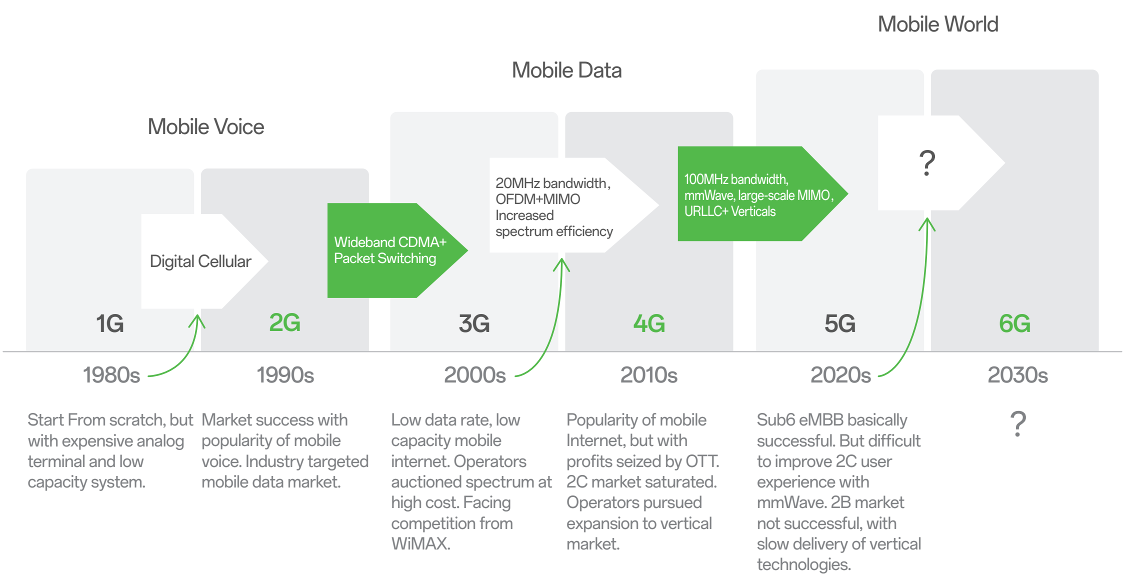


Figure 1-1: Intergenerational evolution of mobile communication technology

The reason why 2G and 4G are more successful than 1G and 3G is that, as the "second half" of a large upgrade ladder, they have driven technical innovation targeted at the problems and gaps exposed in the "first half" (i.e. 1G and 3G), and finally fully achieved the goal of the industrial upgradings.

5G and 6G are committed to a very ambitious industrial upgrading goal, that is, to achieve the mobility of the whole world. However, due to the incompleteness of the requirements definition and the immaturity of the technology, 5G only kicked off the breakthrough from "Internet of Human" to "Internet of Things", which is still far from the final vision of the “connecting and converging everything”. Therefore, **the historical task of 6G is to thoroughly realize the goal of "mobile world" based on the experience and lessons of 5G.**

5G's initial exploration of "world mobility" and lessons learned

1.2

To discuss the experience and lessons of 5G, we should first recall the "original intention" of 5G, that is, back in 2015, what a 5G mobile communication system we wanted to design. The biggest difference between 5G and 4G is to expand the mobile communication system from a "single-function system" connecting human to a "versatile system" connecting human (i.e. eMBB), machines (i.e. URLLC) and things (i.e. mMTC), so as to realize the interconnection of everything in the physical world.

However, 5G has both experience and lessons on how to design this " versatile system".

On one hand, 5G did not pursue the "disruptive change" of the basic wireless transmission technologies. It reasonably inherited most of core technologies such as OFDM (orthogonal frequency division multiplexing) and MIMO (multi-antenna transmission) that have been successful in 4G. Instead, it focused on the expansion of various vertical applications, and focused on the optimization for "low latency, high reliability, and large capacity". The overall design principle is in line with the market demand and industrial development trends.

On the other hand, **5G is still based on the design principle of "single-function system", simultaneously targeting a set of "higher KPIs" (i.e. higher dara rate, lower delay and higher reliability), pursuing integrated design in technology, and trying to meet the fragmented requirements of hunderds of vertical industries through "scalable parameter sets+network slices". However, due to the fact that all 5G vertical technologies use eMBB as the baseline and default design, which limits the space for technological innovation and cannot be thoroughly optimized for the target vertical fields, competition advantages and controllable costs have not been achieved in many vertical fields.**

First, 5G eMBB introduced millimeter wave transmission, and tried to exchange higher frequency band for higher data rate. However, millimeter wave signals only meet the requirements of Line of Sight (LOS) transmission, resulting in limited coverage and limited deployment scenarios, making limited contribution to the overall performance improvement of 5G eMBB. 5G eMBB attempted to improve the spectral efficiency with large-scale MIMO technology. But a large number of antennas cannot significantly improve the system throughput in many deployment scenarios, but results in a significant increase in the complexity, energy consumption and engineering difficulty of the base station.

Secondly, 5G URLLC reused the basic design of the 5G eMBB, and only improved the latency, reliability and other KPI through detailed optimization. This caused the complexity of the URLLC to accumulate on the basis of the eMBB, requiring high software and hardware capabilities of 5G network and terminals, and facing great challenges in cost control.

Finally, for the mMTC application scenario, 5G has not been specially designed, but has only made a series of tailorings based on the core design of eMBB to form the "lightweight 5G" (called RedCap). However, the reduction of power consumption and cost is limited, and the cost performance ratio has no obvious advantage over 4G system. So it is difficult to realize the real connection of everything via 5G mMTC technology.

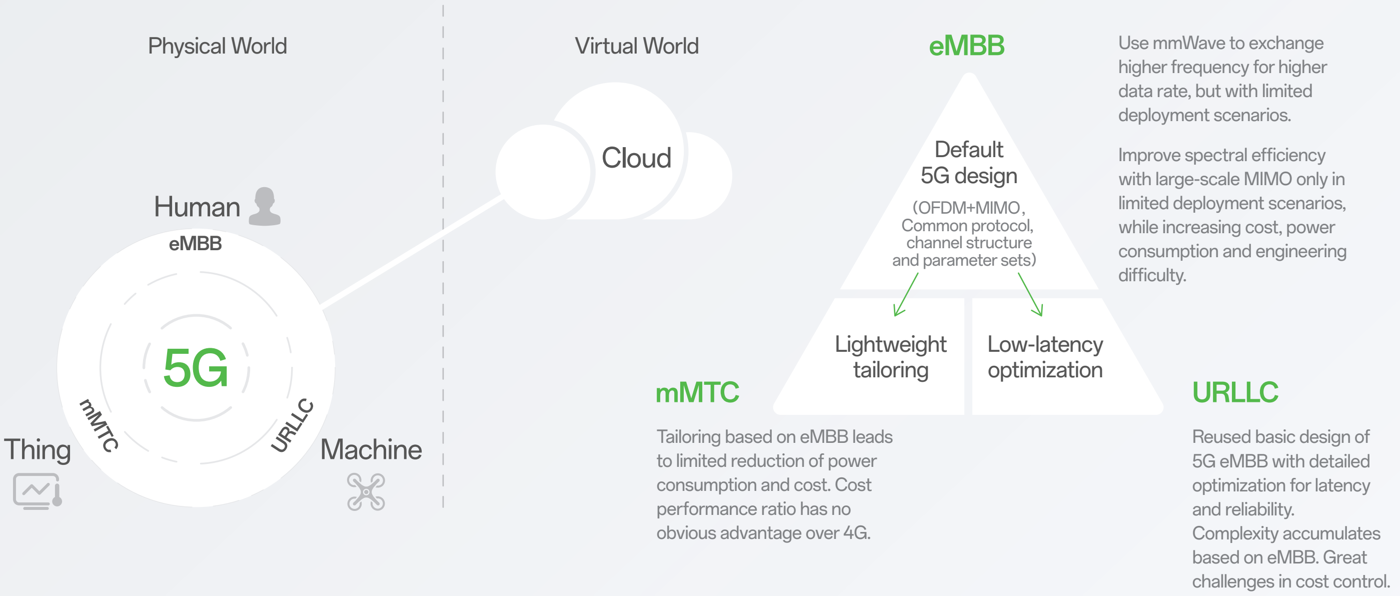


Figure 1-2: Lessons learned from 5G system design

New ideas for the design of Versatile 6G with Minimized Kernel

1.3

1.3.1 Two new findings about the information world

The reason why 6G is more likely to finally complete the historical task of realizing the "mobile world" than 5G is: On the one hand, it can learn lessons from 5G. On the other hand, it is because the information industry has a clearer understanding of how to realize the world's digitalization and informatization in all aspects 10 years later. In general, it can be summarized as two major findings:

The first finding: To build a mobile information world, AI (artificial intelligence) agents must be introduced as the intermediate manager between human, machines and things.

First, after the exploration of the past decade, the industry has realized that only connecting a large number of unintelligent machines and things via 5G network cannot achieve the real world mobility. Because the sensory ability and the processing ability of the human brain are limited, a limited number of human brains are difficult to manage and control a huge number of machines and things. Even if "connecting everything", it cannot "converge everything". Between the limited number of human brains and the huge number of machines and things, there must also be a large number of non-human intelligent agents as "intermediate managers". The limited number of human brains authorize the large number of intelligent agents to manage the huge number of machines and things. The large number of intelligent agents become the media for human to control the information world through AI learning and training.

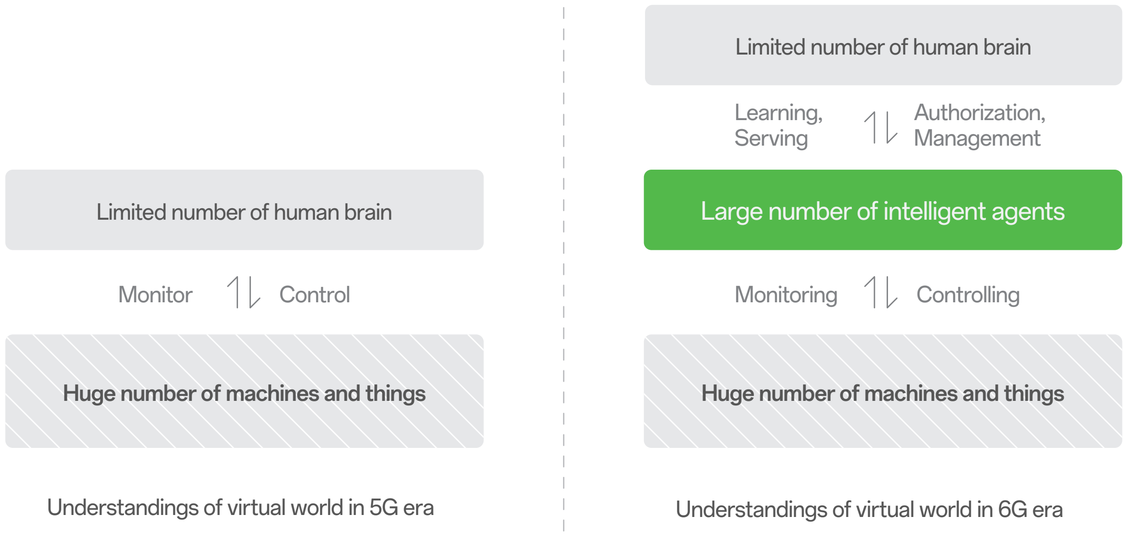


Figure 1-3: Different understandings of the information world in 5G era and 6G era

Controlling the information world through intelligent agents cannot only free the human brain from the burden of "data explosion", but also can better manage the information world. In recent years, AI has achieved great success in computer vision, voice recognition, big data analysis and management, which is a successful example of human brain controlling the information world through intelligent agents.

The bottleneck of "data rate, time delay and reliability" encountered by 5G when directly connecting the limited number of human brains with the huge number of computers and things is expected to be alleviated in the 6G era. Although the communication between human brains and intelligent agents also requires a high data rate, it does not necessarily require the high data rate anytime and anywhere. While the communication between intelligent agents and the huge number of machines and things requires massive connections, it does not necessarily require extremely low latency and high reliability.

The second finding: To build a mobile information world, a virtual world mirroring the physical world must be built for machines, things and intelligent agents.

10 years ago when the 5G concept was formed, our understanding of the virtual world was "a cloud", that is, connecting the huge number of machines and things to the cloud for people to access and manage. **In the 6G era, if human beings will control and manage the information world through intelligent agents, they need to build a more complete virtual world with better correspondence with the physical world. Intelligent agents can control the images of the huge number of machines and things through their twin images in the virtual world, and then control the machines and things in the physical world.**

Some intelligent agents exist in the physical world (such as smart phones, robots, smart vehicles, drones, etc.), while some do not (such as virtual AI assistants). However, any intelligent agent has its twin agent in the virtual world, because AI algorithms are ultimately a software program. Therefore, the control of the huge number of machines and things through intelligent agents is more suitable for realization in the virtual world. The digital twin is used to build the image of the huge number of machines and things in the virtual world. And the control of the physical world is realized by controlling its virtual image. **In recent years, the reason why the metaverse has received wide attention is that it can not only bring people an immersive multimedia entertainment experience. But more importantly, it describes a broad prospect of "managing the physical world through the virtual world and creating a better physical world through the management of the virtual world", providing a possible way to "converging everything".**

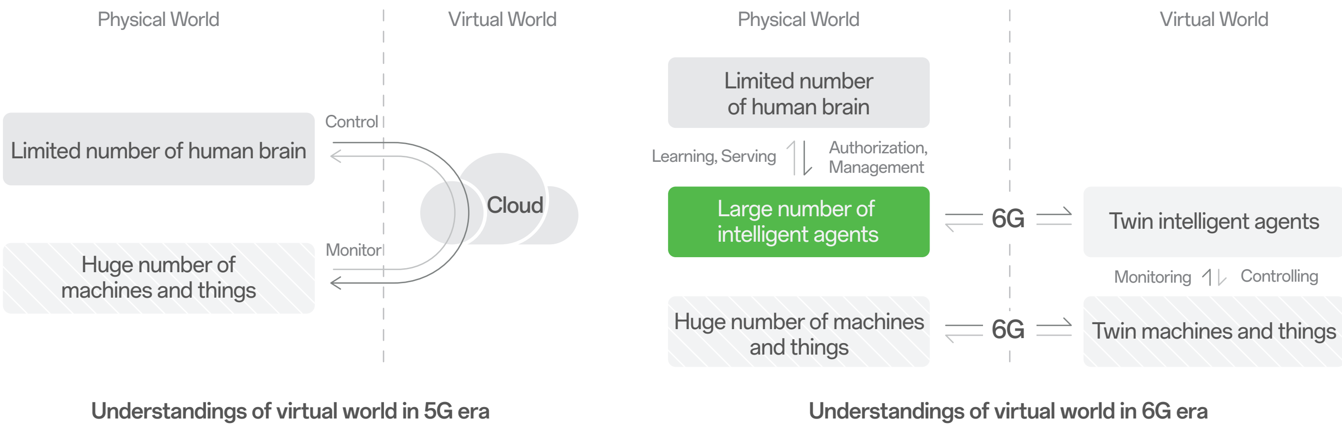


Figure 1-4: Different understandings of virtual world in 5G era and 6G era

Of course, realizing a digital world through artificial intelligence and metaverse is a massive and complex work, which requires long-term investment and construction from the entire information industry and even the whole society. However, 6G technology can at least provide a basis for the information exchange in the mobile information world. **Therefore, we believe that the vision of 6G should be: To communicate the virtual world with the real world, realize the interconnection and convergence of the two worlds, become the infrastructure of the metaverse, and provide a technical base for the mobile information world.**

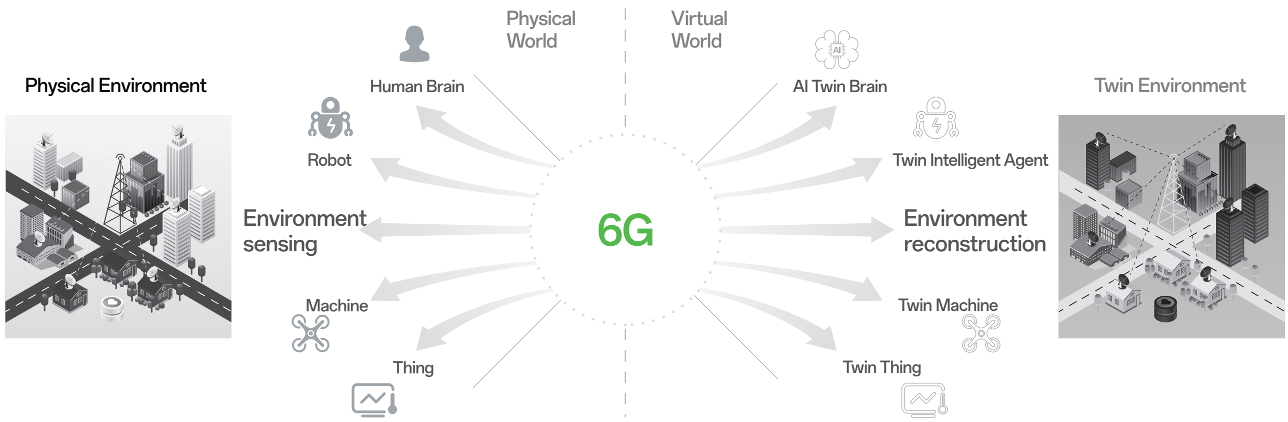


Figure 1-5: The 6G vision is to connect the virtual world with the real world and become the infrastructure of metaverse

1.3.2 6G = Minimized Kernal + N subsystems

As a channel to communicate the physical world and virtual world, 6G needs a comprehensive mapping ability to the physical world. Therefore, in addition to the high data rate, low latency and high reliability 5G has already provided, the connectivity to ubiquitous zero-power things and the perception of physical environment should also be expanded.

This will be a mobile communication system far more "versatile" than 5G. However, the limited "multi-function" goal of the 5G system based on integrated design has not been fully realized in the market, and the goal of "connecting everything" in the physical world is far from being achieved. It is more difficult to achieve the grand vision of 6G by designing 6G as a "larger 5G system" along the existing design principle.

In order to achieve "interconnection and convergence" between the physical world and the virtual world, truly realize "a versatile system for world mobility", further expand to Sensing, Non-Terrestrial, Zero power communication and other application scenarios, and achieve performance improvement several times in all dimensions at a controllable cost, 6G must adopt new design ideas.

In order to become the infrastructure for building a virtual world corresponding to the physical world, it must adapt to the existing form and real composition of the physical world. In the physical world, the deployment scenario varies from urban to rural environment, from land to space and sea, with various types of terminals from complex to simple. The business model varies over hundreds of vertical industries. There has never been a single infrastructure that can be universally suitable for the world at a controllable cost. 6G should not be an exception.

In the industry's vision of 6G, on the one hand, the 6G system should achieve higher system performance than 5G in a wider application scenario than 5G. On the other hand, it should also achieve a "minimized" system, significantly reducing deployment and operating costs, so as to truly achieve universal implementation in hundreds of vertical industries. Facing to this seemingly contradictory design goal, the only feasible solution can only be to design a number of "flexibly converged" subsystems on a minimized common kernel. This design allows the 6G subsystem in each scenario to be properly decoupled and optimized, and achieve a "simple and versatile" 6G system that only provides the functionalities and capabilities when they are truly needed".

