OPPO

AI-zation and versatility with minimized kernel:

A 6G as an infrastructure for inclusive intelligence and metaverse

OPPO 6G White Paper 2023 Edition

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1.0 Concept of 6G system

- Task of 6G in mobile communication development
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- 6G Mobile AI will be the foundation of inclusive intelligence
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- "AI-zation" is a feasible way to Mobile AI
- Versatile 6G with Minimized Kernel is the way to Mobile Metaverse

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 and video", that is, ubiquitous Internet access;**
- **The goal of 5G and 6G is to realize the "mobile AI and metaverse", that is, providing infrastructure for inclusive intelligence and metaverse.**

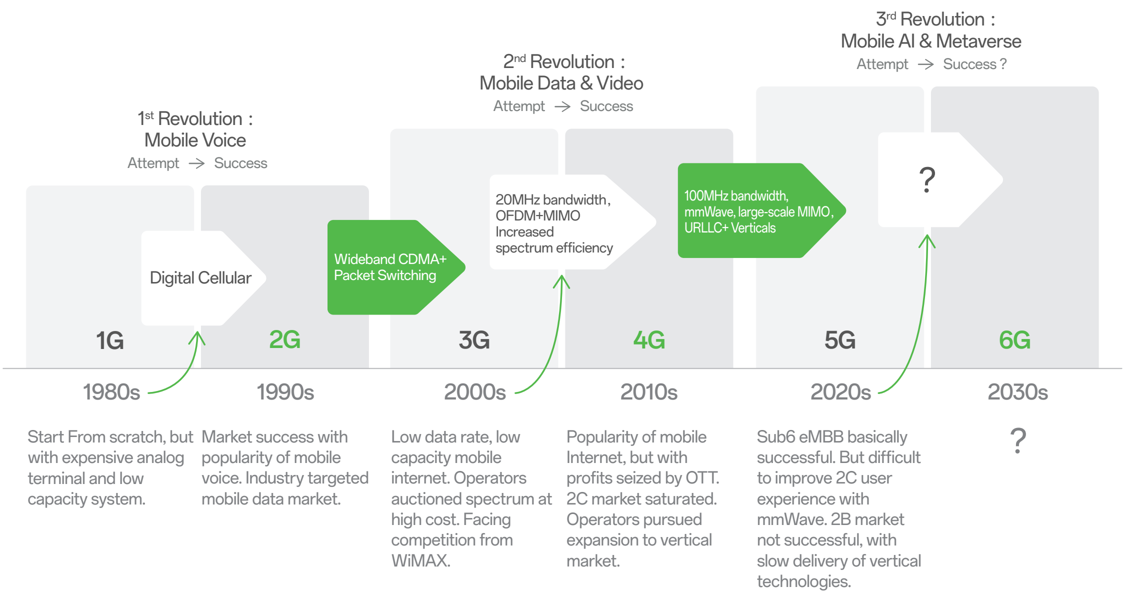

Figure 1-1: Intergenerational evolution of mobile communication technology

Both the two major industrial upgrades in history have activated an emerging "billion-user-level" market. 1G and 2G have made mobile phones popular among billions of people, and 3G and 4G have made mobile data and multimedia among billions of users. 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. However, when defining the top-level design of 5G 10 years ago, the industry's understanding of artificial intelligence and the metaverse was still relatively preliminary.

Designers of 5G system only focused on achieving breakthroughs from "Internet of Human" to "Internet of Things", without fully realizing that in order to become the infrastructure of AI and the metaverse, the mobile communication system cannot still remain in the simple role of "pipeline" and need to have richer system capabilities. **Therefore, the historical task of 6G is, based on the experience and lessons learned from 5G, to thoroughly realize the goal of becoming an infrastructure for inclusive intelligence and metaverse.**

6G should become the infrastructure for inclusive intelligence and metaverse

1.2

In recent years, the industry has been continuously exploring what kind of 6G system should be designed. In July 2023, the International Telecommunication Union (ITU-R) completed the " Framework and overall objectives of the future development of IMT for 2030 and beyond", and the industry has formed a preliminary consensus on the 6G vision and overall concept.

The vision of ITU-R for IMT-2030 (6G) defines six usage scenarios. As shown in Figure 1-2, extending from the three usage scenarios of IMT-2020 (5G), the six usage scenarios of 6G includes Immersive Communication, Massive Communication, Hyper Reliable and Low-Latency Communication (HRLLC), AI and Communication, Integrated of Sensing and Communication, and Ubiquitous connectivity.

The mobile communication industry is highly dependent on economies of scale. The first two major upgrades in the history of mobile communication have brought an emerging market with billion-level of users. Whether it is digital mobile phones in the 2G era or mobile internet in the 4G era, they have been popularized among billions of people worldwide, bringing enormous economic and social benefits to the mobile communication industry. Of course, we also have reason to expect today that the third industrial upgrade completed through 5G and 6G can once again bring about an emerging market with billion-level of users. From the current development framework of IMT-2030 (6G), it is expected that 6G will bring two emerging billion-user-level markets: Mobile AI and Mobile metaverse.

Among the six usage scenarios defined in the IMT-2030 (6G) development framework, AI and Communication is expected to promote the popularization of mobile AI computing, achieve inclusive intelligence through AI computing networks and computing devices, and activate the first new billion-user-level market. The other five usage scenarios are expected to promote the construction of a mobile virtual digital environment, realize the interconnection and integration of the virtual and real worlds through the realization of consumer metaverse and industrial metaverse, and activate the second new billion-user-level market.

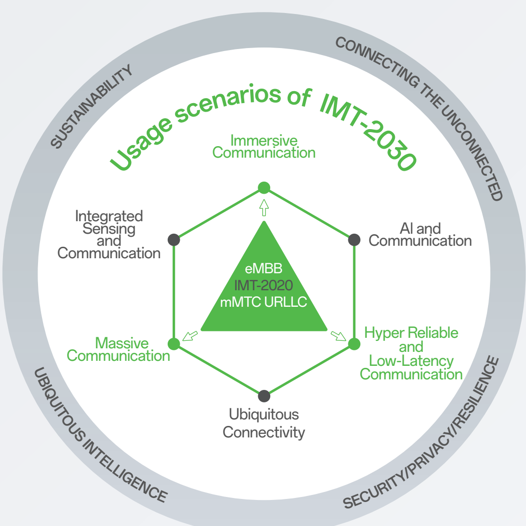

Figure 1-2: Six usage scenarios defined in ITU-R IMT-2030 framework

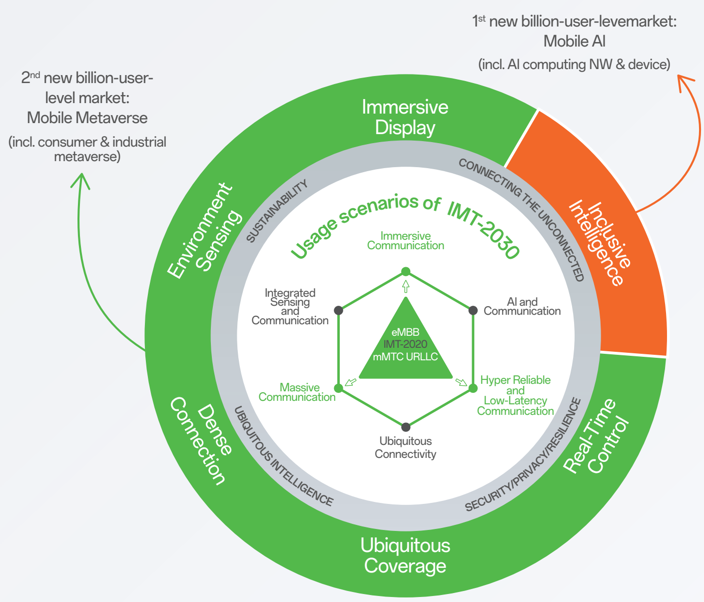

Figure 1-3: 6G is expected to activate two new billion-user-level markets

And these two billion-user-level markets will mutually empower and promote each other: Mobile AI Computing can be seen as the brain of the Mobile Metaverse, providing necessary processing and computing capabilities for the environmental sensing, real-time control, immersive display, etc. required to construct the metaverse. Without ubiquitous AI computing, it is difficult to truly popularize the devices and services of the mobile metaverse. **The Mobile Metaverse can be seen as the body of Mobile AI Computing**, providing a wide range of senses for collecting data, visions for displaying the effects, and limbs for executing actions for the inclusive intelligence.