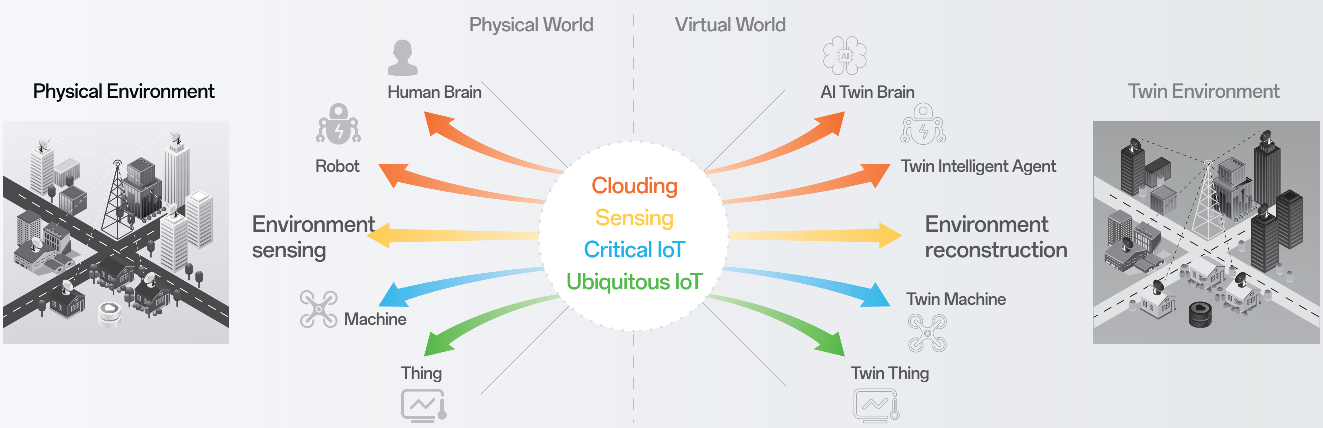


Figure 1-6: Adapt to the existing form of the physical world, design a flexibly converged subsystem set, and achieve a truly " simple and versatile" 6G

The design of the versatile 6G system with minimized kernel mainly includes the following elements:

- A minimized kernel provides common capabilities such as native AI, security and flexible spectrum management;
- Separate optimization is made for four different capabilities, including: Clouding, Critical IoT, Ubiquitous IoT and Sensing.
- One or multiple subsystems are designed for each capability. Key technologies can be selected independently according to application scenarios, spectrum, topology, etc., and hardware and software can be designed separately for different subsystems. For example, it can be divided into: 6G broadband cellular, 6G D2D, 6G URLLC, 6G sensing, 6G massive IoT, 6G non-terrestrial networks and other subsystems.
- Compatibility between subsystems can be supported or not supported depending on whether it is truly needed. Determine ow much common air interface technology and design to share between 6G broadband cellular and other subsystems based on whether the commonality is truly needed.
- Replace artificially-designed generalized algorithms with a black box professional AI algorithm library, to realize the "relatively independent and optimized" of each subsystem and the substantial simplification of communication protocol. And through the switching and combination of various AI models, the switching and combination of multiple subsystems can be realized.

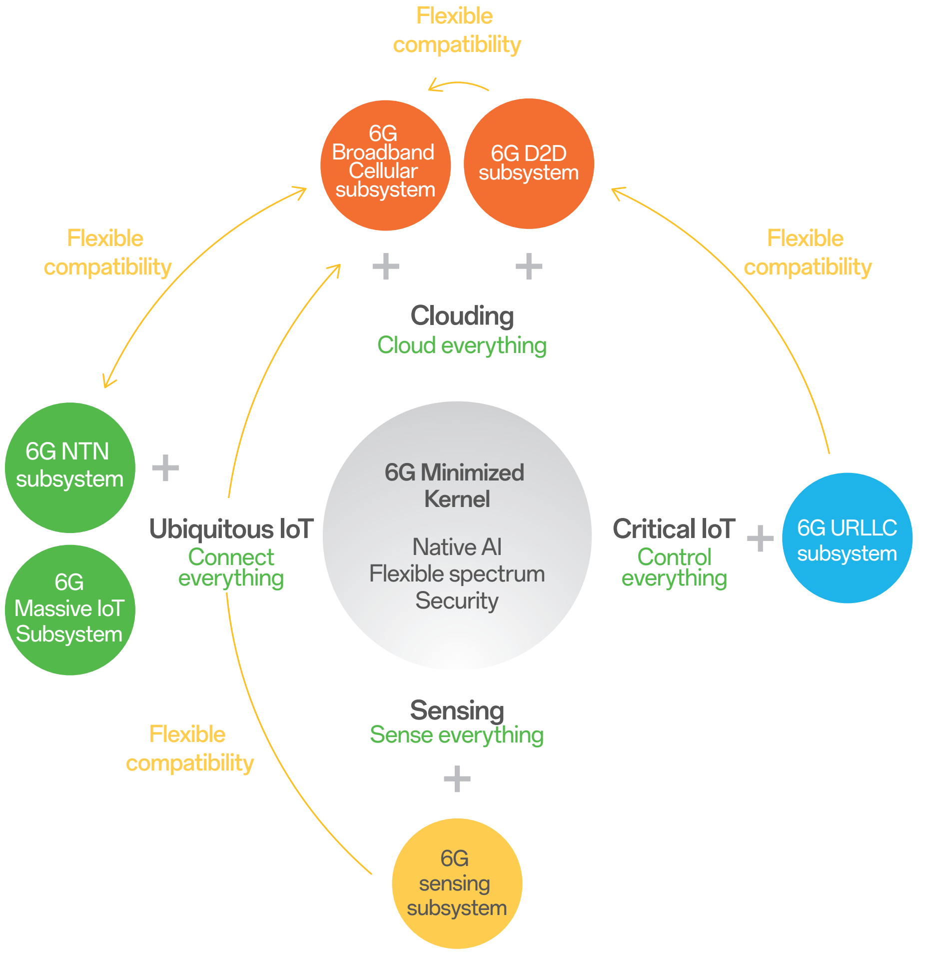


Figure 1-7: 6G = Minimized Kernal + N subsystems

It should be noted that the 5G system has also tried to achieve flexible reconfiguration of the resource and functionalities for multiple scenarios through network slicing, network virtualization, etc.. However, because it is completely based on the common basic transmission technology and can only be flexibly reconfigured on parameter and configuration levels, its adaptation to different scenarios and vertical industries is limited. On the contrary, due to the consideration of unnecessarily high KPI targets, the slicing of each scenario has the problems of "over design" and high cost. 5G-Advanced technology is developed for in-depth optimization for various vertical industries. But in most cases, it will introduce additional complexity. And at the same time, it is unable to make necessary "subtraction" for the common technology base (that is, the mandatory feature in the eMBB mode), which further increases the system complexity. One exception is that RedCap (lightweight 5G) technology is targeting the low-cost IoT and tailoring some redundant hardware capabilities. However, since the baseline of the tailoring is the full-capacity eMBB, it is difficult to tailor it in place after a long time of work to achieve the extremely low cost expected by the market.

Therefore, in the design of the 6G system, the specific requirements of each application scenario should be considered from the beginning. The appropriate KPI subset should be selected. And a subsystem should be designed to optimize for the corresponding application scenario. In the following sections of this white paper, we will respectively introduce our preliminary consideration of the 6G minimized kernel and each subsystem.

2.0 6G Minimized Kernel

The 6G minimized kernel is the most critical part to realize the versatile 6G system. Each subsystem would more or less use the common capabilities and resources provided by the minimized kernel. However, in order to effectively reduce the complexity and cost of each 6G subsystem, the minimized kernel should only contain the minimum common capabilities. In our opinion, it can only include the following three capabilities:

- Native intelligence;
- Security;
- Flexible spectrum management.

It should be noted that the 6G minimized kernel is not necessarily concentrated in the 6G core network. Some of its resources may also be distributed in the 6G RAN nodes (e.g., 6G base stations).

Native Intelligence of 6G Minimized Kernel

2.1

With the AI technology [1] evolves and becomes more sophisticated, and better understandings of use cases that benefit the AI-enabled network operation and application services become more apparent [2]. The AI-enabled mobile network functions deliver the following system benefits.

Value Propositions from AI empowered mobile system

Value Proposition-1 AI assisted accurate decision-making ability	Learning samples from the data collection with the assistance of AI inference provide accurate summary of the general rules between inputs and outputs to support decision making. When network functions faced with more and more complex scenarios, it is difficult to make quick and accurate decision relying on human experience. Using the outcome of the AI learning and training to match specific functional operation in different scenarios can provide more effective assistance on the decision making.
Value Proposition-2 AI's powerful inference ability	With the continuous improvement of network computing processing power, AI inference capabilities have become more effectual, which amplifies the usefulness provided by the AI algorithms and functions.
Value Proposition-3 self-evolving capabilities	AI's inference functionality is not static due to the nature of the iterative operation in analytic learning and training. As the system environment could be changed over time, the analytic operation will continue to optimize and to refine the AI inference operation which assures the accuracy of the analytic outcome.
Value Proposition-4 AI's transfer learning ability	The trained AI model can be refined through learning and make adjustment corresponding to the changing conditions. In time, AI model becomes more sophisticated and it can apply to broader scope of system functions to deal with more variety of scenarios, providing the possibility to populate the AI and ML analytic results to more diversified applications.

The service/application that leverages AI technology in mobile system will go through a three-stage process: For-the-AI, By-the-AI, and Of-the-AI. For-the-AI refers to stage-1 support where the -mobile system is used as a transmission pipeline to support the application layer AI business, By-the-AI refers to the stage-2 support where part of the network functions (such as eMBB and URLLC) within the mobile system with some enhancements to support AI/ML operation based on architecture framework, Of-the-AI refers to the stage-3 support where the AI/ML functionalities as a fundamental system component to be imbedded into the mobile system architecture in order to achieve the objective of "Intelligence Everywhere".

2.1.1 Artifact Intelligence in 6G network

AI technology will be an important part of the 6G network. Unlike the flexibility dimension of control and the performance dimension of user response, the intelligence dimension corresponding to AI technology will become a new dimension of the 6G network. The reason why the intelligent dimension is a new dimension is that the corresponding data features, values and functions of the AI dimension are significantly different from the existing control plane and user plane functions [3]:

Artifact Intelligence Plane (AP) dimension

This is a new dimension of 6G, including AI services and AI resources provided for each 6G subsystem, including AI data collection, training, deployment, management, transmission, activation, selection, switching, configuration and inference of AI models, as well as providing computing power, storage, signaling and other resources required for AI operations. The performance of intelligent dimension is determined by AI operation efficiency and optimization degree:

- AI operation efficiency:the resources consumed to complete specific AI processing tasks (including computing, data and communication resources used), so AI operation efficiency is closely related to the selection of AI algorithm;
- AI optimization degree:reduce or simplify the number of CP/UP functions by replacing or partially replacing CP/UP functions through AI optimization.

User Plane (UP) dimension

This dimension includes the user interface functions that the 6G communication network needs to have, specifically, the UP functions that 3GPP needs to standardize and define in 6G. As the demand for synaesthesia fusion is proposed, the data transmitted on the UP side in the 6G era needs to support both communication functions and business functions.

Control Plane (CP) dimension

This dimension includes the control plane functions that 6G communication networks need to have. Specifically, it can refer to the CP functions that 3GPP needs to standardize and define in 6G. The CP function in the 6G era has higher requirements for achieving service stability and system response speed, and is also used to control the configuration related to communications and services.

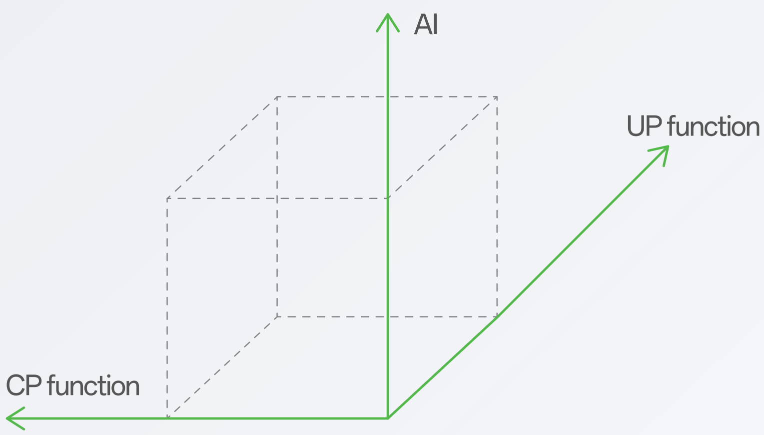


Figure 2-1： Three dimensions of 6G network

In order to achieve an efficient 6G network architecture, reduce the complexity of product development, improve the business experience in a targeted way, and achieve a "minimized and versatile" 6G system, the minimized kernel native intelligence should have two major capabilities: on-demand networking and intelligent replacement。 The following is an introduction to these two capabilities.

2.1.2 On-demand networking based on 6G native intelligence

As described in Chapter 1, the only way to achieve the design goal of "simplicity and versatility" of the 6G system is to design multiple application scenario oriented subsystems. However, **one of the core issues of the 6G system composed of subsystem sets is how to configure network resources on demand and truly deploy the "capable and cost controllable" 6G subsystem for each vertical industry. Due to the ever-changing needs of thousands of industries, this on-demand networking is difficult to be realized manually, and should be realized through AI training and intelligent methods.**

With the intelligent on-demand networking capability, the minimized kernel can only include the CP, UP and AP functions required by the target scenario:

Intelligent dimension: on-demand networking engine (select additional CP, UP and AI functions according to scenario requirements)	On the basis of the most basic functions of the minimized kernel, in combination with the scene characteristics, additional CP, UP, AP functions and technical indicators QoAIS [4] are superimposed for an instance subnet. CP and UP functions refer specifically to the functions defined by 3GPP, while AP functions refer specifically to the AI inference model and implementation method introduced to achieve specific services.
CP dimension: including basic registration operation connection management	Any service in the 6G network needs registration and connection management, and other additional functions can be added or removed as needed, such as AIoT devices do not need accessibility connection management capabilities, and URLLC devices do not need mobility capabilities
UP dimension: Basic data transmission and basic QoS guarantee	Establishing connection is the most basic feature of data transmission. Additional QoS transmission capabilities (such as bandwidth, delay, reliability, etc.) and 6G application service processing capabilities (such as application service data processing capabilities) are added as required

The functions included in the minimized kernel are the basic mandatory functions on the standardization protocol. For example, 3GPP must standardize the content, and then map the personalized functions of different subnets according to the scene characteristics and instantiate them, which is the effect of "intelligent networking". On the basis of the minimized kernel, we can apply the minimized kernel to a subsystem (i.e. "on-demand networking"). As shown in Figure 2-2, among them, one of the characteristics of on-demand networking in the 6G network is the mapping relationship between scenarios and network features. Here we define that scenarios are composed of three elements: communication, sensing and computing. The network is composed of 3GPP's CP, UP, AP functions and QoAIS, and further exemplified to the 6G network through the native intelligent architecture.

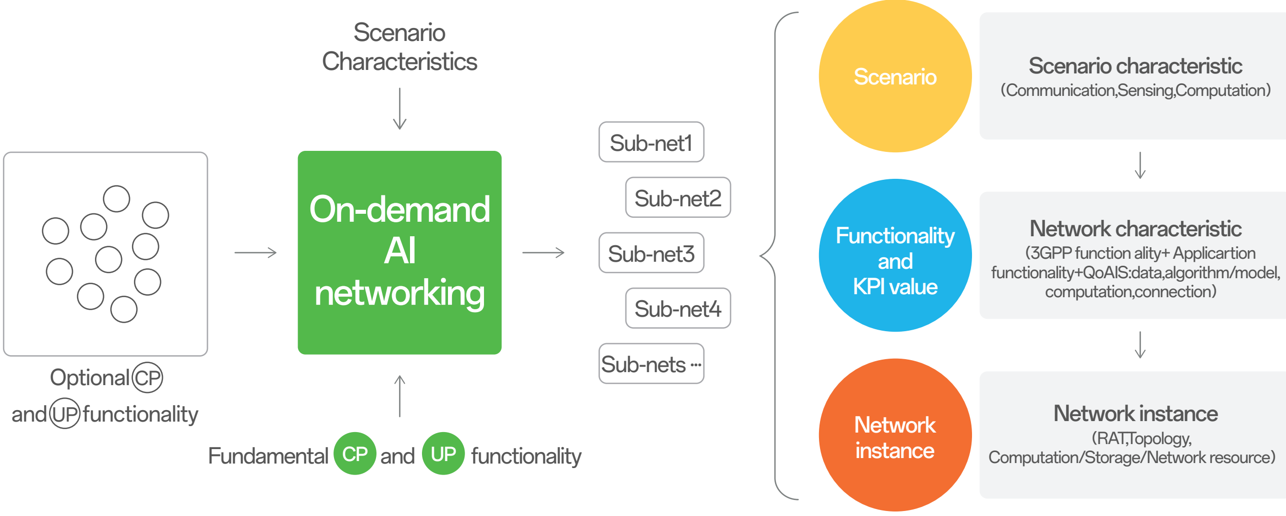


Figure 2-2 : On-demand networking based on native AI of minimized kernel

2.1.3 AI replacement based on 6G native intelligence

6G deployment scenarios are much richer than 5G, and the number of subsystems has also increased significantly. Only relying on the intelligent on-demand networking capability, the existing CP/UP/AP functions can be selected and organized according to the scenarios, which can only make the 6G network less complex than 5G. To significantly reduce complexity on the basis of 5G, we must rely on another ability of native intelligence - intelligent replacement.

Intelligent replacement will replace a considerable part of traditional protocols and algorithms with "black box" AI protocols and AI algorithms. The preliminary research results of 3GPP Rel-18's AI related research projects have revealed that the standardization impact of various AI application cases is basically similar, which is nothing more than to define the life cycle management (LCM) of AI, including AI data collection, AI model training, deployment, management, transfer, activation, selection, switching, configuration and inference. No matter which technology point uses the AI model, the relevant protocols simply define these processes. Although different data interface formats still need to be defined, the differences and specificity of the protocols have been greatly reduced. For example, in the 3GPP Rel-18 "AI/ML for NR air interface" project, the three use cases of CSI enhancement, beam management, and location enhancement need to define different AI model input and output formats, but the protocols related to AI lifecycle management are basically the same and can be universal. In the existing 5G standard, the air port protocols of these three technologies are completely different and quite complex.

This section mainly introduces the intelligent replacement of the network layer protocol. We will introduce the AI algorithm replacement of the physical layer technology in Section 3.3.

The purpose of the intelligent replacement of the network layer is to minimize the definition of new CP and UP standardization functions on the basis of the minimal core CP/UP functions, but to replace the standardization requirements through AI algorithms to achieve the lightweight protocol of the 6G network. In the 6G minimized kernel of deep native intelligence, AI intelligent optimization can help reduce the number and complexity of CP and UP functions, so that the originally required standardized definition of CP and UP functions can be greatly reduced, and the product development complexity and deployment cost can also be reduced accordingly.

Figure 2-3 is based on the description of AI Cube space [3]. Taking 6G Sensing as an example, there are many standardized CP and UP functions that need to be implemented. After intelligent optimization, the functions of CP and UP dimensions can be reduced, and the intelligent dimension can be improved instead.

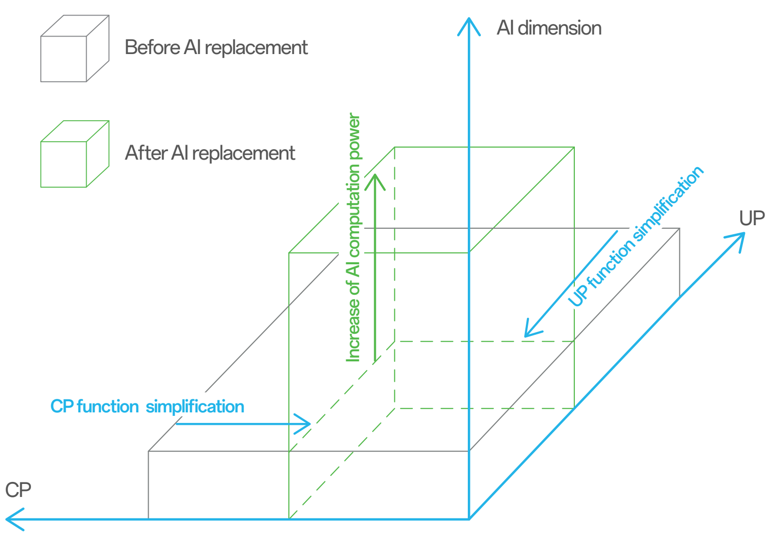


Figure 2-3: Replace some CP and UP functions with AI computation

Specifically, intelligent replacement includes decision type optimization and non decision type optimization.

Decision type optimization can simplify the CP function through the following two types of inputs (as shown in Figure 2-4):

- The first category of input is general prediction (including business prediction, location prediction, load prediction and user behavior prediction). Each specific CP function can use one or several general predictions as an important basis for input decision, to simplify the CP function. In order to achieve general prediction, it is necessary to collect and build data sets from terminals, networks and applications to train AI models.
- The second type of input is personalized data. When AI enables different functions, there will be different personalized input parameters. For example, for switching scenarios, RSRP, measurement event configuration, etc. are personalized input parameters. For random access scenarios, cell interference and historical random access data are personalized input parameters.

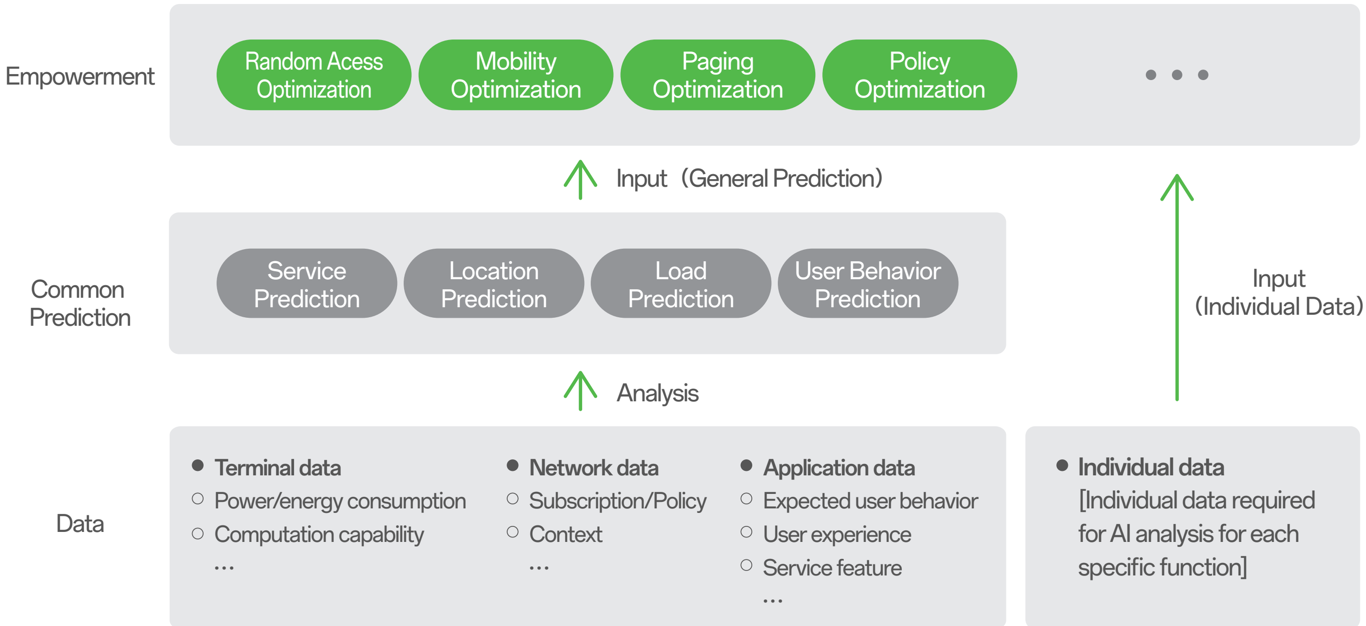


Figure 2-4： Simplify CP functions through intelligent replacement

Non decision optimization can be used to simplify UP functions (as shown in Figure 2-5).

The specific form of non decision-making functions enabled by AI is the inference process that replaces part or all of the steps of data processing with AI models. For each UP function, the AI model can achieve the best data processing through personalized definition of limiting factors and expected effects. Through AI enabling, the data processing process that originally required manual maintenance and iterative optimization can be replaced by the self-learning and self evolution process of AI algorithm to achieve continuous optimization of performance.

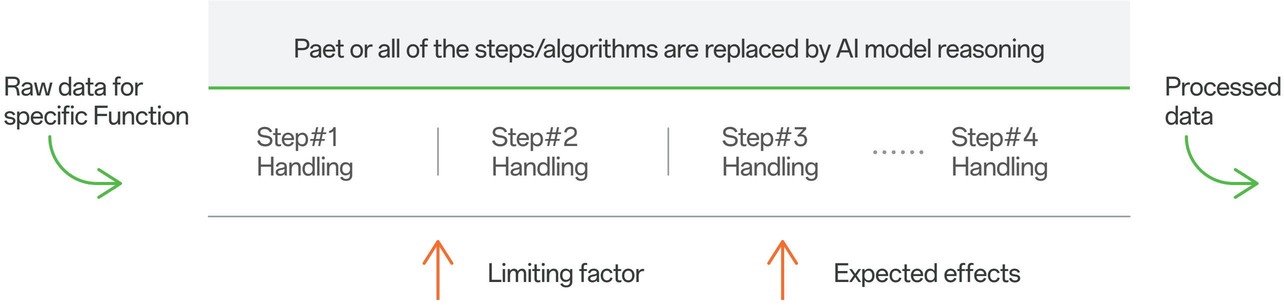


Figure 2-5： Simplify UP functions through intelligent replacement

Security of 6G Minimized Kernel

2.2

2.2.1 The Transformation and Security Trend in the 6G Era

In the 6G era, everything is interconnected with diversification of services, connection methods, and access devices such as industrial Internet of Things, smart home, smart logistics and other services. Users in these industries usually use dedicated user equipment that support fast data flow between machines using Sidelink connection mode. These requirements will bring great transformation to the soon-to-be classic human-to-human communication mode.

For the 6G security architecture, the envisioned key changes are as follows:

- **The security trust model is transforming from mutual trust model to multi-party trust model, which requires the establishment of multi-party trust model and endogenous security**
- **The security protection of service data is transforming from single-focus to multi-focus, and it is increasingly necessary to establish intelligent security for the protection of service data that covers all angles**

Multi-party Trust Model and Endogenous Security

3GPP 5G security standard TS 33.501 [5] defines the security architecture of mutual trust, that is, UE (User Equipment) and operator HE (Home Environment) share the pre-provisioned user root key as the credentials for establishing mutual trust. When UE accesses the operator network and uses network resources and services, the user and the operator network perform mutual authentication based on the user root key. Moreover, using the root key, the UE and operator network each derive a series of protection keys that are used to provide confidentiality protection (i.e., ciphering) and integrity protection of the signaling data and user data during two-way communication.

In the 6G era, users of Industrial Internet of Things, smart home, smart logistics and other services usually use dedicated terminal equipment. When these equipment access the operator network and use network resources, they need to be authenticated. The authentication differs than traditional mutual authentication in that the authentication need to take place among multiple parties of access equipment, industry users and operators. At a minimum, a tripartite trust model needs to be established among them.

When the connection modes and service models continue to evolve to allow the flexibility of new service creation using various combination of these connection modes and service models, scenarios such as Sidelink machine-to-machine connection, multi-service collaboration, MEC deployment have emerged. The trust relationship based on the tripartite trust model of access equipment, industry users and operators will further evolve into a multi-party trust model including multiple terminals, multiple industry users and multiple network nodes. The credentials and trusted root required by the multi-party trust mode cannot rely solely on a single user root key. There is a need to establish endogenous security credentials according to the basic components of equipment, services and networks.

Multivariate Distributed Service Data and Intelligent Security

In the 6G era, the use of artificial intelligence will become the mainstream trend, and data assets have become the key production factors in the digital society. The new services represented by Industrial Internet of Things and smart logistics will generate a large amount of data. More and more data generated by the new terminals and communication methods represented by zero-power consumption, and integrated sensing and communication that are carried in the network will come from distributed terminal equipment. Multivariate industrial data needs efficient and flexible security protection mechanism. Distributed multi-source data acquisition and convergence mode makes two-way transmission protection less relevant. Security protection based on keys derived from a single user root key will change, and more flexible and intelligent security protection mechanism is needed.

2.2.2 Key Security Technology in the 6G Era

Blockchain supports multi-party trust mode and distributed service data protection

Blockchain is distributed and trusted, which can promote data sharing and will become the critical infrastructure of industrial digitalization in the 6G era. In industrial applications, telecom operators and blockchain suppliers vigorously develop blockchain infrastructure networks and launch and promote blockchain services for all walks of life, including blockchain identity management services, access authentication services and other security services.

Blockchains are divided into public chains, private chains and alliance chains. Among them, alliance chains and private chains are considered highly trusted blockchains. Alliance chains can involve multiple trusted parties with the trust relationship among the participants can be realized through proven strong security algorithms. Alliance chains can also be used to realize the multi-party trust mode in the 6G era by creating an endogenous and trusted multi-party credentials without relying on third parties. Additionally, DID (Distributed Identity) technology based on blockchains can support distributed identity management and can be used to realize distributed authentication.

By design, lightweight IoT and IIoT terminals such as zero-power devices are limited by computing and storage resources that may not support traditional authentication computing. With the help of blockchains and DID, lightweight identity management and authentication mechanisms and can be used for low-cost authentication.

Physical layer security supports lightweight transmission security

Physical layer security is based on Shannon's perfect security concept and Wyner's eavesdropping channel model to establish the security of transmission channel that does not rely on high-level protocols and encryption calculation by lightweight devices. Zero-power devices are limited by computing and storage resources that may not support traditional encryption mechanism based on 128-bit or 256-bit key and security processing of PDCP protocol layer. Physical layer security offers a good alternative to minimalist IoT devices providing lightweight transmission security.

Intelligent Security Policy

The introduction of new services in 6G does not happen overnight. User-oriented data connections and Industrial IoT-oriented data connections will create added value for all stakeholders in the 6G ecosystem. Zero-power IoT devices and NB-IoT devices will coexist for a long time. While distributed trust mode and distributed authentication mechanism cannot replace centralized security mechanism, lightweight transmission security proves to be a perfect security enhancement for minimalist IoT devices. For 6G multi-service and multi-source data, the security policy must be intelligent, flexible and dynamic.

Intelligent security policies can be considered from the following aspects:

- Intelligent trust model and authentication mechanism. Operators may have a variety of credentials with corresponding authentication mechanisms, the selection and use of the type of trust and authentication mechanisms depend on service types, terminal types, data types, access technology types, and security risk levels. For example, the operator may choose 5G AKA and 5G AKA-based authentication mechanism for establishing credentials between two parties or three parties (e.g., user, network and application server) or the operator may choose the certificate authentication mechanism based on blockchains for establishing trust for the multi-party.
- Intelligent transmission security mechanism. Operators can choose a particular transmission security mechanism or a combination of multiple transmission security mechanisms according to service type, terminal type, data type, access technology type and security risk level.

With the continuous enrichment of service types, terminal types and access technology types in the 6G era, in order to realize flexible and dynamic security policies efficiently, the need for intelligent security policy management mechanism becomes transparent and only then flexible, dynamic, and efficient security policies can be realized.

2.2.3 Zero Trust Security Architecture in the 6G Era

Based on the key transformation of **multi-party trust model and endogenous security**, the division of traditional security trust domains is evolving. The traditional security boundaries are less clear. The trust domains are no longer defined according to the location of devices in the network. With **service data diversification and intelligent security** in 6G, different types of data may be transmitted in the same connection. The level of transmission security protection needs to consider the classification and sensitivity of the data itself transforming from protection of the network to the protection of digital assets. In the 6G era, it becomes mandatory to carry out a more comprehensive security assessment of trust domains, data access, and transmission security, and apply flexible and dynamic security policies.

Since Forrester put forward the concept of zero trust in 2009, zero trust security model has been widely adopted in finance, Internet, cloud services and other industries. Zero trust focuses on protecting resources (network assets, services, workflows, network accounts, etc.), rather than network segments [6]. The design of security system based on zero trust principles can ensure that the access to data and resources is determined by dynamic policy through dynamic identity authentication and authorization.

In the 6G era, we can consider the security architecture based on zero trust principles and incorporate flexible and dynamic security strategies to achieve **multi-party trust model and endogenous security**, as well as **security of service data diversification and intelligent security**.

Flexible spectrum sharing of Minimized 6G kernel

2.3

Efficient spectrum management has always been a difficult problem in traditional communication systems.

First of all, for spectrum authorities, the purpose of spectrum allocation is to enable communication technologies to be implemented more efficiently and be commercialized more quickly, providing the citizens with better serivce quality as soon as possible, while at the same time meeting the actual needs of spectrum users and ensuring high spectrum utilization. Here the spectrum users may be the traditional cellular operators. Generally, for a spectrum user, spectrum usage requirements are not uniformly distributed at any time or among different geographical regions. Ideally, in order to meet the spectrum requirements and ensure high utilization, it would be necessary to achieve extremely fine division of time and geographical location. But this will seriously lengthen the research and preparation work for the spectrum allocation process, which will lead to a huge delay of spectrum allocation. Therefore, the traditional spectrum division cannot achieve fine granularity. It can only allocate spectrum to users from the frequency domain dimension regardless of time and geographical location factors. In addition, when the spectrum is divided and auctioned, the management of the spectrum utilization is also a challenge for the spectrum authority. In order to effectively obtain the spectrum utilization data, the authority needs to monitor the spectrum utilization at different times and locations, collecting and analysing the data, which naturally also increases management costs.

Second, for spectrum users, although the spectrum usage costs vary from country to country, but in general, the major costs at the beginning of the investment are the spectrum auction expense and the deployment expense. Unfortunately, the commercial deployment cannot quickly be ready to achieve full coverage of the entire region. Thus, until the commercializastion reaches a mature stage, the utilization rate of the spectrum remains inefficient, resulting in a low return on investment.

Pain points of traditional spectrum allocation	Flexible spectrum sharing target	Method
• Long allocation cycle and preparation phase • High management cost for spectrum authority • Static spectrum allocation, less efficient spectrum utilization	• Simplifying spectrum allocation process • Providing more reliable spectrum value • Increasing return on spectrum investment • Enhancing spectrum utilization efficiency	• Spetrum authority, operators, vertical industries jointly establish a consortium blockchain • Realize the trade of spectrum utilization license over blockchain to achieve flexible spectrum sharing • Transaction record and spectrum utilization record in blockchain

Therefore, simplifing spectrum allocation and management is also an important function of the Mimimized 6G kernel, where the meaning of minimized is to greatly simplify the spectrum allocation and management process on the one hand, and to improve spectrum utilization on the other hand.

The core of 6G flexible spectrum allocation is the flexible sharing of spectrum with the help of blockchain technology.

A simple description is that the spectrum owner can transfer the spectrum utilization license to other user who is a member of the consortium blockchain. The transfer of the license of spectrum utilization can be fine-tuned into three dimensions, i.e. time, frequency and geographic location. Thus, the spectrum owner can transfer a license according to its own partitioning of these three dimensions. The user that obtains the license can communicate in this spectrum and the spectrum owner can get benefits from sharing the license, achieving the purpose of flexible spectrum sharing in need.

With flexible spectrum allocation, the spectrum authority can carry out relatively simplified initial spectrum allocation process, while the more detailed allocation is handed over to the subsequent flexible spectrum sharing mechanism, and the spectrum owner can allocate the utilization license according to time, spectrum, and geographical location. For example, a spectrum owner can decide to transfer the license to use a certain spectrum in a specific geographic location within a specific time period according to its own situation, as shown in Figure 2-6.

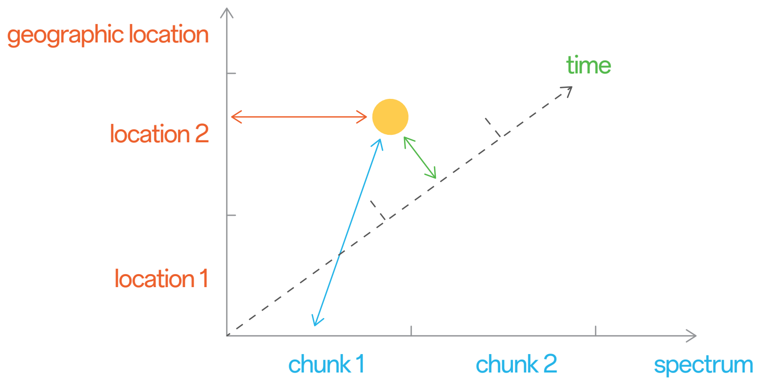


Figure 2-6 : License to spectrum utilization
according to time, spectrum, geographic location, three dimensions

To realize the spectrum utilization license trade, first of all, it is necessary to establish blockchain infrastructure, on which a consortium chain can be created. The consortium can be composed of spectrum authorities, traditional operators, and vertical industry operators and they are also nodes on the consortium chain at the same time. When the spectrum owner issues a smart contract to trigger the sharing of the spectrum. The transfer of the spectrum utilization license can be realized in the form of bidding or non-bidding. For the latter, there may be multiple users in the same frequency spectrum. Therefore, interference avoidance transmission technology needs to be considered in this scenario. When the transaction is completed, the node will record the transaction into a block and further connect it to the chain, so that each full node on the blockchain can have a copy of the latest license transaction status. The entire data structure is shown in Figure 2 -7 shown.

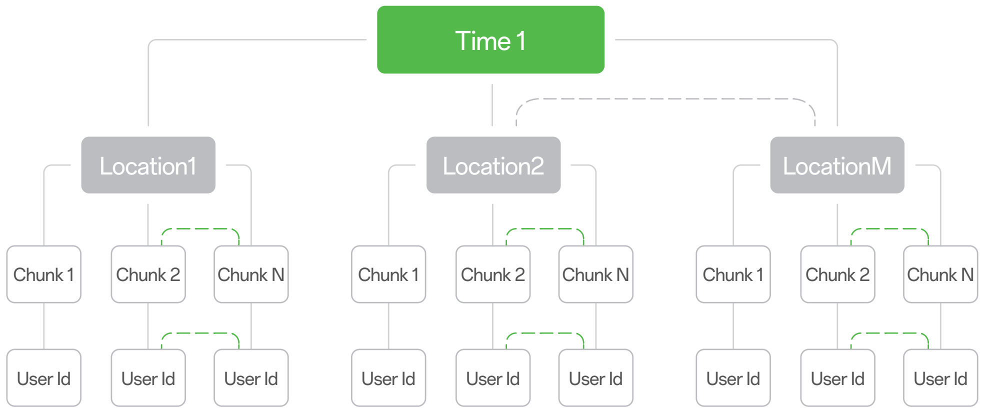


Figure 2-7 : data structure for flexible spectrum sharing based on blockchain

Another advantage of blockchain-based flexible spectrum sharing is that the spectrum authority can obtain the reliable and untamperable spectrum transaction records in real time, and can obtain a more realistic actual market valuation of the spectrum and the utilization rate of the spectrum. On the other hand, spectrum users can record more detailed spectrum usage information through the blockchain, so that the spectrum authority can obtain spectrum usage in a more comprehensive manner, thereby greatly reducing their cost of spectrum management.

3.0 6G Broadband Cellular subsystem

- KPI requirements of 6G Broadband Cellular
- Key techniques and system design of 6G Broadband Cellular
- AI replacement for 6G air interface

KPI requirements of 6G Broadband Cellular

Broadband cellular is the traditional core of 4G and 5G systems, and will still be one of the most important subsystems in 6G systems. At the same time, broadband cellular is also the most mature technology with the highest user satisfaction in 4G and 5G systems. The rapid popularization of 4G and 5G has strongly supported the vigorous development of various mobile Internet applications, proving that 4G and 5G have achieved good results in satisfying the multimedia audio and video experience of mobile phone users. The main goal of 6G broadband cellular technology is to improve the performance of traditional services and expand the scope of applications, mainly including:

- **Popularization of high-resolution video;**
- **Popularization of XR applications;**
- **Distributed AI inference, training and model transfer.**

We believe that the 6G broadband cellular subsystem should meet the requirements as shown in Figure 2-8.

First of all, the theoretical peak data rate of 20Gbit/s of the 5G system can already support the transmission of high-definition video, XR traffic streams and even AI model and data transfer. Therefore, the 6G broadband cellular subsystem does not need to pursue a peak data rate that is significantly higher than 5G.

Secondly, due to the limited coverage of 5G high-order MIMO transmission and mmWave transmission, there is still a challenge to achieve a user experienced data rate of 100Mbit/s at the edge of 5G macro cells. 6G should be committed to ensuring that this rate becomes a user experience available at any time and anywhere. Pursuing a higher theotical data rate is not the primary goal.

Next, due to the great difference between the channel environment, software and hardware capabilities of terrestrial and non-terrestrial systems, the 6G broadband cellular subsystem should focus on defining terrestrial cellular transmission technology. Efforts should be made to improve the coverage depth in areas where people often live. Coverage in areas where people are scarce, such as oceans and deserts, should be achieved by the 6G non-terrestrial communication subsystem.

Finally, the 6G broadband cellular subsystem should still focus on communication capabilities, but only providing basic positioning and sensing capabilities. It should not excessively pursue ultra-high precision positioning and sensing performance, which will greatly increase the complexity and cost of the system and terminals. The basic positioning capability is sufficient for most broad-band multimedia and AI services. For a small number of application scenarios that really require high-precision positioning and sensing, the services can be provided by integrating the 6G sensing subsystem in the network and terminals.