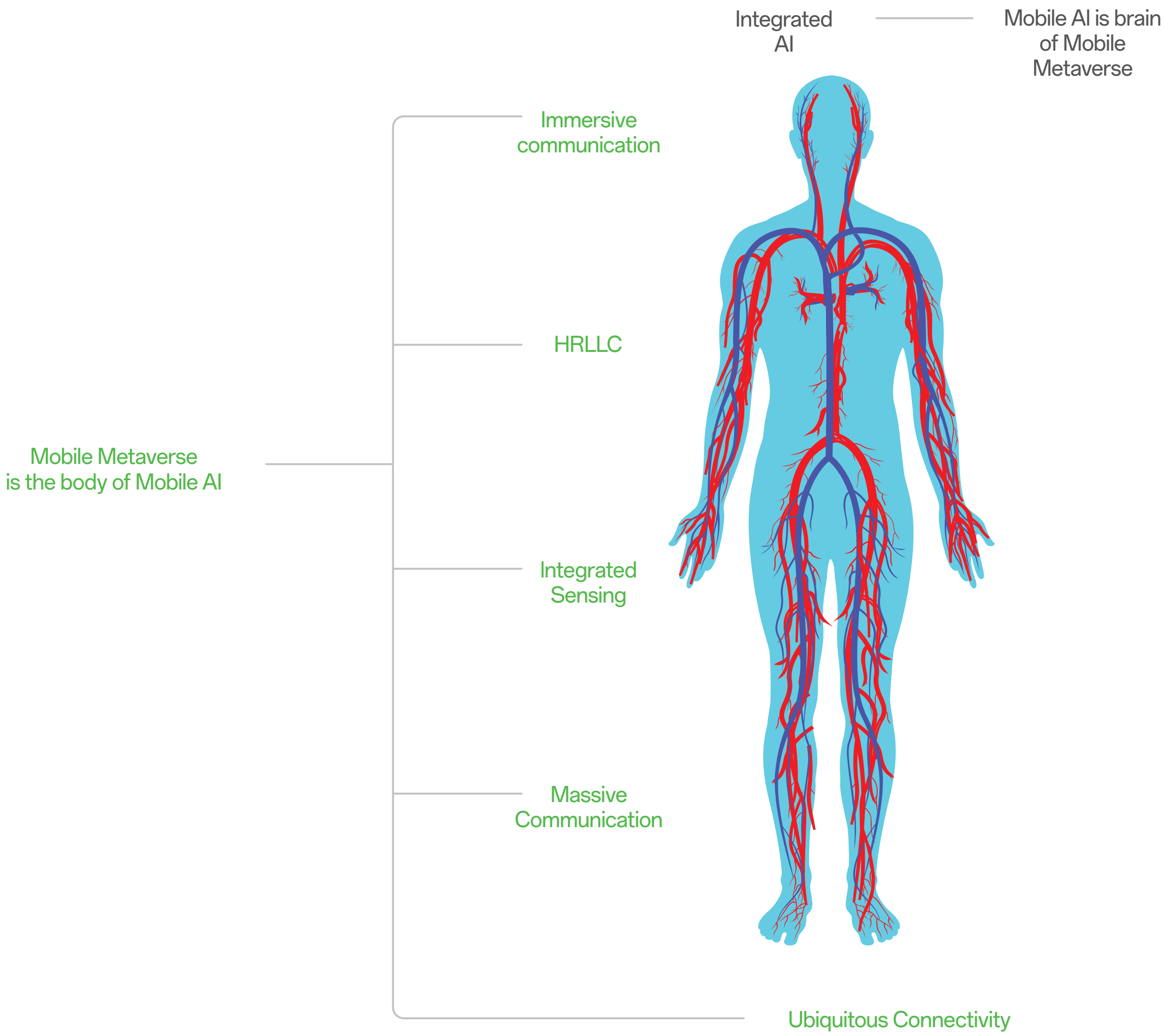

Figure 1-4: Relationship between Mobile AI and Mobile Metaverse

6G Mobile AI will be the foundation of inclusive intelligence

1.3

In recent years, the rapid development of generative AI (e.g., AIGC) based on large pre-training models has shown enormous innovative potential, which will bring profound changes to the entire ICT industry. But in the 5G era, the AI computing architecture that is completely focused on the network side has also raised some potential problems and concerns. As shown in Figure 1-5, centralized AI computing mainly relies on AI/ML models running in the cloud for AI training and inference. The device is only a non-AI device that provides training data for the cloud AI/ML models and executes inference results of cloud AI/ML, while the 5G system is only a pipeline for uploading AI training data and downloading AI inference results.