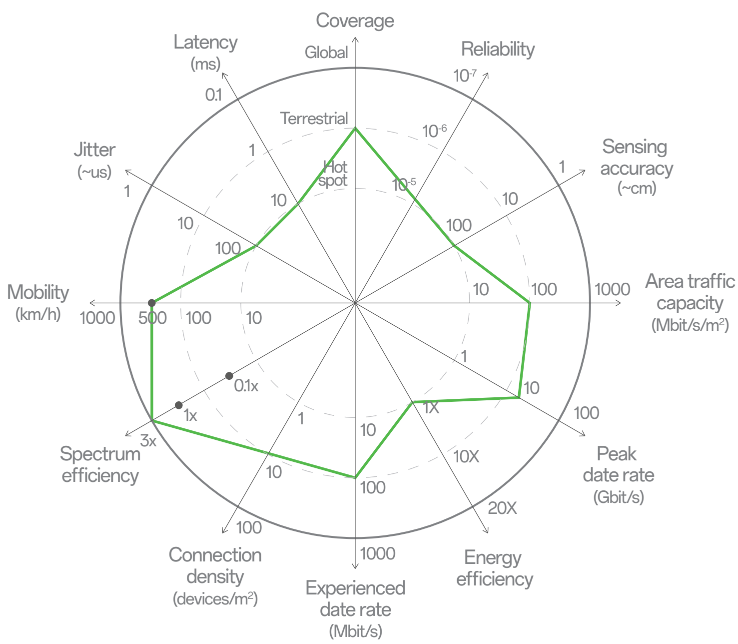


Figure 2-8: KPI requirements of 6G Broadband Cellular subsystem

Key techniques and system design of 6G Broadband Cellular

3.2

Targeting the above KPI requirements of the 6G broadband cellular subsystem, our observations on the potential key techniques are shown in the table below.

Technical catagory	Purpose of the technique	Key technique	Potential to be adopted in 6G
New waveform for higher frequency	Providing higher bandwidth and data rate	New waveform for high-frequency mmWave	Relatively mature. Likely to be adopted in 6G. But the problem of limited coverage of LOS transmission still needs to be solved.
		THz communication	Short transmission distance. More suitable for D2D communication.
		Visible Light Communication	Short transmission distance. More suitable for D2D communication.
Spectrum efficiency improvement	Achieving higher spectrum efficiency	AI-based air interface	Relatively mature. Likely to be adopted in 6G. The actual performance gain needs to be further studied.
		More massive MIMO	Relatively mature. Likely to be adopted in 6G. But the problem of limited deployment scenario and high power consumption still needs to be solved.
		New type multiple access	Depends on whether sufficient performance gain can be obtained and whether consensus can be reached on down-selection of detail solutions.
		Full duplex	The flexible duplex mode is relatively mature, with a high possibility to be adopted in 6G. The maturity of full duplex is still challenging. And the actual performance gain needs to be verified.
Coverage enhancement	Solve the problem of limited coverage of LOS transmission in high frequency	Reconfigurable Intelligence Surface	Relatively mature. Likely to be adopted in 6G. But the actual performance gain and the actual deployment cost needs to be verified.
Reliability improvement	Achieve higher transission reliablility (e.g. 10-7)	New channel coding	Under study. The actual performance gain needs to be verified.

Table 3-1: Potential key techniques of 6G Broadband Cellular subsystem

According to how to contribute for the 6G performance, the candidate techniques can be categorized into four types:

New waveform for higher frequency

The goal of this type of technology is to achieve a larger bandwidth and higher peak data rate than 5G. Since the main way to obtain larger bandwidth is to use new spectrum in higher frequency band, this type of technology is mainly high-frequency transmission technology.

The mmWave transmission technology has been studied in the 5G stage. The conclusion is that the OFDM waveform used in 5G for <6GHz bands can be reused. However, the channel characteristics of high-frequency mmWave signals may change greatly. And waveforms different from traditional CP-OFDM may need to be considered.

Terahertz (THz) and wireless optical communication technology in higher frequency band may realize even a larger bandwidth and higher rate than mmWave. But their transmission distance would be short, which requires a too high base station density for a cellular network to deploy. We believe that THz and wireless optical communication are more suitable for the 6G D2D subsystem, which will be described in Section 4.2. Of course, these two techniques may also be used for the 6G sensing subsystem.

Spectrum efficiency improvement

Since 2G, the improvement of spectrum efficiency has been the long-term goal of mobile communication technologies of all generations. Theoretically, the improvement of spectral efficiency can always be in exchange for higher data rate and system performance. However, in fact, improving spectral efficiency is certainly not without cost, which almost inevitably requires higher equipment complexity and deployment costs.

Taking multi-antenna (MIMO) technology as an example, when introducing MIMO technology into HSPA+ and 4G systems, only 2 to 4 antenna ports were used to achieve spectral efficiency gains. Thus the value of MIMO technology was very high. Using large-scale antenna technology in 5G can realize multi-user MIMO (MU-MIMO) and vertical sectorization for dense-urban coverage, which is a very attractive technology in theory. However, MU-MIMO and 3D MIMO do not achieve significant performance gains in all deployment scenarios. And the cost and energy consumption increases brought by a large number of antennas do not always lead to corresponding performance improvements.

The new multiple access scheme is another key technology that has been studied in depth in the 5G phase. However, due to the fail down-selection among many candidate schemes, no clear conclusion on performance gain and complexity, it has not been adopted by the 5G standard. It is expected that the new multiple access technology will be studied again in the 6G standardization phase, but it will still face similar challenges in 5G. The new multiple access technology can often obtain obvious gains in certain specific scenarios. Whether the industry can reach a consensus on these "advantageous scenarios" and their performance gains will be a difficult question.

As the initial stage of full duplex, 3GPP Rel-18 began to study the flexible duplex technique. Although this technique cannot achieve the real "full duplex", its implementation complexity is relatively low, and it is possible to become a part of the 6G standard. The full version of full duplex technique is still under study in academics. And how to control the complexity of the equipment is still facing challenges.

AI for air interface is another "Pre-6G" technique studied in 3GPP Rel-18. Although the performance gain evaluation has not been completed, it can be basically determined to be one of the core technique of 6G. The reason is not only that AI may achieve a certain performance gain, but also because it may achieve a greatly simplified air interface protocol. And AI-based 6G physical layer can enable the shared inference and training resource between application processing and 6G baseband processsing, so that the application processor and baseband processor of 6G equipements and terminals are expected to be unified into one hardware and software architecture. Replacing 6G physical layer algorithms with AI algorithms will be further introduced in Section 3.3.

Coverage enhancement

In the 5G phase, 3GPP also studied and standardized some coverage enhancement techniques, including relay and various optimization of channel design. Reconfigurable Intelligent surface (RIS) is a candidate coverage enhancement technology to solve the problem of low coverage rate of mmWave LOS transmission. If the coverage of mmWave signals can be significantly improved, it will be more valuable for 6G than the introduction of higher-frequency transmissions, e.g., THz, VLC and other "peak data rate techniques" that only work in hot spot coverage. However, the industry still needs to verify the actual performance gains of RIS and solve the deployment cost problem of RIS sites.

Reliability improvement

The 5G standard introduces LDPC and Polar codes, which respectively contribute to the high data rate transmission of eMBB and the high reliability of URLLC. Whether it is necessary to introduce a new channel coding scheme to achieve higher transmission reliability, the academic community is still studying. However, as described in Section 3.1, the 6G broadband cellular subsystem does not need to further improve transmission reliability. If new channel coding is introduced, its main application scenarios would be the 6G URLLC subsystem. In the 5G system, both eMBB and URLLC share the same channel coding schemes. However, in the 6G system, if the new coding technology has relatively high complexity, it can also be considered to be used only in the 6G URLLC subsystem.

As 4G MBB and 5G eMBB technologies have been quite mature, with their application performance widely verified in the market, under the condition that 6G continues to use 5G core physical layer technology (OFDM+MIMO), 6G broadband cellular subsystem can largely follow the mature design of 5G eMBB, including channel structure, resource allocation, multiple access and other physical processes. However, on this basis, the 6G broadband cellular subsystem can introduce AI algorithms, which can be used in parallel with the traditional algorithms. As mentioned in 2.1.3, the 6G system using AI algorithm may adopt a significantly different system design based on "the AI model lifecycle management". That is to say, the 6G broadband cellular subsystem may include two air interface designs ---- Traditional and AI-based designs.

AI replacement for 6G air interface

3.3

The construction of intelligent wireless network has become an important direction of future mobile communication system design. 3GPP Rel-18 carried out research on AI enhancement technologies for 5G air interface, involving three use cases, i.e. channel state information (CSI) feedback enhancement[13-17], beam management, and positioning enhancement. However, the introduction of AI in these three use cases is still in a traditional transceiver-based architecture. It attempts to replace traditional algorithms with AI algorithms in isolated physical layer technologies. Although some progress has been made, the contribution to the overall performance improvement of the 6G system is limited.

Therefore, it is necessary to make a clearer judgment on the road map of 6G, including the limitations, bottlenecks and expected changes in the evolution of AI based air interface construction. Formulate short-term, medium-term and long-term plans accordingly to achieve theoretical and engineering achievements and breakthroughs.

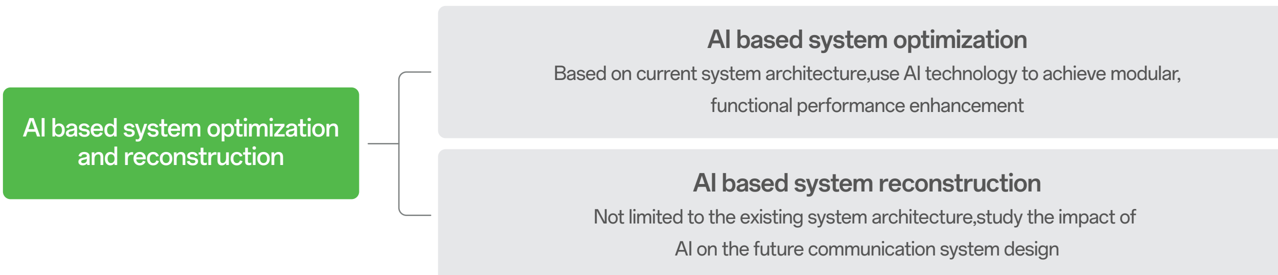


Figure 3-2: AI based system optimization and AI based system reconstruction

The intelligent 6G air interface consists of two levels, i.e. AI based system optimization and AI based system reconstruction.

As shown in Figure 3-2, the intelligent optimization for wireless communication system will first improve the performance of a single module or a specific link relying on data driven or model driven AI technologies. For example, in the physical layer, the channel estimation function, channel state information feedback module, beam management, symbol detection link, sensing subsystem, can be enhanced using AI technologies to improve the performance of corresponding modules. In the access network, for mobility management, resource allocation, load balancing, network/user energy conservation and other issues, the overall performance gain of the access network can be improved by taking advantage of the decision-making and the prediction capability brought by AI based solutions. On the core network, AI based network planning, refinement, optimization, and AI based network fault detection and maintenance capabilities are realized through the introduction of intelligent capabilities.

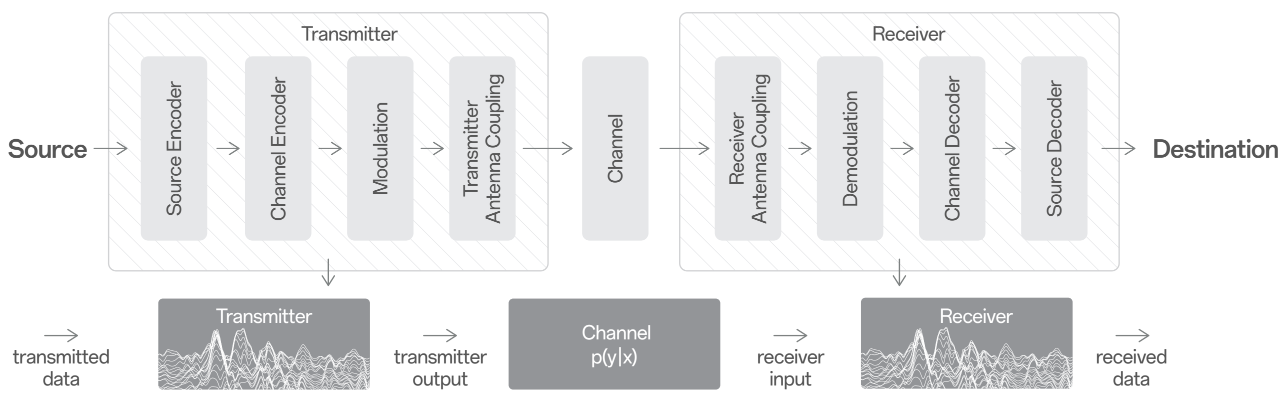
The above air interface oriented AI function is the beginning of the combination of wireless communication and AI technology. In the 6G era, more crucially, the communication industry has once again obtained the opportunity to systematically change the overall architecture. Therefore, at this stage, AI based system optimization based on the existing architecture is not the whole content of intelligent 6G research. Focusing on the influence of AI on the design and reconstruction of future communication systems, some inherent modes need to be tried and be broken, and exploration should be carried out in order to build a new generation of wireless communication system oriented to intelligent requirements and built on intelligent technologies.

The research on the intelligent 6G air interface will not only do the repair and optimization evolution on the specific wireless use cases, but also carry out the in-depth analysis of the common basic problems of wireless AI from the perspective of system reconfiguration, including:

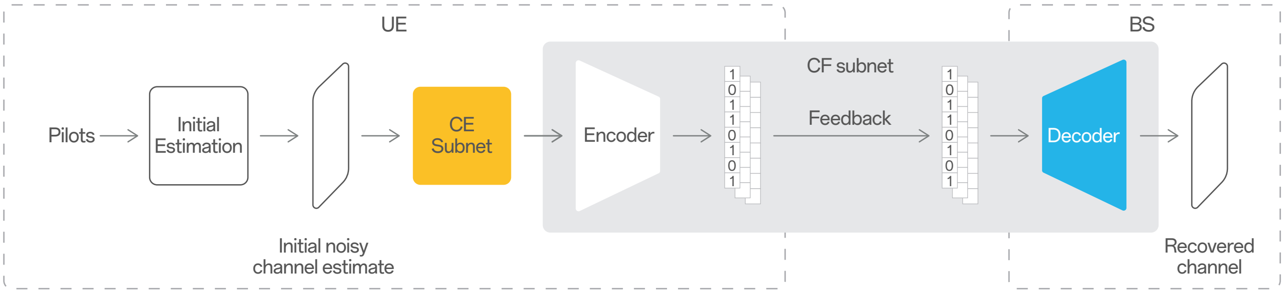
- **Integrated and systematic AI design of future wireless communication system,**
- **Wireless AI solution for scene adaptation and online updating under limited sample conditions,**
- **Wireless AI data set studies with intelligent channel modeling and virtual channel reconstruction.**

1.Integrated and systematic AI design of future wireless communication system

First, the integration and systematic AI design of the future wireless communication system can include top-down design and bottom-up systematic integration, as shown in Figure 3-3. In the traditional communication system, the whole system is divided into specific units based on functional division. These units are cascaded through problem decomposition, function modeling, parameter fitting and other methods to construct a communication system. However, the core purpose of communication is the successful transmission of information. The artificially divided modular design is one way to achieve this goal, while the AI technology provides another way to solve this issue. The communication system design based on AI can take the maximization of transmission gain as the target, the information to be transmitted as the expected input and output of the receiving and transmitting models, and the uncontrollable factors such as channel environment and noise as the limiting conditions of model construction to obtain the overall performance gain. At the same time, it is necessary to point out that although the integrated design of large-scale systems is beneficial in terms of reducing the loss of information, it will also introduce high degrees of freedom and complexity. The extraction of useful information from lossless information is still a challenge to the intelligent 6G system. Therefore, the bottom-up integration based on modular AI is also an important exploration of intelligent evolution of future wireless communication systems.



（a）top-down design



(b) bottom-up systematic integration

Figure 3-3. Integrated and systematic AI design

2.Wireless AI solution for scene adaptation and online updating under small sample conditions

Besides, for the intelligent 6G wireless communication system, it is also necessary to form a clear judgment on the common constraints faced by the deep integration of wireless communication and AI technology. Currently, the focus of research on wireless AI has been expected to give priority to evaluate the changes brought about by the combination of wireless communication system and artificial intelligence technology through performance gain, complexity, generalization and other aspects, and then trigger more targeted researches and works. Relatively ideal data set, training method, scenarios and constraints are given priority to quickly confirm the impact of AI solutions in wireless systems. However, the above assumptions often introduce overly ideal assumptions, such as whether sufficient training data can be obtained, and how to evaluate the cost of obtaining samples. For scenarios, whether model training can be completed in sufficient scenarios, and how to evaluate the impact of different scenarios on intelligent wireless communication solutions.

In addition, it is uncertain whether offline processing can be used to train models and algorithms in different scenarios and data conditions. For the intelligent reconstruction of the 6G system, when a practical system is deeply integrated with AI technology, it is necessary to fully consider these factors and support the deployment of wireless AI solutions (e.g. meta learning and transfer learning, as shown in Figure 3-4) to meet the needs of scenario adaptation and online update under small sample conditions.

Figure 3-4: Meta learning based scene adaptation and online updating under small sample conditions

3.Wireless AI data set studies with intelligent channel modeling and virtual channel reconstruction.

In addition, as the basis of intelligent system design and performance evaluation, the research on wireless dataset itself and its derivatives will play an indispensable role in the 6G era. Take physical layer applications for example, most wireless data can be traced to wireless channels. As a basic solution, the data set obtained from simulation platforms and the realistic data collected from fields can be used to form different wireless AI data sets. However, the wireless channel conditions that communication systems need to face are extremely complex, and the reliability of wireless AI schemes obtained through the simulated data or local field data is usually limited. Faced with such problems, in the construction of intelligent 6G wireless system, it is necessary to fully consider the data set requirements involved in different research directions, fully evaluate the collection methods and potential collection difficulties, and support the completion of field data modeling based on the assumption of a small number of realistic samples. As shown in Figure 3-5, the physical channel is virtually reconstructed through intelligent technologies, and then the availability and effectiveness of wireless AI datasets from different sources in their corresponding wireless AI use cases can be evaluated[18].

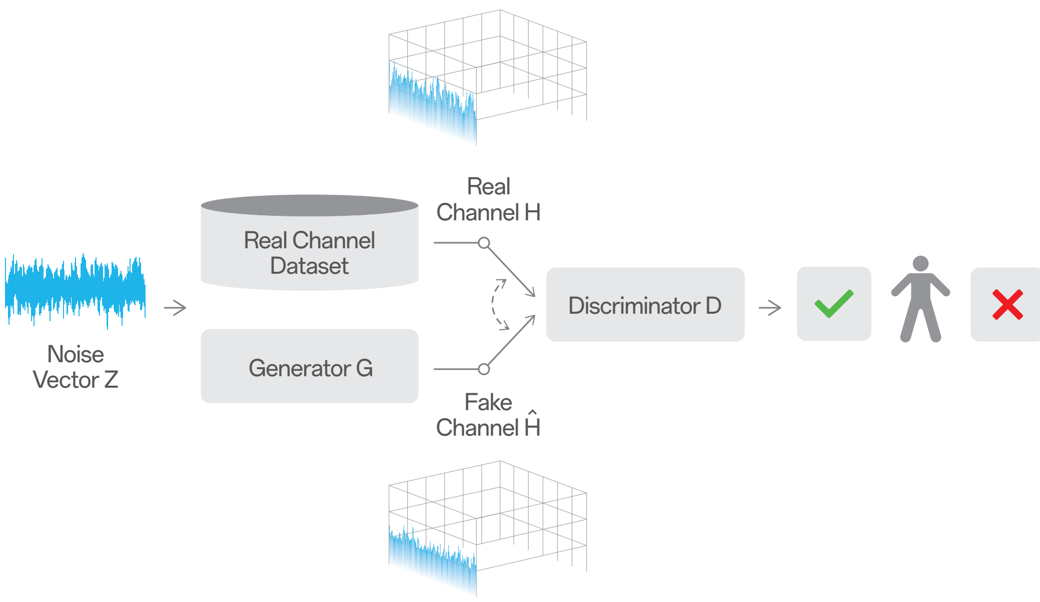


Figure 3-5: Intelligent channel modeling and virtual channel reconstruction.

The development and application of artificial intelligence provide potential for the intelligent construction of future wireless communication systems, but also bring more challenges. For the 6G era, the future wireless communication network will no longer be a simple transmission network. The demand for intelligence, changes by intelligence, and construction of intelligence will run through the design and construction of 6G systems and even longer. We look forward to the arrival of "intelligent wireless, smart world".