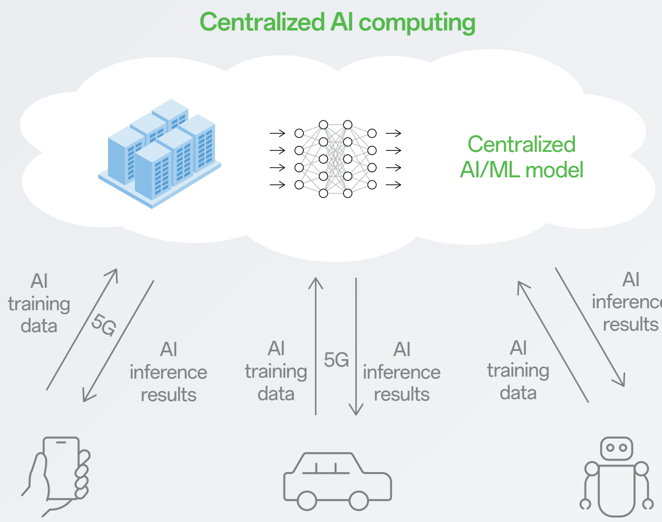

Figure 1-5: The centralized AI computing architecture adopted in the 5G era

The potential concerns about this centralized AI computing architecture include:

1. **Monopoly of AI computing power and knowledge:** Excessive concentration of AI computing in network data centers may lead to a monopoly of AI computing power and AI knowledge. Users have to rely on the network computing power of AI service providers and cannot even control the AI computing power directly related to their work and life.

2. **AI replaces human intelligence:** Millions of years of human beings' evolution is a history of mutual development and positive interaction between "generic intelligence" and "personalized intelligence". The generic part of personalized intelligence is condensed into the generic intelligence universally recognized by humans. But at the same time, personalized intelligence still flourishes, maintaining certain differences from generic intelligence and continuously promoting the correction and evolution of generic intelligence. But currently, centralized AI relies on powerful computing power and big data, always able to provide the "best" answer even to personalized questions. This gives people an illusion that "a super strong AI brain can replace individual human thinking", inducing humans to give up their own thinking and rely entirely on AI to solve all problems. This dependence may lead to the convergence and depersonalization of human intelligence. Then human intelligence may degrade and stop evolving, and ultimately be replaced by AI intelligence.

3. **Personal information safety issues:** In a centralized AI architecture, all end user data is reported for training and inference of network-side AI models. End users cannot conduct preliminary training and inference on their own data, and may become mere providers of AI data. This may lead to risks of personal data safety and privacy disclosure.

For above reasons, although a centralized AI computing architecture can also support the rapid development of AI business, it may lead to the centralization and homogenization of human intelligence development. This makes it difficult to achieve autonomous and controllable AI computing for each user, ensuring the right of personalized intelligence development for each person, and ensuring user privacy and safety.

A more reasonable AI computing architecture is based on 6G mobile AI computing. As shown in Figure 1-6, each device has a lightweight AI/ML model that can be used for personalized AI training and inference based on the user's own data. At the same time, it can fully utilize the generic large model on the network side for high complexity general AI training and inference. In this way, the network side model and the device side model can cooperate for a split training and inference, jointly completing the AI computing tasks required by users. This mobile AI computing architecture has the following advantages:

1. **User-controllable AI computing:** Although high-complexity general AI training and inference are still carried out using the network-side computation power, personalized training and inference are completed on the device side, allowing users to achieve controllable AI computing for the user-related services, without completely relying on the computation power on the network side.
2. **User-controllable intelligent evolution:** Lightweight AI models on the device side (such as AIGC) can reflect the user's own ideological characteristics and personal ideas. Although network side AI model is used for generic intelligent inference, device-side AI computing can still maintain personalized differences from generic intelligence, ensuring the user-controllable intelligent evolution and avoiding "homogenization" development of users' intelligence. This will benefit the diversified, healthy evoluation of human intelligence, and prevent human intelligence from gradually being replaced by a "super strong AI brain".
3. **Protecting personal data privacy and safety:** Data directly related to users is processed locally by the lightweight AI models on device side. Only intermediate data from AI training and inference is transmitted to the network, which can prevent user data from leaving the device and being directly exposed to the network, thus achieving protection and desensitization of private user data.

In the mobile AI computing architecture, the "Integrated of AI and Communication" usage scenario of 6G can effectively achieve split AI/ML inference and training, making 6G the key infrastructure of Mobile AI Computing, the emerging billion-user-level market. While promoting inclusive intelligence, it can achieve the third industrial upgrade and market return for communication industry.

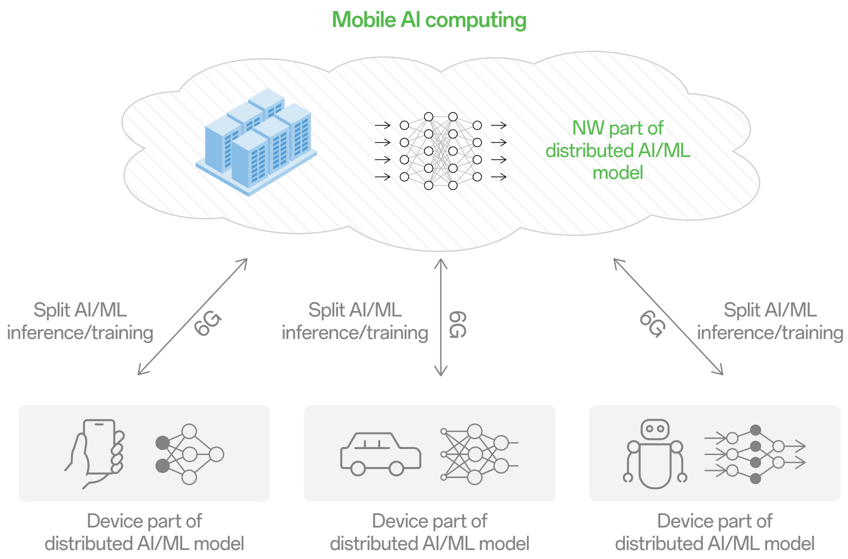

Figure 1-6: 6G-based Mobile AI computing architecture

6G Mobile metaverse is the foundation for constructing the Metaverse

1.4

Why does the body that matches the brain of "Mobile AI" have to be a "Mobile Metaverse"?

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 Informatized World. Because the sensing ability of human sensory 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. 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 learning and training.

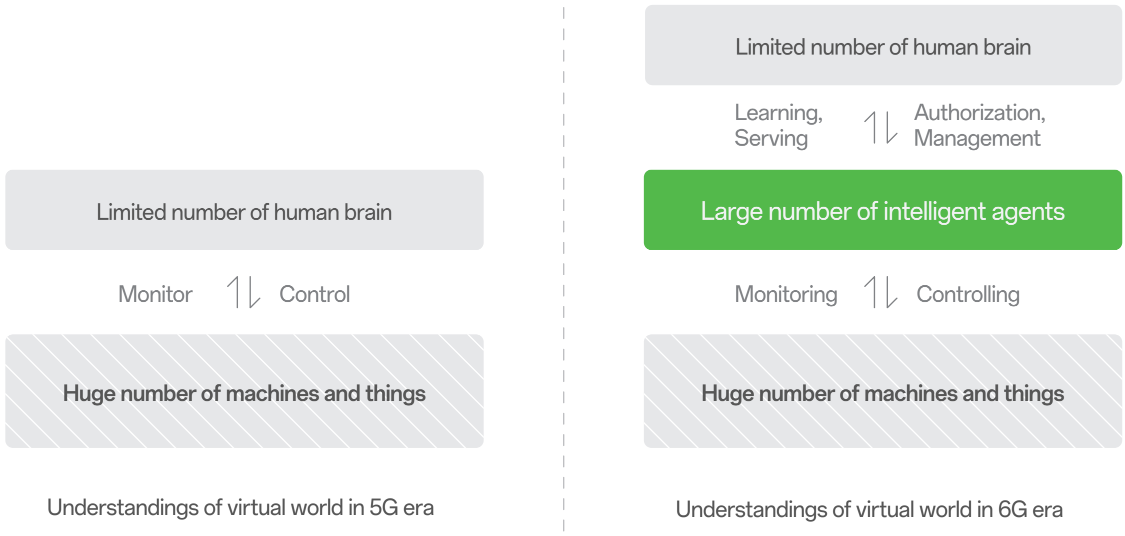

Figure 1-7: Different understandings of the information world in 5G era and 6G era

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.