4.0 6G D2D subsystem

- KPI requirements of 6G D2D
- Key technology and system design of 6G D2D
- Design of AI based D2D system
- THz communication
- Visible light communication

KPI requirements of 6G D2D

4.1

The KPI requirements of the 6G D2D subsystem are shown in the following figure.

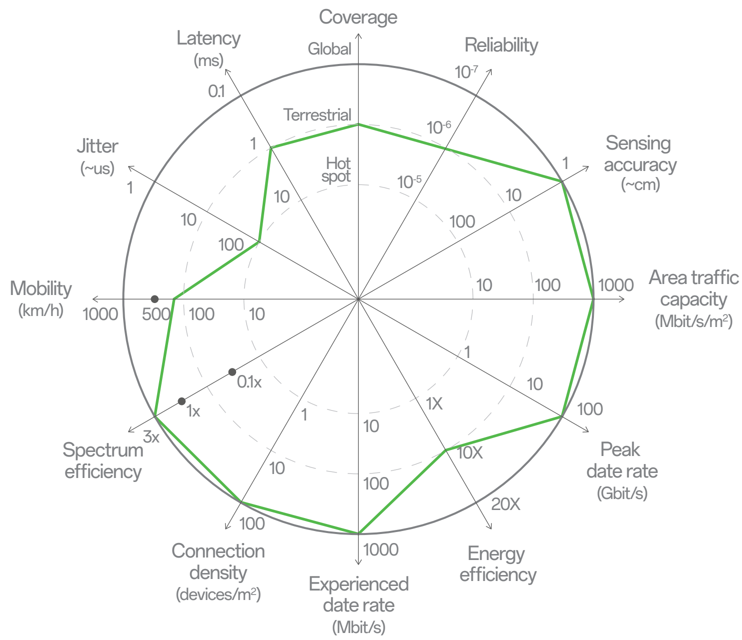


Figure 4-1 : KPI requirements of 6G D2D subsystem

Peak rate and data rate

The 6G system considers the transmission technology with higher frequency bands, such as terahertz communication and visible light communication. These high-frequency bands have large bandwidth and can provide high transmission rate. However, its transmission distance is too short, which requires extremely high base station density for cellular networking, and it is difficult to deploy. Terahertz communication and visible light communication are more suitable for 6G D2D subsystem, which can directly transmit data between decives over a distance of several meters or even shorter. Therefore, the peak rate and data rate of the 6G D2D subsystem may exceed that of the 6G broadband cellular subsystem. In other words, the highest peak rate and data rate of the 6G system may be achieved through the D2D subsystem.

Connection density

As the D2D communication between consumer electronic devices may take place in a very short distance, the D2D subsystem can achieve a high connection density and support a high number of connections. The connection density of the 6G D2D subsystem may also exceed that of the 6G broadband cellular subsystem.

Spectrum efficiency	In 5G D2D, in order to reduce the standard complexity, it only supports two layers transmission and 256QAM. In the 6G D2D subsystem, it can be considered to support more layers data transmission and higher modulation schemes to improve spectrum efficiency.
Mobility	The main application scenarios of D2D communication are still the interconnection between personal devices or vehicles, so the mobile speed below 150km/h can meet the requirement. Supporting excessive mobile speed may increase the complexity and cost of the D2D subsystem.
Positioning accuracy	Because D2D sensing is mainly used for accurate positioning between adjacent devices,where the rang is short and the LOS connection ratio is high. It is more conducive to achieve high positioning accuracy. Therefore, the perception accuracy of the 6G D2D subsystem is expected to reach the centimeter-level, and such high-precision positioning is also necessary for high-precision interactive services (such as interactive XR games and cooperative driving) between adjacent devices.

Key technology and system design of 6G D2D 4.2

As the available frequency band in the 6G system becomes higher and higher, it becomes more difficult to achieve seamless coverage through the base station. Using D2D technology to achieve direct communication between devices will become an increasingly important communication mode in the 6G system. In addition, D2D technology can be combined with other technologies, such as sidelink based positioning technology, sensing technology, large-scale IoT technology, artificial intelligence, etc. Therefore, D2D technology will become one of the most important technologies in the 6G system.

4.2.1 Design of AI based D2D system

At present, artificial intelligence (AI) is widely used in computer vision, natural language processing and other fields. How to introduce AI technology into wireless communication has become a research hotspot of 6G. The following new points can be considered for AI application in the D2D subsystem:

- **AI based resource allocation and power control**
- **AI based traffic and load prediction**
- **AI based Mesh networking**

1.AI based resource allocation and power control

3GPP has launched the research and standardization of sidelink (SL) to support D2D communication. First of all, the resource allocation of sidelink has two modes, namely mode 1 and mode 2. In mode 1, the transmission resources are allocated by the base station. The base statiom can dynamically schedule resources or configure sidelink configured grant (SL CG) resources for the user equipments (UE). In mode 2, the UE can automatically select transmission resources from the (pre-)configured resource pool. In 3GPP Release-16 standard, the full sensing based resource selection is supported. Furthermore, in Release-17, the partial sensing based and random selection based resource selection are standardized. In mode 2, since each UE independently determines its own resources, this distributed mode has natural advantages to introduce machine learning (ML) algorithms, especially reinforcement learning. The resource allocation methods based on reinforcement learning have achieved an amount of research results in the academic community.

Reinforcement learning is an important branch of ML, which is used to maximize reward through learning strategies in the interaction between the agent and the environment. In other words, reinforcement learning does not need a training data set in advance, but obtains the reward of the action by executing the action in the enviroment, and constantly updates the model until it converges.

According to whether to follow the mode 2 resource selection, the resource allocation based on reinforcement learning can be divided into the following two directions:

- Based on the mode 2 resource selection, that is, resource reservation and resource exclusion, reinforcement learning is introduced to determine the optimal value for some parameters. For example, in [7], Q learning is used to optimize the RSRP threshold value used for resource exclusion in V2V. The return function is designed based on the average packet reception ratio (PRR) to determine the optimal RSRP threshold value. For another example, [8] selects collision probability and delay as the reward, and then adjusts the counter in the semi-static transmission and the reselection probability after the counter is reduced to 0, so that the UE adopts a semi-static strategy matching the transmission traffic or load. Therefore, following this principle, the parameters used in resource selection or exclusion of other steps can also be optimized through reinforcement learning.
- Another possible direction is to break the existing mechanisms of resource reservation and resource selection. Each UE directly perceives the environment, for example, through CSI and interference measurement, and introduce reinforcement learning to determine the optimal transmission resources and maximize system throughput and reliability [9] [10]. However, compared with the first direction, this direction is more destructive to the traditional resource reservation and resource exclusion mechanisms that have been used since Release-14.

2.AI based traffic and load prediction

Prediction is also an important branch of AL/ML, which is to train the model according to the existing training set and use the trained model to provide a correct answer for the unknown data as far as possible. Prediction can be either classification or regression. For example, if it predicts whether the traffic will arrive, it is a classification problem; if it predicts the arrival time of the traffic, it is a regression problem. In sidelink, traffic or load prediction can be applied for the following aspects:

- **Channel access based on traffic or load prediction**
- **Resource allocation based on traffic or load prediction**
- **Congestion control based on traffic or load prediction**

Firstly, the traffic or load prediction can be used for channel access on unlicensed spectrum. Unlicensed spectrum is used for radio equipment communication and is considered as a shared spectrum. Therefore, when the UE transmits on unlicensed spectrum, it needs to perform Listen before Talk (LBT) before data transmission. Data can be transmitted if LBT is successful. When a UE transmits on unlicensed spectrum, it is likely that the LBT of other UEs will fail and the channel cannot be accessed by other UEs. If a UE can predict other UEs' traffic, it can know the spectrum occupation in advance, so as to avoid the LBT failure. In this case, the channel access opportunities of each UE can be coordinated as far as possible to reduce the impact of LBT, so that the communication on unlicensed spectrum will be similar to that on licensed spectrum.

Secondly, as mentioned above, model 2 resource selection is based on resource reservation, that is, when other UEs reserve a certain resource through sidelink control information (SCI), the UE performing resource selection will exclude the reserved resource to avoid resource collision. However, the resources reserved by other UEs may not be used, resulting in a waste of resources. By combining resource reservation with traffic prediction, the above problems can be solved to improve the spectrum efficiency. Furthermore, traffic prediction can also replace resource reservation to save the signaling cost of transmitting resource reservation information. In addition, from the perspective of the resource reservation UE, if the UE can predict whether the data will be transmitted on the reserved resources, when the data will not be transmitted, the resource reservation will not be performed and the corresponding resources can be used by other UEs to improve the resource utilization.

In addition, traffic prediction can also be applied for congestion control. For example, in the existing sidelink mechanism, channel occupancy ratio (CR) is a basic measurement used to support congestion control. CR at slot n is defined as the total of sub-channels for the UE's transmision within slots [n-a, n-1] and granted within slots [n, n+b] divided by the total number of sub-channels belonging to the resource pool within [n-a, n+b]. The measured CR is compared with the channel occupancy threshold (CRlimit). If the measured CR exceeds CRlimit, the corresponding transmission is dropped. According to the definition of CR, the current calculation of CR is based on the number of sub-channels granted within slots [n, n+b], but in fact, the granted sub-channels may not be used. Therefore, the prediction of the number of resources that will be used within [n, n+b] is beneficial for improving the measurement accuracy in congestion control.

3.AI based Mesh networking

In the future, there will be a very rich variety of intelligent devices, such as smart phone, wearable device, intelligent vehicle, and the intelligent equipments used to build various vertical industries such as smart medical, smart factory, smart home, and smart transportation. At the same time, XR devices and robots are expected to shine in the 6G era, and even new interactive products may appear in the future. If different devices cannot connect with each other due to physical boundaries, it will not be able to provide a more intelligent user experience. 6G system will realize the interconnection of various intelligent devices and build a mobile world of "everything is connected"。

However, when the variety and quantity of devices are in explosive growth, it will also bring new challenges to the communication quality and network performance. The cellular network only relying on the centralized scheduling of the base station maybe not enough to support the demand for interconnection of various intelligent devices. 6G is expected to surpass 5G and expand from the cellular network to a distributed network in order to deploy more application scenarios. Mesh network is different from the centralized cellular network. There is no central controller in the mesh network. The devices form an self-organized network by single-hop or multi-hop connection. Any two devices in the network can maintain wireless interconnection. Such a network is suitable for smart home, industrial Internet of Things, emergency rescue and many other scenarios. Mesh network has no restrictions on the physical layer technology, so D2D communication can obviously provide a convenient channel for mesh networking.

The research on the key technologies of mesh networking includes network discovery, routing/forwarding, and network maintenance. Network discovery is used to discover surrounding nodes and join the existing mesh network. The devices in the mesh network communicate with each other through single-hop or multi-hop, so the design of routing path algorithm will directly determine the network performance. How to select the routing path and relay nodes needs to consider multiple performance metrics to achieve the optimal topology. A stable mesh network may encounter unexpected situations such as the existing nodes breakdown or departure. An important advantage of mesh network is that it will not cause communication failure due to a certain node breakdown. This is because mesh network can update the network routing list in real-time to maintain network stability. In the future, intelligent devices may be present in the "fusion" world of both physical and virtual, and the surrounding environment will be more complex. At the same time, they may be in a high-speed mobile state. Therefore, intelligent devices in the Mesh network need not only to quickly join the network to establish communication connection, but also to quickly respond to changes of the dynamic environment and maintain the network topology in order to maintain an efficient and stable operating state. However, the present devices may not be able to support such strong prediction and decision-making capabilities. In the 6G era, AI can enable the D2D subsystem. Intelligent devices, as the natural carrier of edge cloud computing and distributed AI computing, can give full play to powerful computing of AI to solve the key problems in mesh networking and realize the deployment of mesh network in wide application scenarios.

4.2.2 THz communication

1.Characteristics of THz communication

Many new applications are emerging in the 6G network, such as immersive telepresence, holographic teleportation, connecting robots and autonomous systems, extended reality (XR) and digital twins. These bandwidth-intensive applications require at least 1000 times more capacity than the 5G system, and these applications also require multi-purpose wireless functions, including communication, sensing, positioning and control. Therefore, it is necessary to migrate to higher frequency THz band. The THz frequency band is 0.1Thz-10THz (1Thz=10^{12}Hz), between microwave and infrared, with rich band resources. Previously, due to the limitation of semiconductor development technology, there was no effective transceiver and antenna, and THz communication technology was not applied. However, due to the latest progress in plasma device and graphene design, THz communication technology has become a research hotspot in 6G network.

THz band has the following characteristics: 1. High data transmission rate and rich spectrum resources, which can improve the transmission rate for 6G D2D system; 2. High pathloss and reflection loss; 3. The LOS link is easily blocked; 4. Molecular absorption, although it is harmful for the communication in the THz band, this feature significantly improves the sensing ability of THz; 5. The quasi optical characteristics of THz band have good sensing, imaging and positioning functions.

The pathloss of THz communication is characterized by a "transmission window", as shown in Figure 4-2. When the communication is performed within the transmission window, the pathloss is relatively small. However, the transmission window is not fixed. It is affected by the environment and weather changes, and is related to the transmission frequency and distance. Therefore, it is more meaningful to use THz communication to transmit in a controlled or indoor environment.

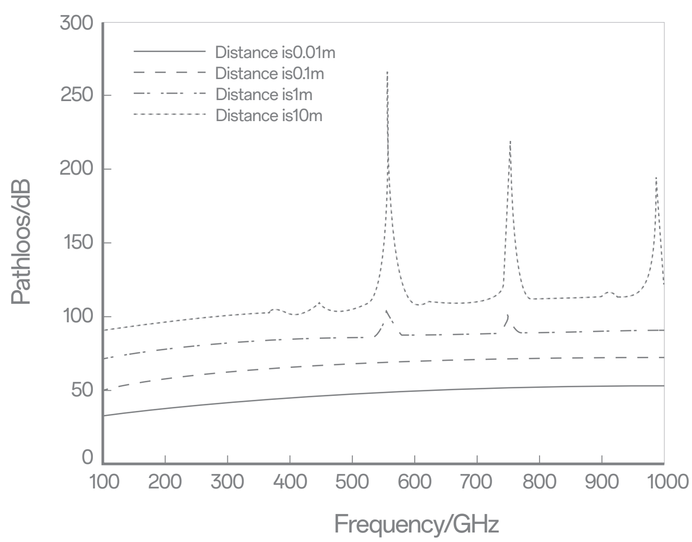


Figure 4-2: Pathloss characteristics of THz communication

The characteristics of THz communication make it suitable for indoor and short-range communication. Therefore, the combination of THz technology and D2D communication technology will be a major application scenario in the 6G system. The application scenarios can include:

- Internet of Vehicles: super fast data transmission between vehicles;
- Harmonized communication and sensing: vehicles or handheld devices send THz signals through the sidelink to sense the surrounding environment information;
- Tactile communication: real-time transmission of tactile or sensory information;
- Interactive interface: control vehicles or terminals through human brain;
- Indoor applications: such as smart home, high-definition holographic games, VR, AR, etc.

2.Challenges and methods of THz beam management

Because the THz operating frequency band is extremely high and the size of its corresponding physical unit is very small, it is possible for an antenna panel to integrate hundreds of antennas to form a ultra-massive MIMO system. By generating narrow beam with high beamforming gain, THz communication can overcome the problem of communication distance limitation in the THz band, and is expected to achieve high energy efficiency and support mobile coverage.

Because THz beam is extremely narrow and the tolerable transmission delay is very low, Direction of Arrival (DoA) estimation with extremely high angle resolution and fast beam tracking are required in THz narrow beam management. In order to achieve millisecond-level DoA estimation and millisecond-level beam tracking, beam training methods based on deep learning (DL) can be used in THz communication. For example, DL based algorithms for DoA estimation include deep convolutional neural network (DCNN), convolutional long short-term memory (ConvLSTM), etc. The millisecond-level DoA changes can be achieved with low computational complexity and beam training overhead.

Due to the large bandwidth of THz system, the array pattern will shift significantly with frequency, resulting in beam squint effect. Beam squint will cause beam misalignment at different frequencies, which seriously degrades the system performance. Therefore, it is necessary to develop an effective training program to eliminate beam squint effect. In order to alleviate the beam squint effect in THz systems, one method is to re-aggregate the squint beams. In this method, a hybrid beam shaping structure based on a time delay phase shifter and corresponding training scheme can be used to replace the frequency independent phase shifter with a frequency dependent true time delay (TTD) phase shifter to eliminate the beam squint effect. Another method is to separate the angles of the beam to expand the angle coverage. The angle expansion is obtained by dividing the beams into different directional beams. While increasing the angle coverage, the directional gain of each subband will not be reduced. Therefore, large angle coverage can be achieved while maintaining the distance coverage.

4.2.3 Visible light communication

Twenty years ago, Light Emitting Diodes (LED) began to be widely used. After the development of LED, visible light communication (VLC) has received extensive attention in the research field. VLC communication uses visible light (380mm-780nm) as the data carrier. Under the premise of normal lighting, the information is modulated into the visible light emitted by the LED lamp. The receiving node uses a photoelectric detector to convert the visible light into an electrical signal and demodulate the corresponding modulation information.

1.Characteristics of VLC

VLC technology has the following characteristics:

- Rich spectrum resources and high data transmission rate: Compared with RF communication, VLC communication has huge free spectrum resources, which can achieve a very high data transmission rate and in 6G. In addition, combining with MIMO technology can further improve the transmission rate.
- Limited penetrability: The main difference between VLC communication and RF communication is the inherent characteristics of the used electromagnetic wave. RF wave has the ability to penetrate most non-metallic materials, while visible light can only penetrate transparent materials.
- Low deployment cost and simple implementation: The existing LED lighting equipment can be used for VLC communication after being modified and with low cost and easy deployment.
- Energy saving: VLC communication does not need to consume additional electric energy, and the same equipment can be used as both lighting and data carrier.
- Good security and privacy: The signal isolation feature of VLC communication can prevent eavesdropping on indoor or building internal communication, thus improving the security of communication.

VLC communication technology is mainly proposed for indoor and underwater communication. However, because of its high transmission rate, it can be applied in many fields, such as using intelligent desk lamps to transmit information, sending invisible advertising to customers in shopping malls. The application scenario of Internet of Vehicles based on VLC communication has been widely concerned. Traffic signal lights and car lights can be modified to improve driving safety through VLC communication. In the scenario of platooning , high data rate based on VLC can be realized between front and rear vehicles through lamps. VLC communication can also be used for wearable devices for real-time health monitoring.

2.Physical layer challenges in VLC

Although visible light spectrum resources are rich and can provide high data rate, compared with traditional communication systems based on RF technology, visible light for data communication will face corresponding challenges.

- LoS and NLoS paths have a great impact on the reception strength: LoS and NLoS paths affect the reception strength of light. In addition, the angle of the transmitter will also affect the reception strength. The wider the transmitter angle is, the weaker the received signal is, and the narrower the angle is, the stronger the signal is. When the receiver is a mobile device, the user can constantly change the direction, resulting in the reception strength varies between strong and weak. Therefore, it is necessary to develop high-speed communication technology that is not within the LoS path of the transmitter. The intelligent reflective surface (IRS) technology can control the signal reflection direction, and the combination of VLC and IRS technology can improve the visible light transmission performance.
- Difficulty in VLC uplink implementation: In an indoor environment, smart phones and other low-power devices send information back to LED bulbs. If VLC is used for uplink, multiple light sources need to be added to mobile devices. Most of the light sources have random directions, which may cause uncomfortable to the human eyes. The current main solution is to establish the uplink using RF, infrared, etc.
- Mobility: VLC based systems must support mobile devices. In order to make VLC a ubiquitous technology, there needs to be a mechanism to ensure uninterrupted high-speed connection within the system coverage. In order for VLC systems to be commercially successful, especially in the consumer market, challenges related to signal coverage and mobility need to be addressed.

3.Main research directions of VLC

The openness and broadcasting character of the visible light communication system make it vulnerable to eavesdropping. In order to improve the communication security of the VLC system, it is necessary to study the physical layer security communication method suitable for the VLC system. The physical layer security communication refers to the transmission using the difference of modulation, signal and channel attributes, without resorting to data encryption, and without the need for a key before transmission. There are two main methods for security communication in the physical layer: 1. By using the reciprocity and uniqueness of the wireless channel, both legal communication parties independently generate keys for high-level encryption according to the extracted channel parameters of the physical layer . This kind of method can avoid the transmission leakage of the keys. The main difficulty is how to generate the same keys when there is noise interference for both communication parties; 2. The physical layer security is realized by using the spatial attribute of the wireless channel, which increases the difficulty of the eavesdropper to recover the signal, and increase its bit error rate to achieve the transmission with low probability of information interception.

It has always been a problem about how to perform uplink of the VLC system. At present, the traditional scheme is to use RF communication as the uplink of the VLC system, that is, to use the RF and VLC hybrid networking. In the 6G system, the research directions of RF and VLC hybrid networking may include:

(1) introducing new efficient optimization technologies to improve the performance of hybrid RF/VLC networks;

(2) Use software radio system to improve the realization of network configuration;

(3) Through the application of machine learning algorithm, performing spectrum sensing and using the best RF or visible spectrum;

(4) Look for new applications of RF/VLC system.

- KPI requirements of 6G URLLC
- Key technology and system design of 6G URLLC

5.0 6G URLLC subsystem

Low latency high reliability (URLLC) scenario, introduced by 5G, is mainly used for critical IoT services that require lower latency and higher reliability, such as industrial Internet and Internet of Vehicles. It can be expected that the URLLC subsystem will also become an important part of the 6G system. 5G URLLC has been initially supported in Rel-15, and has been enhanced in Rel-16 and Rel-17. However, its industrialization process is not smooth, and it has not yet achieved large-scale commercial application.

The reason is that 5G URLLC is enhanced based on 5G eMBB. While pursuing lower latency and higher reliability, the redundant design of eMBB has not been reduced for scenarios such as the industrial internet and the internet of vehicles, resulting in unnecessary superposition of complexity and cost. Trying to take into account multiple business scenarios at the same time, then it cannot be sufficiently optimized for any industry. Therefore, 6G URLLC can try to locate the target market more accurately and make bolder trade-offs on technical features to realize performance optimization and cost control for key application scenarios and improve the competitiveness of 6G in the horizontal market.

KPI requirements of 6G URLLC

5.1

In 5G, URLLC covers a wide range, including both real-time control services, such as industry and transportation, that require medium/low rates, very low latency and high reliability, and XR (Extended Reality) business that requires high rate and low latency. Such contradictory KPI requirements create great difficulties for system design, and it is easy to lose sight of one another, then the performance of any business cannot be truly optimized. **The 6G URLLC subsystem should be divided into the following two categories according to the different needs of different target services, and should be optimized separately:**

- **Service Target 1: Enable real-time control with medium/low bandwidth and high reliability in industries or transportation, etc. KPI requirements are shown in Figure 5-1.**

In order to satisfy the efficiency, precision and reliability requirements of industrial automation dynamic control, the delay needs to be 1ms or less, and the reliability requirement is 99.99999%. For systems using vision control, the experienced date rate needs to reach 100 Mbit/s. In high-density deployment scenarios, the connection density needs to reach 10 devices/m². To achieve real-time control of high-speed rail, the system supports a mobility speed as high as 500km/h.

- **Service Target 2: Real-time interactive multimedia entertainment with broadband. KPI requirements are shown in Figure 5-2.**

Real-time interactive multimedia entertainment services such as AR and VR do not pursue the high delay and reliability performance of industrial control. The delay requirement can be 1ms, the reliability requirement can be 99.999%, and the connection density can be 1~5 devices/ m². But AR and VR require high data rate, especially when it combines with AI, the user experience rate requirement will be as high as 10 Gbit/s. In order to satisfy the application requirements in next-generation high-speed rail trains, URLLC services also need to support a mobility speed of 500km/h.

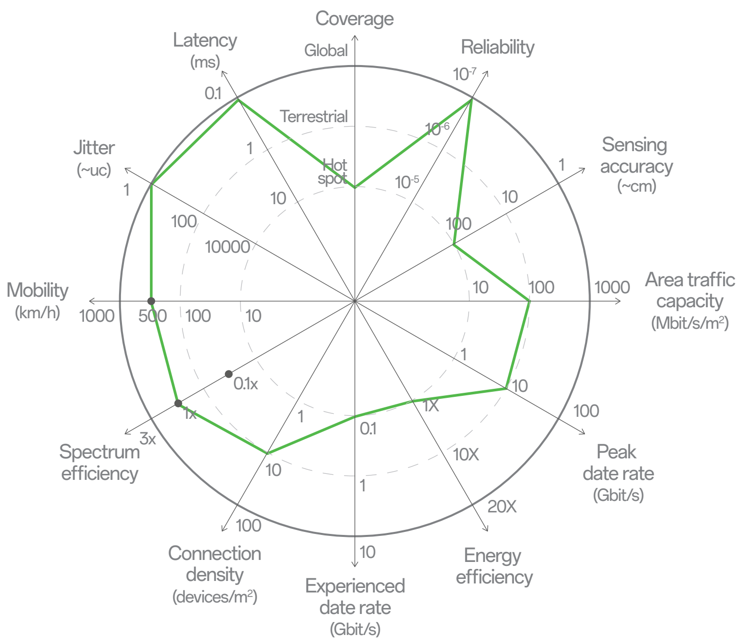


Figure 5-1: KPI for Service Target 1 of 6G URLLC subsystem

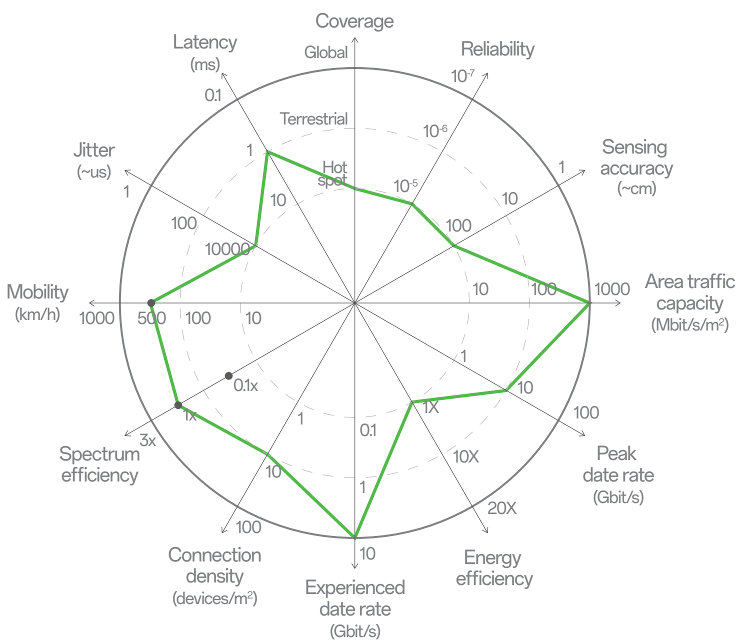


Figure 5-2: KPI for Service Target 2 of 6G URLLC subsystem

Key technology and system design of 6G URLLC

5.2

In order to satisfy the requirements of high reliability, low delay and high data rate, the 6G system will further explore to support wider bandwidth and faster UE processing capabilities.

In 5G system, when a UE is configured to use a high-level processing capability (corresponding to shorter PDSCH processing time and PUSCH preparation time), all data is processed using high-level capability. Specifically, for a UE that supports both broadband data transmission and low-latency high-reliability data transmission at the same time, the receiving processing and sending processing of broadband date also need to satisfy the requirements of the low-latency service. Such method will affect the performance and experience of broadband data transmission on the one hand, and on the other hand, the UE power consumption is relatively high since the UE is always in a state of high-speed data processing. In the 6G system, while improving the speed of UE processing, it is also necessary to consider supporting dynamic switching of UE processing capabilities, that is, using lower processing capability to receive and send broadband data, and using higher processing capability to receive and send low-latency high-reliability services. Thereby UE power consumption can be effectively reduced.

To achieve dynamic switching of UE processing capabilities, flexible timeline also needs to be supported, including: scheduling timeline, feedback timeline, multiplexing processing timeline, etc. For the same type of data transmission (i.e. data corresponding to the same processing capability), 5G timeline can still be satisfied. For example, the data scheduled earlier is processed first, and the data transmitted earlier is fed back first. However, the timeline conditions between different types of data (i.e., data corresponding to different processing capabilities) should be released or cancelled. Otherwise, after receiving a broadband data with a lower processing capability, the subsequent low-latency data transmission cannot be received with a higher processing capability before the broadband data is demodulated and fed back.

For UEs that support both broadband data and low-latency high-reliability data at the same time, different types of data can be received and sent independently at the same time, that is, different types of data can be transmitted simultaneously on independent channels, which can improve system efficiency.

For a TDD carrier, the HARQ retransmission delay caused by TDD uplink and downlink configuration needs to be further reduced. In the 6G system, carriers with different uplink and downlink configurations can be considered for aggregation, and the HARQ retransmission delay can be reduced by adopting cross-carrier retransmission of HARQ process or unified management of multi-carrier HARQ processes.

In addition, the 6G URLLC subsystem can also introduce AI technology to assist in the following functions:

- **Prediction of data arrival: Base stations can perform pre-scheduling based on the prediction of data arrival time and data amount. UEs can realize complete grant-free transmission or autonomous transmission based on the prediction results;**
- **Prediction of scheduling or retransmission: UEs can perform data preparation in advance based on the prediction results to reduce data preparation delay. Base stations or UEs can directly retransmit data based on the prediction result without waiting for feedback information;**
- **Prediction of collision: Avoid inter-UE or intra-UE resource collision.**
- **UCI (uplink control signaling) enhancement: UCI compression based on AI algorithm to reduce the amount of feedback information.**

- KPI requirements of 6G Sensing
- Key technology and system design of 6G Sensing
- Modes for 6G sensing system
- Key technology for integrated communication and sensing
- Key technology for Sensing-only mode

6.0 6G Sensing subsystem

The sensing system is a new system introduced by 6G. Although the 5G system has positioning functions, the comprehensive support of physical environment sensing is a new change for the mobile communication system.

KPI requirements of 6G Sensing

6.1

The 6G sensing will enable the ubiquitous sensing ability to capture the environmental details of the physical world and support the twin reconstruction of the virtual world. The 6G sensing not only enables detecting, positioning (ranging, velocity measurement, angle measurement), tracking , but also has function of imaging, material detection, pattern recognition and medical assistance. Some sensing KPIs are summarized based on above 6G sensing application and the sensing accuracy needs to reach the cm level, as shown in Figure 6-1. But at the same time, **since the 6G sensing sub-system should ensure its market competitiveness in sensing performance, it is impossible to require it to have the same communication performance as the 6G broadband cellular system and the 6G URLLC system. The requirements in data rate, spectral efficiency, system capacity and other aspects should be appropriately relaxed to leave design space for the optimization of sensing performance.**

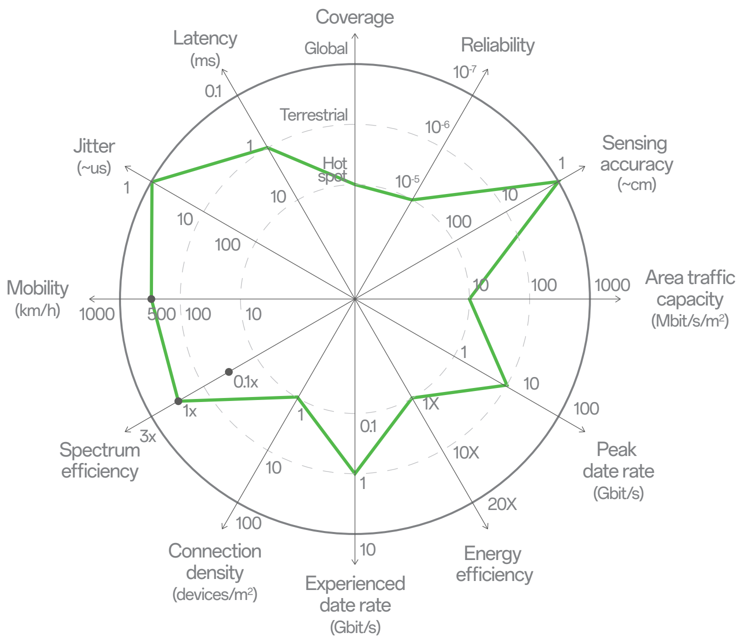


Figure 6-1: KPI requirements of 6G sensing system

Key technology and system design of 6G Sensing

6.2

6.2.1 Modes for 6G sensing system

In the history of signal processing technology, sensing and communication are two technologies with different requirements. 6G intends to integrate communication and sensing technologies into one system, reusing software and hardware resources as much as possible, and achieving the effect of "Kill two birds with one stone". However, if one system takes into account two kinds of services and two services share resources, the communication performance and sensing performance may be restricted each other. It is impossible to fully develop their technical potentiality respectively. Therefore, **to adapt to different application scenarios, the 6G sensing system can consider two modes: integrated communication and sensing mode and sensing-only mode.**

The integrated communication and sensing mode is applicable to the scenario where an operator provides communication and sensing services, meanwhile terminals support communication and sensing. In this case, the integrated design can share spectrum and hardware resources between communication and sensing and cooperate flexibly. In this mode, the operator and user do not pursue the unilateral optimal performance, but the trade-off performance of the two functions.

However, for one operator with sensing-only business, sensing-only mode may be a better solution. The operator strives to optimize sensing performance to obtain sufficient competitiveness in the professional market. Users use dedicated sensing terminals and services to obtain the optimal sensing performance In this mode, communication capability mainly provides the transmission of sensing related information and signaling. In this mode, the system should select key technologies and framework to achieve optimized sensing performance.

The above two modes have common and differentiated key technologies, as shown in Table 6-1.

	Integrated communication and sensing mode	Sensing-only mode
Common key technology	Parameter estimation, AI-assisted algorithm, cooperative sensing, etc	
Differentiated key technology	Integrated hardware Integrated signal Integrated architecture	Sensing signal and channel Hardware for sensing Architecture for sensing

Table 6-1: Key technology for integrated communication and sensing mode and sensing-only mode

6.2.2 Key technology for integrated communication and sensing

1.Integrated technology

- Integrated hardware

Both wireless communication and sensing systems use electromagnetic waves to transmit information, but one is carried by electromagnetic waves, the other is embedded in electromagnetic waves. Because of different functions and requirements, there are significantly differences between two systems in terms of signal receiving and transmitting mode, receiver sensitivity requirement, synchronization accuracy requirement, and performance requirement of RF channels. Currently, communication and sensing systems are usually independent or one function dominates. For example, the radar system mainly focuses on sensing function with low rate data transmission. Integrated hardware needs to reuse one set of hardware systems for sensing and communication as much as possible to gain advantages in cost, size and performance.

- Integrated signal

There are two types of integrated communication and sensing signal . One type is system-level integration. Independent signals for communication and sensing are multiplexed in one system. Two types of signal can be multiplexed in term of time domain, frequency domain or space domain. Another type is signal-level integration. Communication and sensing are implemented by one signal simultaneously.

2.Signal processing

6G sensing includes not only classical parameter estimation, such as detection, positioning (ranging, velocity measurement, angle measurement), and tracking, but also imaging, pattern recognition, material detection, etc. For classical parameter estimation, some classical nonlinear algorithms, such as FFT and MUSIC, balance complexity and performance. And ESPRIT algorithm has high complexity, but it can obtain better detection performance. For complex application, such as imaging, pattern recognition, material detection, etc, it is inevitable to collect a large amount of sensing data from the physical world. AI algorithm will extract abundant and complex environment information from sensing data .

3.Cooperative sensing

Cooperative sensing accomplishes one sensing task through multiple sensing chains, improving the accuracy and integrity, and enlarging coverage. There are various types of cooperative sensing, including multi-node cooperative sensing, multi-spectrum cooperative sensing and Multi-modality cooperative sensing. Among them, multi-node cooperative sensing and multi-spectrum cooperative sensing can be widely used in base stations and terminals. Multi-modality cooperative sensing combines wireless sensing with cameras, gravity sensing and other sensing modules in terminal devices to improve user experience.

- Multi-node cooperative sensing

Multi-node cooperative sensing is cooperative sensing through multiple sensing chains within the same sensing system. This technology is widely used to solve the problems caused by noise, interference and implementation error, and improve the sensing performance. Moreover it can overcome occlusion to some extent, realize continuous sensing.

In multi-node cooperative sensing, there are two key technologies : sensing node selection and sensing information combination. In addition, multi-node sensing signal coordination and enhancement in core network should be considered.

Sensing node selection aims to select the sensing nodes that can perceive and provide reliable sensing results. So sensing node selection should not only consider authorization and security issues, but also consider the air interface capability of the sensing node. For example, the bandwidth and transmission power of the sensing signal, communication traffic volume and so on. The reliability of the sensing results is related to the relative positions between sensing node and sensed object. Other factors affecting sensing reliability needs to be identified, so that the control node can select high-quality sensing nodes through the measurement reports of the sensing node. To support sensing service continuity, concrete procedure should also be considered.

Sensing information combination intends to combine and process the sensing information from multiple sensing nodes. Sensing information combination depends on the feedback of single node. Therefore, according to sensing feedback type of single node, sensing information combination technology can be divided into three types: combination based on original channel information, combination based on channel characteristics and combination based on sensing result.

For combination based on original channel information, the control node can obtain the complete channel information and fully excavate transmission environment from the massive channel information. For combination based on channel characteristics and the combination based on sensing result, the advantage is low feedback overhead of single node. However, due to the lack of information, the transmission environment information obtained by the control node is limited, which reduces combination gain. On the one hand, some combination algorithms or filtering techniques can be used to excavate combination gain. On the other hand, the sensing node can also feedback some auxiliary information to assist the control node in the combination processing of multi-node sensing results.

- Multi-spectrum cooperative sensing

The operating frequency band supported by the 6G system will be wider, including sub6G, millimeter wave, THz and visible light, and different frequency bands have their own suitable application scenarios. Due to physical constraints, the sensing capabilities provided by electromagnetic waves in different frequency bands are different. Usually, higher frequency band with wider frequency band provides higher sensing accuracy and time-frequency resolution; However, due to larger attenuation, sensing distance and range will be shorter and smaller. In general, sensing signal in lower frequency bands can achieve coarse resolution, while sensing signal in higher frequency bands can achieve fine resolution.

4.UE sensing

- Multi-modality cooperative sensing

In addition to communication functions, UE also has a large number of sensors for enhancing human-terminal interaction experience, such as cameras, accelerometers, gyroscopes, light sensors, distance sensors, gravity sensors, magnetic field sensors, air pressure sensors, etc. With the continuous evolution of UE forms and human-computer interaction functions, 6G UE will have more and more sensors in future. These sensors equipped at UE can provide various sensing information for the physical environment around UE. In order to meet the various sensing requirements of 6G, it can be considered to combine the dedicated sensors-based sensing with wireless sensing. Compared with single wireless sensing, multi-modality cooperative sensing can utilize the unique advantages of different sensing technologies to sense the physical world more accurately and comprehensively. The gain of multi-modality cooperative sensing mainly comes from the fusion of sensing information obtained by different kinds of sensing technologies. Since the sensing information obtained by different sensing technologies has different data attributes, sensing precision, sensing range, and data format, the fusion technology for different sensing data is the key technology of multi-modality cooperative sensing.

- Resource allocation

As mentioned above, in the network of communication and sensing integration, a signal can meet the needs of communication and sensing at the same time. From the perspective of resource allocation, the resource allocation of sensing reference signal is also the resource allocation for communication resource allocation. In the existing sidelink communication system, sidelink communication resources can be scheduled by the network or selected by the UE autonomously. The resource allocation of network scheduling requires the participation of network operators, and a UE has to be under the coverage of operators' networks. UE autonomous selection mainly relies on the decoding of resource reservation signaling, and then perform resource selection according to RSRP measurement. In 6G sidelink communication, reinforcement learning can be used to further improve the performance of UE autonomous resource selection. These sidelink communication resource allocation methods can be used to solve the problems of resource allocation for signals of communication and sensing integration.

If the signal for sensing is different from the communication signal, and there is no static resource division between the sensing signal and the communication signal, the sensing signal resource allocation needs to solve the interference between the sensing signal and the communication signal and the interference between the sensing signals transmitted by different UEs. For UE autonomous resource selection, the reserved resources for sensing signals and communication signals should be considered in the process of resource selection. If there is static resource division between sensing signals and communication signals, sensing signal resource allocation only needs to solve the interference between sensing signals, and the UE autonomous resource selection for sensing signals is similar to that for communication signals. However, if reinforcement learning is used in the resource selection for sensing signal, sensing related optimization objectives need to be included, such as maximizing detection probability and maximizing sensing accuracy. When there is no static resource division between sensing signals and communication signals, communication related optimization objectives even need to be considered at the same time.