However, the "Internet of Things" of 5G still only connects the devices collecting data. The data that can be utilized is far from enough to "feed" the large AI model. **In the era of 6G, if humans are to control and manage the informatized world through AI agents. It is necessary to build a more complete virtual world better corresponding to the physical world. By controlling the digital twin of massive machines and things in the virtual world, we can control the machines and things in the physical world. Building a Metaverse is a feasible method to realize the virtual world.** In recent years, the reason why the Metaverse has received widespread attention is not only because it can provide humans with realistic immersive multimedia entertainment experiences, but more importantly, it describes a broad prospect of "managing the physical world through virtual world and creating a better physical world through managing virtual world".

The other five usage scenarios of 6G can respectively achieve the three major steps of building a Metaverse: "Sensing the physical world and building a virtual world", "Controlling the physical world from the virtual world", and "Displaying the virtual and real worlds to users". At the same time, "Massive communication" and "Ubiquitous connectivity" serve as the two basic capabilities. The five usage scenarios will make 6G the key infrastructure of Mobile Metaverse, and achieve the third industrial upgrade and market return for communication industry.

- Sensing physical world for constructing virtual world.
- Controlling physical world from virtual world.
- Presenting physical + virtual world to human.

Ubiquitous coverage & Massive communications is the foundation

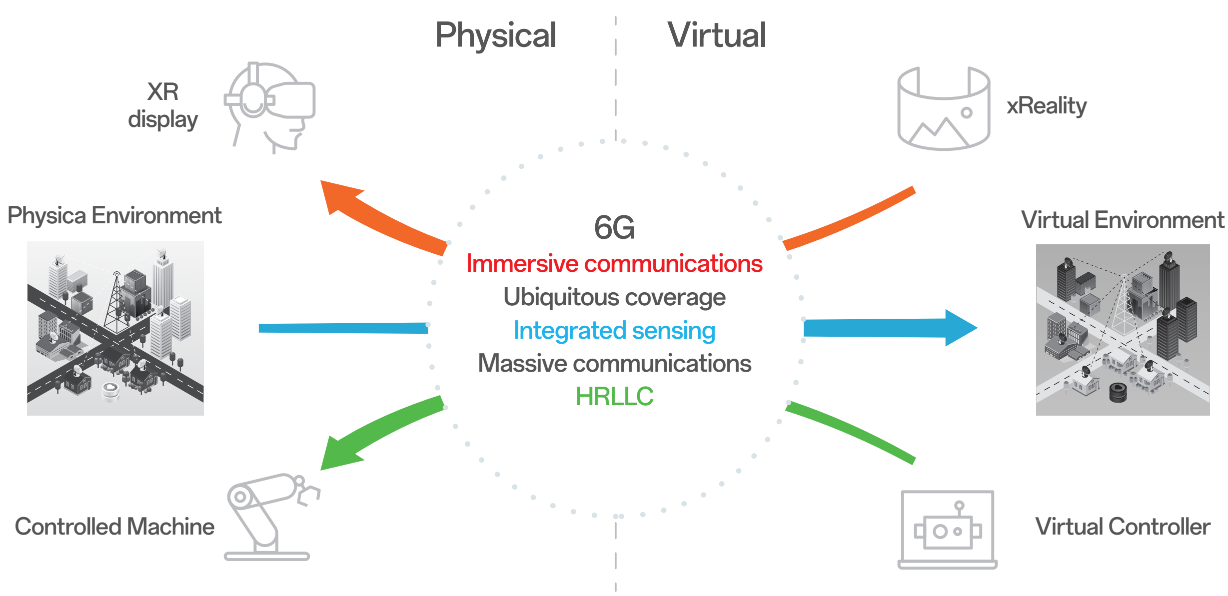

Figure 1-8: The other five usage scenarios makes 6G a key infrastructure of Mobile Metaverse

"AI-zation" is a feasible way to Mobile AI

1.5

As the first billion-user-level market in 6G, Mobile AI poses a challenge in 6G system design: How to implement an efficient and cost-effective software and hardware design that can simultaneously meet the needs of 6G communication and AI computing on both network and device sides? In today's 5G system, "5G for AI" and "AI for 5G" are designed and implemented separately, making it impossible to share software and hardware resources, resulting in higher costs. **In the era of 6G, "AI zation" will provide a feasible path to a Mobile AI.**