5.Network Architecture

The network architecture of Integrated Sensing and Communication is shown in Figure 6-2. Sensing Control Function and Sensing Data Collection Entity are deployed in the Core Network. Sensing Control Function is responsible for the control plane signaling interaction, including authorization of the sensing service request from AF, generating the sensing task for specific location or specific UE, exposing the sensing result to AF etc. The sensing info detected by sensing nodes(e.g. UE or AN) is normally point cloud data which at huge amount size, thus should be transferred over user plane. The Sensing Control Function can provide the IP address of Sensing Data Collection Entity to UE or AN, when the UE or AN needs to report the collected sensing info, it encaptures the sensing info into IP packets and reports the sensing info to Sensing Data Collection Entity by IP routing. Sensing Data Collection Entity can perform further analysis on the received sensing info and generate the sensing result. Sensing Data Collection Entity provides the sensing result to Sensing Control Function, then Sensing Control Function exposes the sensing result to AF. If the sensing result is till at large amount size, Sensing Control Function provides AF with an IP address or URL of retrieving sensing result, then AF visits the IP address or URL to get the sensing result. The operator can deploy Sensing Control Function and Sensing Data Collection Entity in the same network entity.

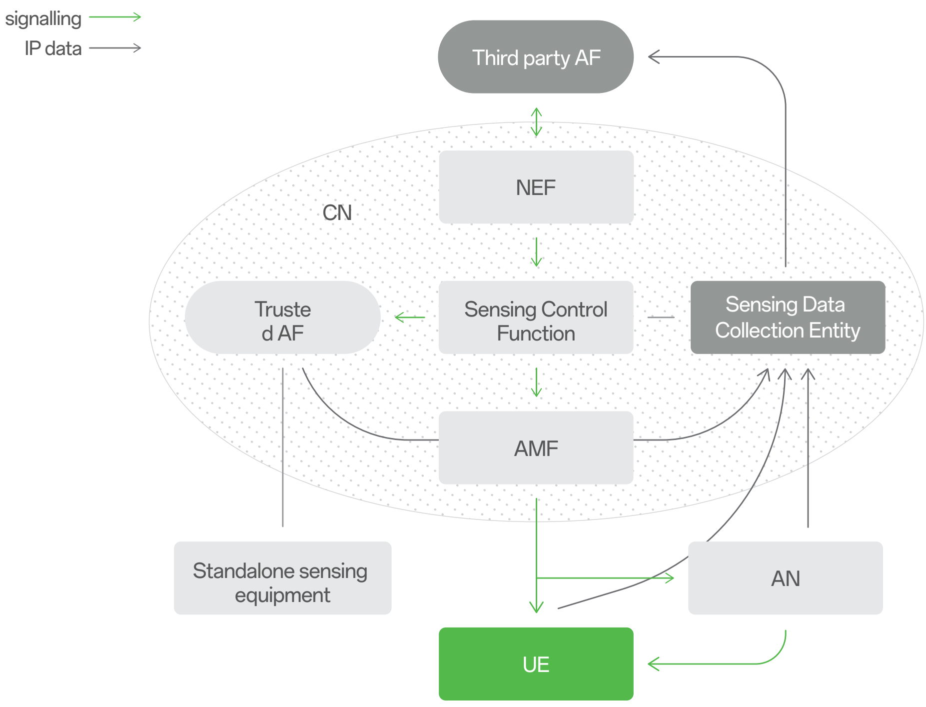


Figure 6-2 : Network architecture of Integrated Sensing and Communication

6.2.3 Key technology for Sensing-only mode

1.High performance hardware	To meet sensing requirements, high-isolation, high precision and high speed processor are essential. The former is necessary to solve the self-interference problem of duplex systems, and the latter enables precise synchronization and high-speed data processing.
2.Signal and channel design	The sensing waveform usually requires excellent auto correlation characteristics, large signal band-width,high dynamic range, and tolerance to doppler frequency offset. For sensing-only mode, some classic or advanced radar signals can be considered, such as FMCW.
3.Network Architecture	In order to support the standalone sensing equipment, as shown in Figure 6-2, a trusted AF managed by operator can be deployed in the Core Network. The trusted AF retrieves sensing info from the standalone sensing equipment by application layer interaction. The trusted AF is under control of the Sensing Control Function, and reports the sensing info to Sensing Data Collection Entity.

7.0 6G 6G Massive IoT subsystem

- Technical requirements of 6G Massive IoT subsystem
- Technical requirements
- KPI requirements
- Key technology and system design of 6G Massive IoT

Technical requirements of 6G Massive IoT subsystem

7.1

From the beginning of designing 5G, massive machine to machine communication is listed as one of the three major required scenarios. It targets to satisfy the growing requirement of Internet of Things in 5G era. The cellular IoT communication technology and standard have been gradually developed in the past decade. Among them, 3GPP standardized a series of Internet of Things technologies such as MTC (Machine Type Communications), NB IoT (Narrow Band IoT) and RedCap (Reduced Capacity UE). These IoT technologies apply small bandwidth, single antenna, reduced peak data rate, half duplex, reduced transmission power and other technologies to significantly lower the cost of IoT terminals. Further, the introduction of eDRX (enhanced Discontinuous Reception), PSM (Power Saving Mode), BWP (Bandwidth Part) and other technologies has greatly reduced the power consumption of IoT terminals. At the same time, network can support a large number of IoT terminals, to meet the needs of large number of connections. Thanks to these technologies, the Internet of Things is booming. As of August 2022, the number of Internet of Things subscriptions in China has reached 1.698 billion. It has 1.678 billion individual users.

In the 6G era, with the popularization and application of Internet of Things technology in different industries and consumers, it can be predicted that the Internet of Things will prevail. People expect hundreds of billions or even trillions of Internet of Things links, and Internet of Things technology will continue to change social/economic development and style of work/living.

7.1.1 Technical requirements

The technical requirements of 6G massive IoT include:

Larger number of links	With the progress of the Internet of Things technology, the Internet of Things will accelerate its popularization in all industries. Energy, manufacture, transportation, logistics, agriculture and animal husbandry, medical care, environmental protection and other industries, as well as smart home, wearable, comprehensive health and other personal consumption fields will significantly benefit from the development of Internet of Things technology. Therefore, the 6G Massive IoT needs to support a larger number of links and provide high-quality Internet of Things services.
Multilevel/ multi-functional Internet of Things	Orienting application requirements, there will be multi-level requirements in the future Internet of Things. Corresponding to different usage scenarios and deployment methods, the cost, data rate, communication delay, coverage, power consumption of IoT terminals will also be diversified. The Internet of Things will also support object recognition, sensor data acquisition, positioning information collection and other functions. To meet different needs, the 5G era has targeted the development of NB IoT, MTC, RedCap and other technologies. At the beginning of design, 6G Massive IoT needs to do a fine technical planning for different scenarios, and ensure compatibility and interworking of technologies while meeting diversified needs, so as to minimize R&D costs.
Integration capability of Internet of Things and different technologies	The 6G Massive IoT has the ability to integrate with different 6G technologies. Internet of Things terminals can naturally integrate with communication sensing technology to enhance the sensing of 6G networks by virtue of their ubiquitous perception capabilities. The ubiquitous Internet of Things links can realize low-cost, big data collection, and better enable 6G AI technology. Vehicle mounted or roadside IoT terminals will build an better intelligent V2X system. The low power consumption, low cost and other technologies of the Internet of Things will also be applicable in the 6G MBB terminal. Therefore, the design of 6G Massive IoT will consider the integrated requirements of technologies.

Covering unsatisfied IoT communication needs

The Internet of Things is booming, but there are still many scenarios where the communication needs of the Internet of Things cannot be met by existing technologies, such as:

- **Extreme communication environment**

  Some IoT scenarios have extreme environments such as high temperature, extremely low temperature, high humidity, high pressure, high radiation or high-speed movement. Such as ultra-high voltage substations, high-speed train track monitoring, environmental monitoring in cold regions, industrial production lines, etc. In these scenarios, the existing IoT terminals is not funtional due to its normal working environment with conventional power supply. In addition, the extreme working environment is not desirable to the maintenance of the Internet of Things, such as battery replacement.

- **Extremely small form factor requirements**

  Some Internet of Things communication scenarios, such as food traceability, commodity circulation and intelligent wearable, require the terminal to have a very small size for easy use in these scenarios. For example, the Internet of Things terminals used for commodity management in the logistic usually use the form of electronic labels, which are embedded into the commodity packaging. For another example, lightweight wearable devices can improve user experience while meeting user needs.

- **Extremely low-cost Internet of Things communication requirements**

  Numerous IoT communication scenarios require IoT terminals to be economical to ensure competitiveness. For example, in the logistics or warehousing scenario, in order to facilitate the management of a large number of circulating items, the Internet of Things terminal can be attached to each item, so as to complete the accurate management of the entire logistics process and cycle through the communication between the terminal and the logistics network. These scenarios require competitive price of IoT terminals.

Therefore, in order to cover these unsatisfied Internet of Things communication needs, 6G Massive IoT needs to develop ultra-low cost, extremely small, battery free/maintenance free Internet of Things.

7.1.2 KPI requirements

The characteristic KPIs of the 6G Massive IoT subsystem include:

- **It is necessary to support low power consumption or even extremely low power consumption. For example, some scenarios need to support milliwatt or even microwatt communication power consumption;**
- **Need to support larger connections;**
- **It is required to support diversified coverage requirements from short distance coverage (tens of meters), medium distance coverage (hundreds of meters) to several kilometers.**

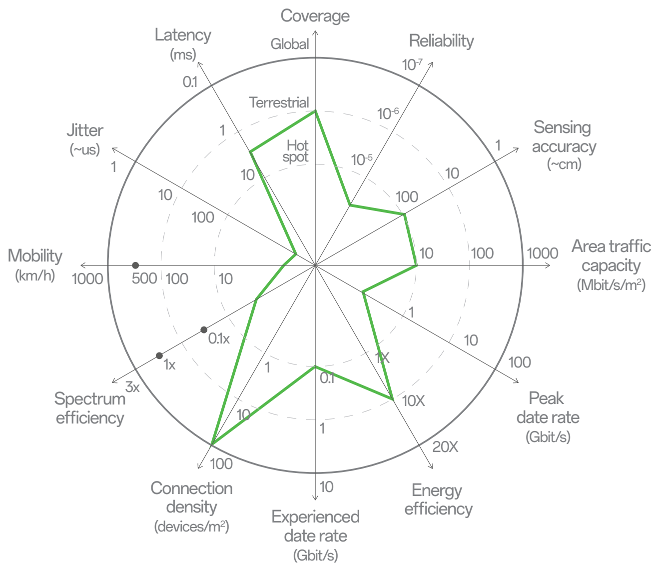


Figure 7-1: KPI requirements of 6G massive IoT subsystem

Other conventional KPIs, such as peak data rate, communication delay, mobility, spectral efficiency, etc., are not required to be high as eMBB communication. For example, the peak data rate of some communication scenarios can be as low as tens of kbit/s; Some fixed deployment scenarios do not require mobility; It can be deployed in a private network or provided with spectrum at the service low point of the mobile communication network.

Key technology and system design of 6G Massive IoT

7.2

The key technologies that may be adopted by the 6G Massive IoT subsystem include:

Battery-less communication technology

As mentioned earlier, in order to support more application requirements, supporting Battery-less communication will be an important requirement for 6G Massive IoT. Therefore, it is necessary to study Battery-less communication technology. IoT terminals can collect the energy required for communication from various environmental energies, such as light, radio waves, thermal energy, vibration energy, etc. That is to avoid dependence on traditional technologies. Such terminals can be called zero power IoT terminals.

Among them, the energy of radio waves can be provided from the 6G network. It is necessary to study how to efficiently and reasonably provide radio energy to zero power consumption IoT terminals. Further, it is also necessary to study how to improve the energy harvesting efficiency and harvesting sensitivity of the terminal.

On the other hand, various environmental energies have the following characteristics:

- The available environmental energy is low, generally in the range of several microwatts to several milliwatts;
- The environmental energy is unstable; For example, sufficient light can be obtained in sunny days, while insufficient light at night or on cloudy days;

Therefore, it is necessary to research Battery-less communication technologies that adapt to the above characteristics, such as ultra-low power consumption communication technology, energy management technology, and energy adaptive communication protocols.

Low power/ultra-low power communication technology

Regardless active IoT terminals or the above battery-less and maintenance free IoT terminals, reducing the power consumption of the terminal and even achieving ultra-low power communication can significantly improve the service life of the terminal, reduce the use/deployment cost, and contribute to energy conservation and environmental protection (considering the power consumption of a huge number of IoT terminals in the future). Therefore, low power/ultra-low power communication will be the constant target of the Internet of Things. The practical power consumption of current IoT terminals is generally tens to hundreds of milliwatts, and the power consumption of low power/ultra-low power communication terminals needs to be reduced to less than 1 milliwatt.

The following methods can be considered to realize low power/ultra-low power IoT communication:

- Simplified transceiver and simplified modulation

In the technologies such as MTC, NB IoT and RedCap for the Internet of Things, although the capabilities of terminals are significantly reduced compared with LTE terminals or NR terminals, they basically inherit these traditional modulation or coding methods. For example, MTC/NB IoT can support modulation methods such as BPSK, QPSK and 16QAM, as well as Turbo codes and convolutional codes, while RedCap can also support BPSK, QPSK, 16QAM and 64QAM, as well as LDPC coding and Polar coding.

However, these commonly used modulation and coding methods for ordinary terminals are a great challenge for low-power/ultra-low power communication terminals. Low power/ultra-low power communication has a very simple RF and baseband structure. At the same time, low power/ultra-low power communication terminals need to transmit data in an ultra-low power way. Therefore, the signal modulation and coding methods that can be used by low power/ultra-low power communication terminals will bring strong constraints and restrictions. Specifically, the extremely simple RF and baseband structures make it difficult for the terminal to realize phase and amplitude modulation and demodulation at the same time, so QPSK and QAM modulation are difficult to support. Despite excellent signal encoding and decoding performance, forward error correction channel coding methods such as Turbo, LDPC, Polar and Convolutional are also difficult to be realized by low/ultra-low power Terminals that pursue extremely low complexity and power consumption.

Some low-power technologies, such as switch modulation technology and backscattering technology (as shown in Figure 7-2), can be combined to enable the terminal to achieve ASK, FSK or PSK modulation methods with an extremely simple hardware structure, so as to achieve backscattering data transmission. Using keying modulation technology, low/ultra-low power communication terminals only need to have the ability to adjust their circuit impedance, capacitance or phase delay in hardware to achieve signal modulation and backscatter transmission. On the other hand, simple ASK, FSK or PSK signals also enable signal demodulation to be realized through simple hardware structure. For example, ASK signals can be demodulated through a comparator, which avoids complex baseband signal processing and greatly reduces terminal power consumption.

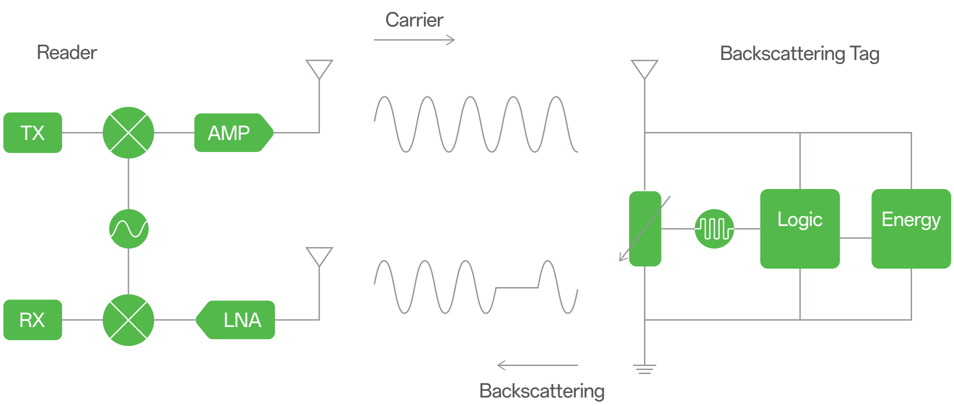


Figure 7-2: Backscattering communication technologie

- Ultimate energy saving mechanism

For low-power/ultra-low power communication, based on existing energy saving mechanisms such as DRX, eDRX, WUS, intermittent control channel monitoring and other schemes, it can further design energy saving mechanisms, such as triggering communication on demand based on services, and the terminal is in deep sleep for the rest of the time.

At the same time, it is also necessary to design a reasonable energy management mechanism to precisely manage the weak energy, maximize the efficiency of energy use, and improve the efficiency of energy use.

Flexible tailorable protocol architecture

For low-power/ultra-low power communication, in addition to supporting minimal physical layer technology, it is also necessary to support flexible and tailorable protocol architecture, which can be tailored flexibly for different use needs. For environments requiring very low power consumption, lightweight protocol architecture can be used.

Possible ideas for designing lightweight protocol architecture include: supporting connection free communication, greatly simplifying the access process, and saving the signaling overhead and protocol layer requirements for connection establishment.

Rich communication security suite set

For 6G Massive IoT, users' privacy and communication security need to be guaranteed. To meet different application scenarios and corresponding different security requirements, it is necessary to design a rich set of optional communication security suites to adapt different terminal capability levels.

The computing, storage and transmission resources that low power and ultra low power devices can support are very limited compared with traditional terminals. The traditional security mechanism is challenged by resource constraints. It is necessary to study how to provide users with reliable access and secure transmission under resource constraints.

For the massive links and devices of 6G integration of everything, efficient distributed authentication and authorization needs to be redesigned on the current centralized trust mechanism to ensure trusted identity, flexible authorization and distributed authentication. Blockchain is a better technology choice, but it needs to be considered in terms of infrastructure construction and ecological maturity to support a trusted security mechanism with multiple scenarios, multiple services and multiple users.

For low-power and ultra low-power devices, trusted identity management and reliable secure transmission are necessary to ensure business, network and user rights and interests. It is necessary to optimize the transmission security mechanism based on the traditional security mechanism and in combination with the low cost characteristics of the device, considering the hierarchical protection mechanism of data transmission, and considering the enhanced security scheme combining the physical layer and transmission layer.

Support ultra-low power positioning

Many IoT scenarios put forward clear positioning requirements. The 6G Massive IoT needs to support positioning functions, especially for low-power and ultra-low power devices, such as accurate product management of the production line, low-cost indoor positioning (such as shopping mall navigation and parking lot navigation, as shown in Figure 7-3 below), and logistics. In such applications, terminal devices will have extremely low complexity, and may use environmental energy to drive their own work, thus only supporting extremely low power consumption (such as less than 1 milliwatt). It is necessary to study how to achieve certain positioning accuracy (such as meter level or sub meter level) for such simple devices.

Figure 7-3: Illustration of indoor positioning scenario

8.0 6G Non-Terrestrial Networks (NTN) subsystem

- KPI requirement of 6G NTN
- key technology and system design of 6G NTN

KPI requirement of 6G NTN

8.1

KPI requirements of 6G NTN subsystem are shown in Figure 8-1. Although the service type of 6G NTN is similar to the eMBB service, NTN subsystem does not pursue a high data rate, but focuses on the coverage of the service due to the limitation of its communication environment.

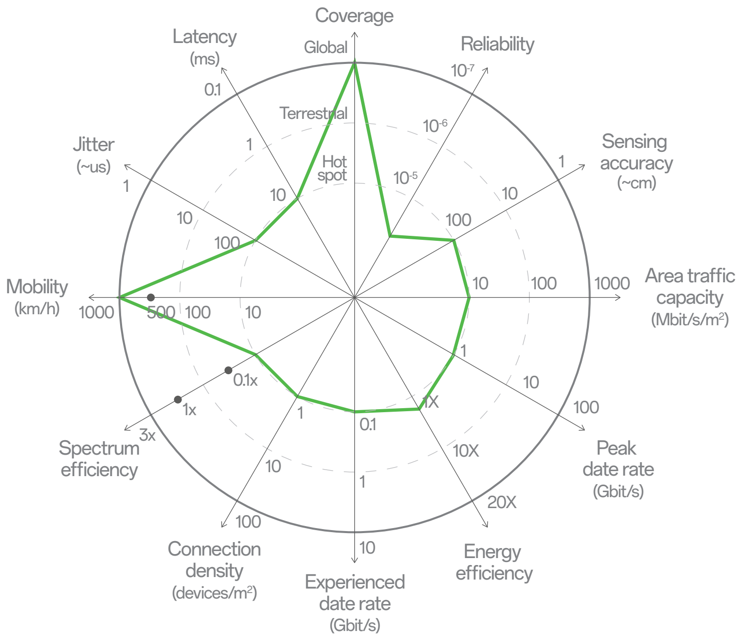


Figure 8-1: 6G NTN subsystem KPI

key technology and system design of 6G NTN

8.2

For the promotion of the new generation of communication technology, a big challenge is that operators need to spend a lot of costs to deploy networks to achieve wide coverage, because for many countries and regions, full coverage cannot be achieved so far. In China, even if 4G and 5G systems basically cover the whole country, communication coverage is still unavailable in some specific areas, such as oceans and mountains. The coverage limitation here is mainly due to the time, cost, or geographical environment limitation. In the future, the 6G system needs to break these restrictions and truly achieve full coverage. With the gradual reduction of the cost of space transportation, NTN communications can more effectively break the geographical constraints and provide effective technologies for real full coverage.

The 5G NR NTN system provides a basic framework for terminal and satellite communication, but does not further optimize the terminal power consumption. For example, the 5G NTN terminal needs to frequently adjust the uplink synchronization through the terminal GPS system. This makes NTN terminals consume more energy than traditional cellular terminals. Therefore, in order to further improve the energy saving efficiency of NTN terminals, the power consumption of 6G NTN terminals needs to be further optimized. In addition, support for high-speed scenarios is also an important goal of 6G NTN communication. How to further improve the peak data rate while improving coverage is also a challenge for 6G NTN communication.

In the 5G NR NTN system, since the NR OFDM and OFDMA waveforms are reused, uplink synchronization is more sensitive when multi-user uplink transmissions are multiplexed in a same slot. The traditional TA adjustment method, which is controlled by gNB, i.e., by indicating the TA adjustment value using MAC-CE to adjust uplink synchronization, can no longer meet the requirements of NTN uplink synchronization. On top of traditional TA adjustment, the NTN terminal is also required to independently adjust and maintain uplink synchronization according to the satellite ephemeris information provided by the network. This greatly increases the power consumption of the NTN terminal. The 6G NTN communication system may consider to design a new waveform more suitable for satellite communication, such as a single-carrier waveform, so that the system's requirements for uplink synchronization can be greatly reduced, and the terminal can save power consumption for synchronization maintenance.

Besides, due to the large coverage area of the satellite, in order to ensure a good link budget, the satellite side usually uses beamforming to transmit and receive signals. However, the 5G NR NTN system has not further optimized the satellite beam management. The problem is that when the number of users increases or the number of satellite beams in the cell increases, the signaling overhead of inter satellite beam switching will be increased significantly, hence the spectral efficiency will be reduced. For 6G NTN communication system, efficient beam management mechanism for satellite beam will be a necessary research direction.

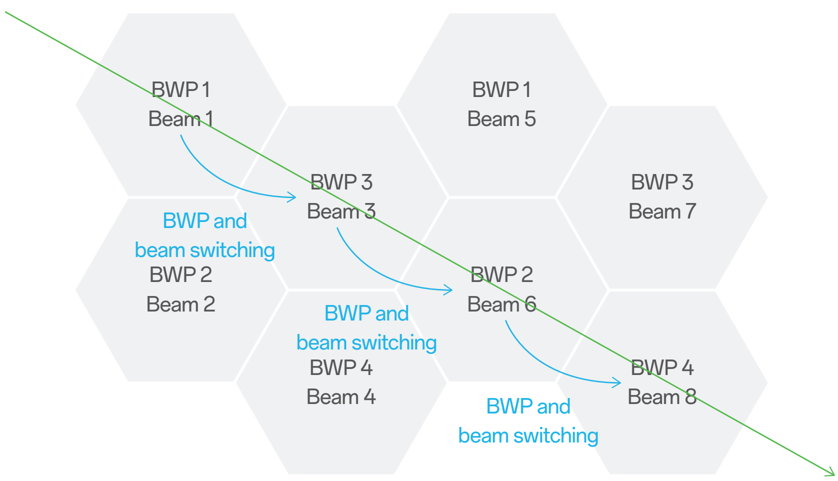


Figure 8-2: Beam management for 6G NTN

In addition, the dual connectivity between satellite network and terrestrial network will greatly improve the user experience. Imagine that the satellite network can provide users with wide coverage for basic coverage connection, while the terrestrial network can provide users with additional high-data rate for user experience, not only can this ensure requirement for high-data rate service, but also can significantly reduce the frequent cell switching caused by users' mobility. At present, 5G only supports the dual connectivity of TN networks, and 6G needs to further study the dual connectivity of NTN networks, or between TN and NTN networks.

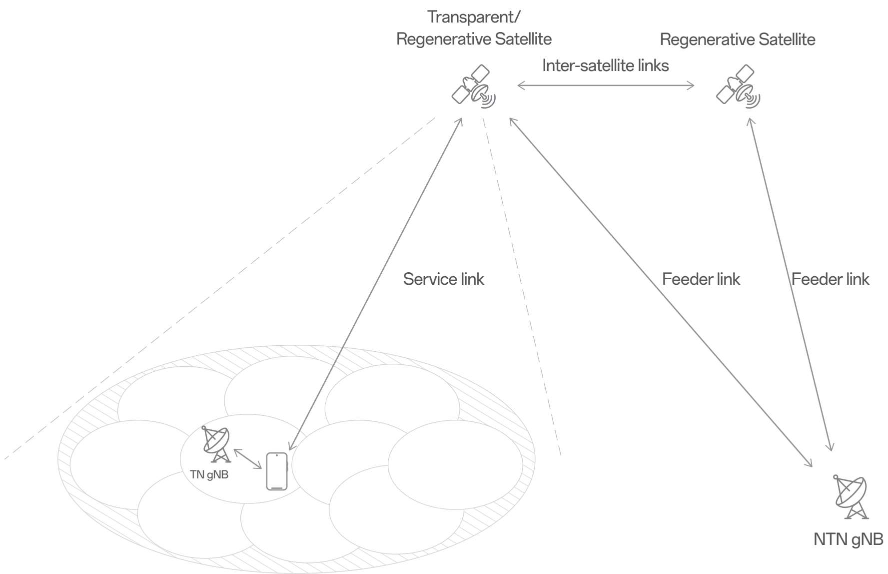


Figure 8-3: Dual connectivity between TN and 6G NTN

On the other hand, the large data rate transmission of satellite network itself is also limited in the 5G era. The main reason is that the 5G NR NTN is based on transparent forwarding payload. As a result of the overlapping transmission delay between the terminal and satellite and between the satellite and the ground station, it cannot support high data rate services. To support such services, it is necessary to consider the scenario of regenetative satellite. Therefore, the architecture of regenerative forwarding payload needs to be considered in the 6G system. It is inevitable to further study the problems caused by inter-satellite-link transmissions. Therefore, regenerative forwarding payload will also become an important topic under the 6G NTN system.

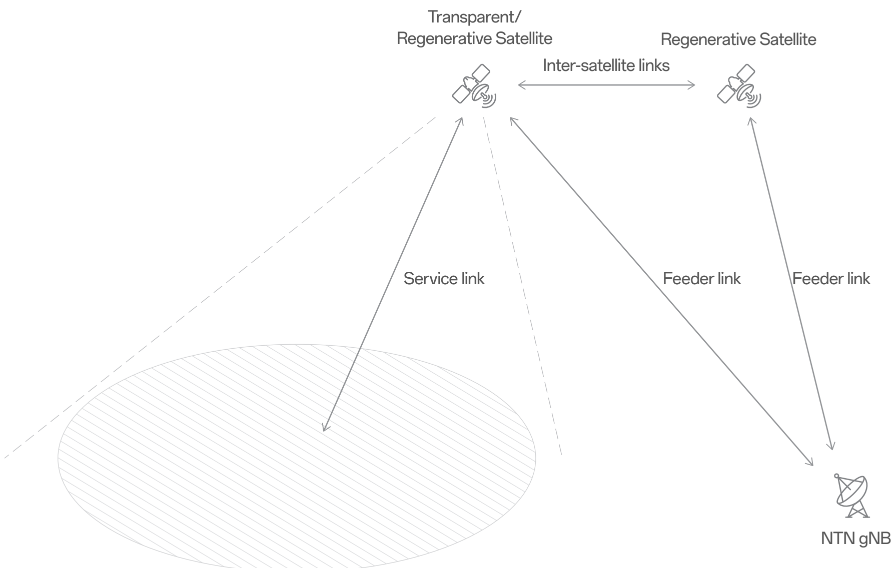


Figure 8-4: Regenerative payload for 6G NTN

Finally, the device-to-device communication technology based on sidelink system can be considered under the framework of NTN system. At present, there are two scenarios for sidelink communication: in coverage and out of coverage. In out of coverage scenario, when the sidelink communication users are not within the network coverage, the communication of sidelink users will fall back to a collision-avoidance based transmission mode, e.g., sensing and reserving the resource before transmission, which may cause longer transmission delay, higher terminal power consumption and lower transmission efficiency. If the sidelink communications can be performed under the satellite coverage in combination with the NTN system, the above problems will be greatly alleviated.

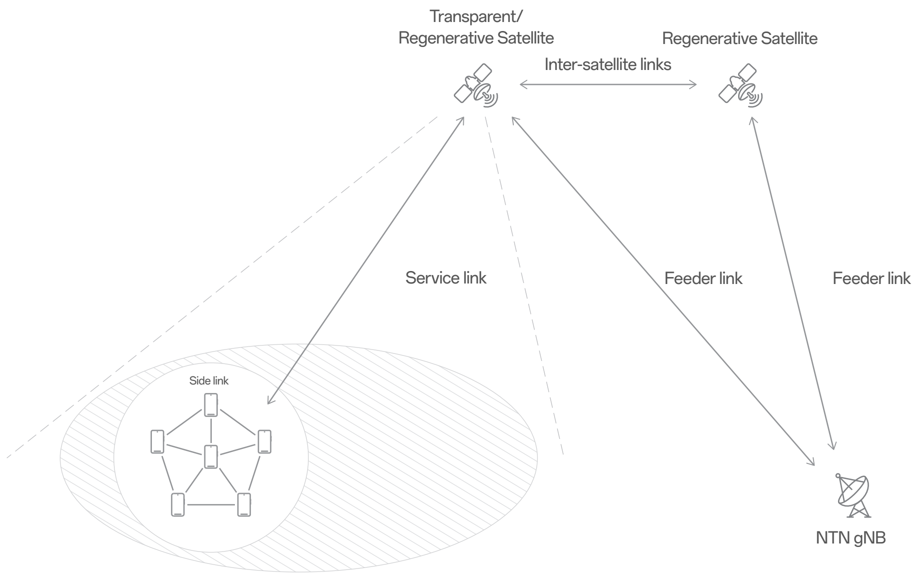


Figure 8-5: Combination of sidelink and 6G NTN

9.0 Summary

The key points of the white paper include:

- Mobile communication does not actually achieve an industrial upgrading through every generation, but a major industrial upgrading goal every two generations of technology

- The historical task of 6G is to thoroughly realize the goal of "mobile world" based on the experience and lessons of 5G.

- 5G is still based on the design principle of "single-function system", simultaneously targeting a set of "higher KPIs" (i.e. higher dara rate, lower delay and higher reliability), pursuing integrated design in technology, and trying to meet the fragmented requirements of hunderds of vertical industries through "scalable parameter sets+network slices". However, due to the fact that all 5G vertical technologies use eMBB as the baseline and default design, which limits the space for technological innovation and cannot be thoroughly optimized for the target vertical fields, competition advantages and controllable costs have not been achieved in many vertical fields.

- Two new findings in past decade determines the 6G's role:

  ——The first finding: To build a mobile information world, AI (artificial intelligence) agents must be introduced as the intermediate manager between human, machines and things.

  ——The second finding: To build a mobile information world, a virtual world mirroring the physical world must be built for machines, things and intelligent agents.

- The vision of 6G should be: To communicate the virtual world with the real world, realize the interconnection and convergence of the two worlds, become the infrastructure of the metaverse, and provide a technical base for the mobile information world.

- In order to achieve "interconnection and convergence" between the physical world and the virtual world, truly realize "a versatile system for world mobility", further expand to Sensing, Non-Terrestrial, Zero power communication and other application scenarios, and achieve performance improvement several times in all dimensions at a controllable cost, 6G must adopt new design ideas.

- The design of the versatile 6G system with minimized kernel mainly includes the following elements:

  ——A minimized kernel provides common capabilities such as native AI, security and flexible spectrum management;

  ——Separate optimization is made for four different capabilities, including: Clouding, Critical IoT, Ubiquitous IoT and Sensing.

  ——One or multiple subsystems are designed for each capability. Key technologies can be selected independently according to application scenarios, spectrum, topology, etc., and hardware and software can be designed separately for different subsystems. For example, it can be divided into: 6G broadband cellular, 6G D2D, 6G URLLC, 6G sensing, 6G massive IoT, 6G non-terrestrial networks and other subsystems.

  ——Compatibility between subsystems can be supported or not supported depending on whether it is truly needed. Determine how much common air interface technology and design to share between 6G broadband cellular and other subsystems.

  ——Replace artificially-designed generalized algorithms with a black box professional AI algorithm library, to realize the "relatively independent and optimized" of each subsystem and the substantial simplification of communication protocol. And through the switching and combination of various AI models, the switching and combination of multiple subsystems can be realized.

- **AI technology will be an important part of the 6G network. Unlike the flexibility dimension of control and the performance dimension of user response, the intelligence dimension corresponding to AI technology will become a new dimension of the 6G network.**

- One of the core issues of the 6G system composed of subsystem sets is how to configure network resources on demand and truly deploy the "capable and cost controllable" 6G subsystem for each vertical industry. Due to the ever-changing needs of thousands of industries, this on-demand networking is difficult to be realized manually, and should be realized through AI training and intelligent methods.

- Intelligent replacement will replace a considerable part of traditional protocols and algorithms with "black box" AI protocols and AI algorithms. The preliminary research results of 3GPP Rel-18's AI related research projects have revealed that the standardization impact of various AI application cases is basically similar, which is nothing more than to define the life cycle management (LCM) of AI, including AI data collection, AI model training, deployment, management, transfer, activation, selection, switching, configuration and inference.

- For the 6G security architecture, the envisioned key changes are as follows: The security trust model is transforming from mutual trust model to multi-party trust model, which requires the establishment of multi-party trust model and endogenous security; The security protection of service data is transforming from single-focus to multi-focus, and it is increasingly necessary to establish intelligent security for the protection of service data that covers all angles.

- The core of 6G flexible spectrum allocation is the flexible sharing of spectrum with the help of blockchain technology.

- Therefore, it is necessary to make a clearer judgment on the road map of 6G, including the limitations, bottlenecks and expected changes in the evolution of AI bsed air interface construction. Formulate short-term, medium-term and long-term plans accordingly to achieve theoretical and engineering achievements and breakthroughs.

- The research on the intelligent 6G air interface will not only do the repair and optimization evolution on the specific wireless use cases, but also carry out the in-depth analysis of the common basic problems of wireless AI from the perspective of system reconfiguration, including: Integrated and systematic AI design of future wireless communication system; Wireless AI solution for scene adaptation and online updating under limited sample conditions; Wireless AI data set studies with intelligent channel modeling and virtual channel reconstruction.

- As the available frequency band in the 6G system becomes higher and higher, it becomes more difficult to achieve seamless coverage through the base station. Using D2D technology to achieve direct communication between devices will become an increasingly important communication mode in the 6G system. In addition, D2D technology can be combined with other technologies, such as sidelink based positioning technology, sensing technology, large-scale IoT technology, artificial intelligence, etc. Therefore, D2D technology will become one of the most important technologies in the 6G system.

- The 6G URLLC subsystem should be divided into the following two categories according to the different needs of different target services, and should be optimized separately: Enable real-time control with medium/low bandwidth and high reliability in industries or transportation; Real-time interactive multimedia entertainment with broadband.

- The 6G URLLC subsystem can also introduce AI technology to assist in the following functions: Prediction of data arrival, Prediction of scheduling or retransmission, Prediction of collision, UCI (uplink control signaling) enhancement.

• Since the 6G sensing subsystem should ensure its market competitiveness in sensing performance, it is impossible to require it to have the same communication performance as the 6G broadband cellular system and the 6G URLLC system. The requirements in data rate, spectral efficiency, system capacity and other aspects should be appropriately relaxed to leave design space for the optimization of sensing performance.

• To adapt to different application scenarios, the 6G sensing system can consider two modes: integrated communication and sensing mode and sensing-only mode.

• The characteristic KPIs of the 6G Massive IoT subsystem include: Support low power consumption or even extremely low power consumption. For example, some scenarios need to support milliwatt or even microwatt communication power consumption; Support larger connections; Support diversified coverage requirements from short distance coverage (tens of meters), medium distance coverage (hundreds of meters) to several kilometers.

• The key technologies that may be adopted by the 6G Massive IoT subsystem include: Battery-less communication, Low power/ultra-low power communication, Flexible tailorable protocol architecture, Rich communication security suite set and Ultra-low power positioning.

• The following key technologies should be studied for 6G NTN subsystem: Terminal power consumption optimization, Transmission data rate improvement, Waveform design probably decoupled with terrestrial systems; High-efficiency satellite beam management, Dual connectivity of NTN networks, regenerative forwarding, Sidelink communications under the satellite coverage.

Finally, considering the work load of 3GPP in each release of 6G standardization, we can consider completing 6G standardization in the following two releases to achieve the "minimized and versatile" 6G system architecture:

• The first release (Rel-21) completes the minimized kernel, broadband cellular and D2D subsystems.

• The second release (Rel-22) starts the work on 6G URLLC, sensing, NTN communication and massive IoT subsystems.

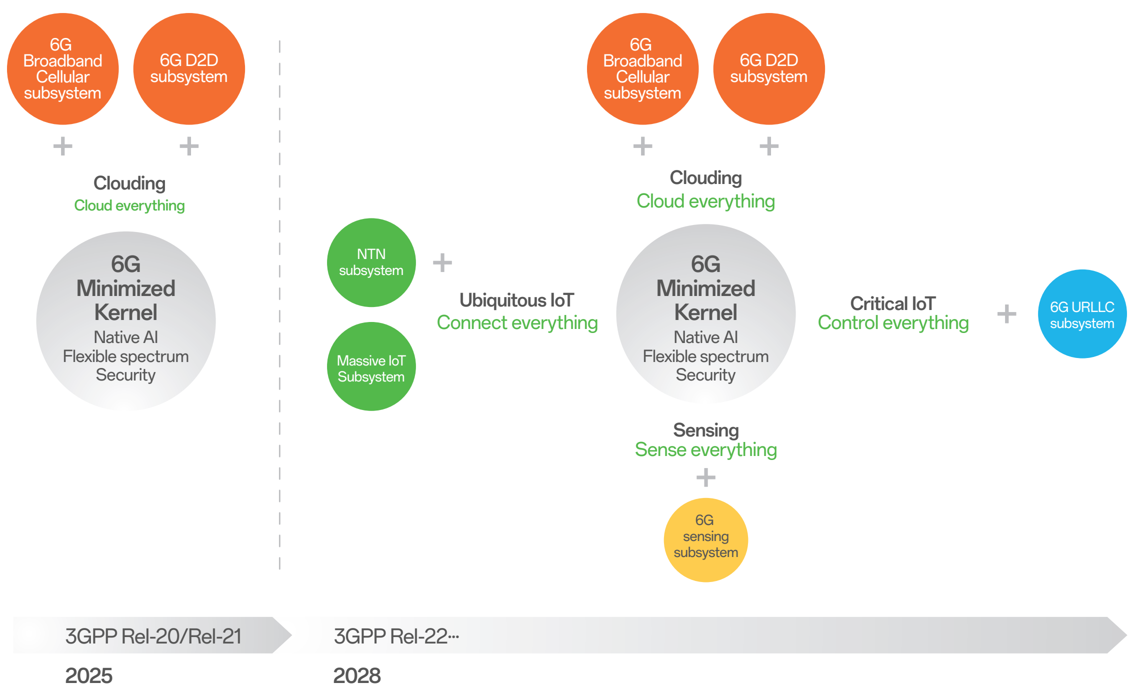


Figure 9-1: Two stages of 3GPP 6G standardization

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