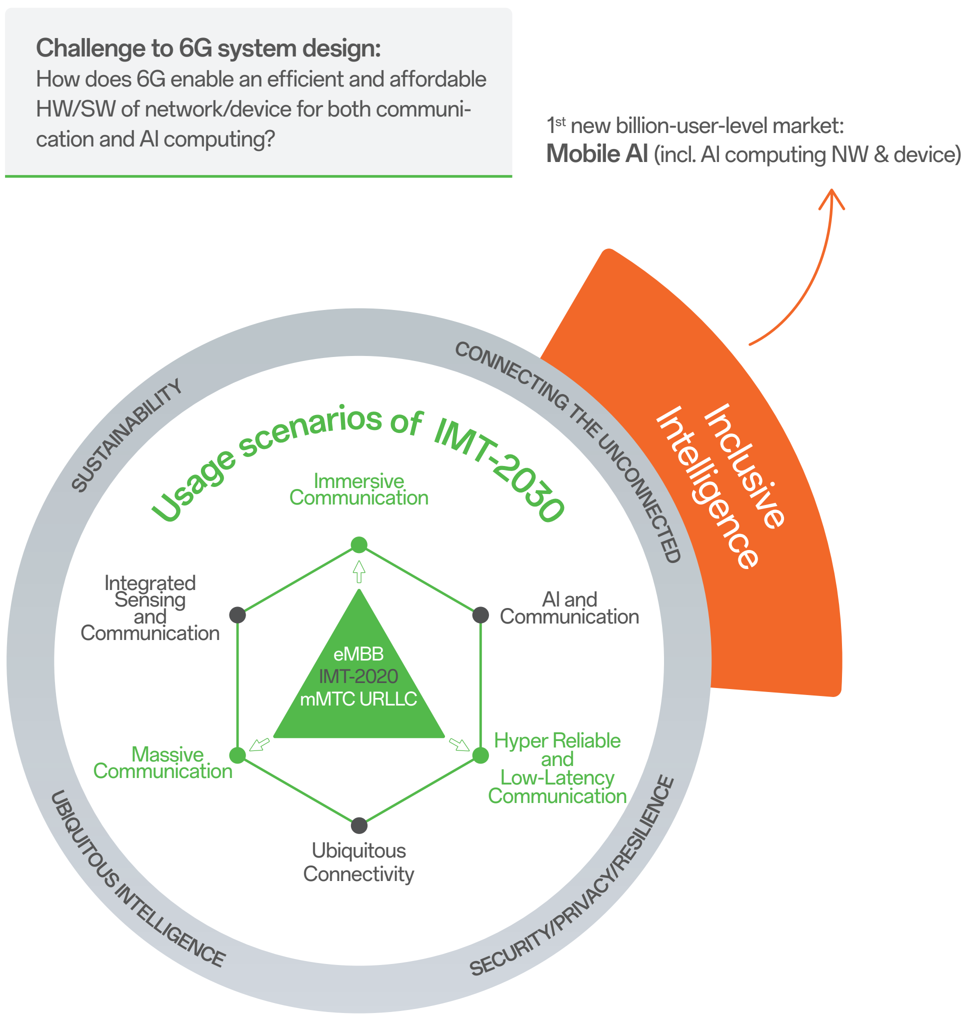

Figure 1-9: The challenges brought by Mobile AI to 6G system design

There are two options to introduce AI technology into 6G systems: "Use-case-based AI enhancements" and "AIzation".

Option 1: Use-case-based AI enhancements

In the standardization of 5G, use-case-based AI/ML enhancement was adopted, in which each part of the 5G system is separately considered whether to introduce AI/ML algorithms. In 5G Rel-18 and Rel-19, AI/ML enhancements may be applied to 4 use cases including CSI feedback, beam management, positioning, and mobility management, provided that the AI/ML algorithm shows significant gains compared to traditional algorithms. The advantage of this option is that it is relatively stable and can avoid introducing unnecessary equipment upgrade costs during the 5G-Advanced stage. However, applying this option to the system design of 6G mobile AI will bring obvious problems:

- Firstly, if treating the 6G system as a series of isolated parts and considering whether to introduce AI algorithms for them separately, it is difficult to obtain the system-level AI gains brought about by end-to-end AI. Requiring each isolated use case to achieve AI performance gain will result in a low AI-zation ratio for the 6G system. Many AI algorithms, on the other hand, can only share training data, conduct joint training, and achieve maximum AI gain after all relevant parts have been AI-zed.
- Secondly, the AI-zation of 6G system will become a slow and gradual process. That is, in the first release of 6G, only a small number of use cases will be AI-zed. Even if 6G software and hardware already have the strong AI compution power, only a limited number of use-case-level AI algorithms can be implemented. Then, AI-zed use cases will gradually be added in the subsequent releases of 6G (e.g. in 6G-Advanced). But this will lead to an unfavorable situation of "product implementation waiting for standards".
- Finally, at least in the first release of 6G, it is not possible to achieve the integration of "AI for 6G" and "6G for AI", making it difficult to achieve a true "native AI", and also unable to achieve high-level sharing of software and hardware between AI applications and 6G communication processing.

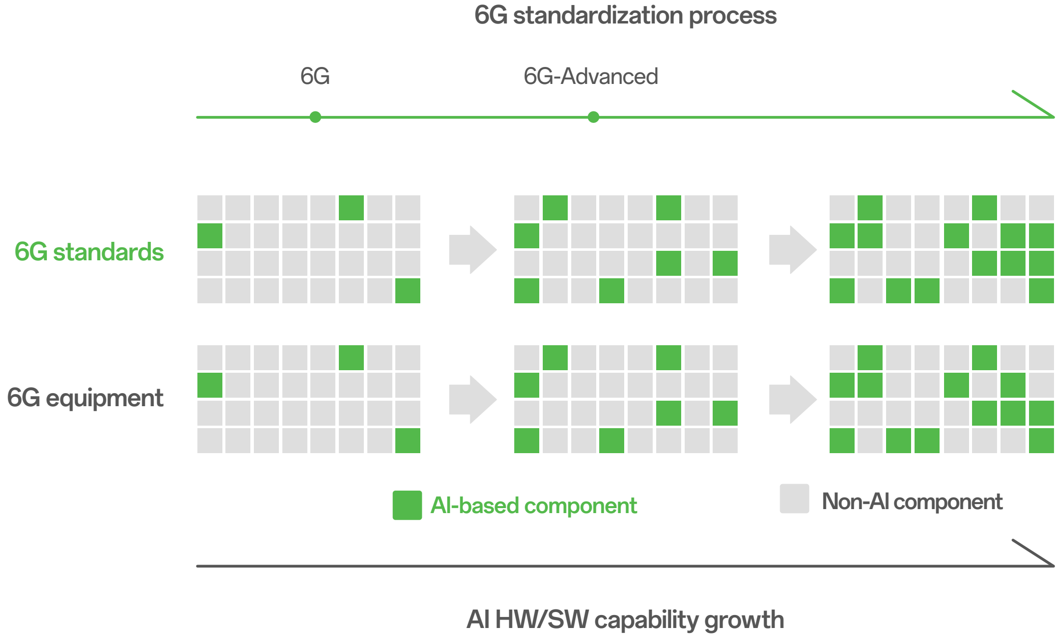

Figure 1-10: Use-case based gradual AI enhancements for 6G

Option 2: Fast "AI-zation"

This approach is to adopt AI algorithms in as many aspects as possible in 6G standards, and be open to AI-based proposals in all agendas of 6G standardization. The performance of the entire 6G system can be evaluated to meet the IMT-2030 requirements. It is not required that in each individual aspect of the 6G system, AI algorithms must provide performance gains over non-AI algorithms. This option has the following advantages:

- Firstly, it is possible to achieve as much AI-zation as possible in the 6G system, so that after multiple relevant parts of the system are AIized, they can share the training data for joint training, and obtain the system-level AI performance gain brought by end-to-end AI.
- Secondly, it is possible to achieve rapid AI-zation in the first release of 6G standards. That is, to achieve a high proportion of AI-zation in the first release of 6G, forming a favorable situation of "standards waiting for product implementation". This enables the industry to freely choose the proportion of AI algorithms used in 6G systems based on the gradual enhancements of 6G AI software/hardware computation capabilities.
- Finally, the integration of "AI for 6G" and "6G for AI" can be achieved as soon as possible, allowing 6G device vendors to develop software and hardware for AI applications and 6G communication. This can reduce the software and hardware costs of 6G mobile AI, and achieve true "native AI" from the first release of 6G.

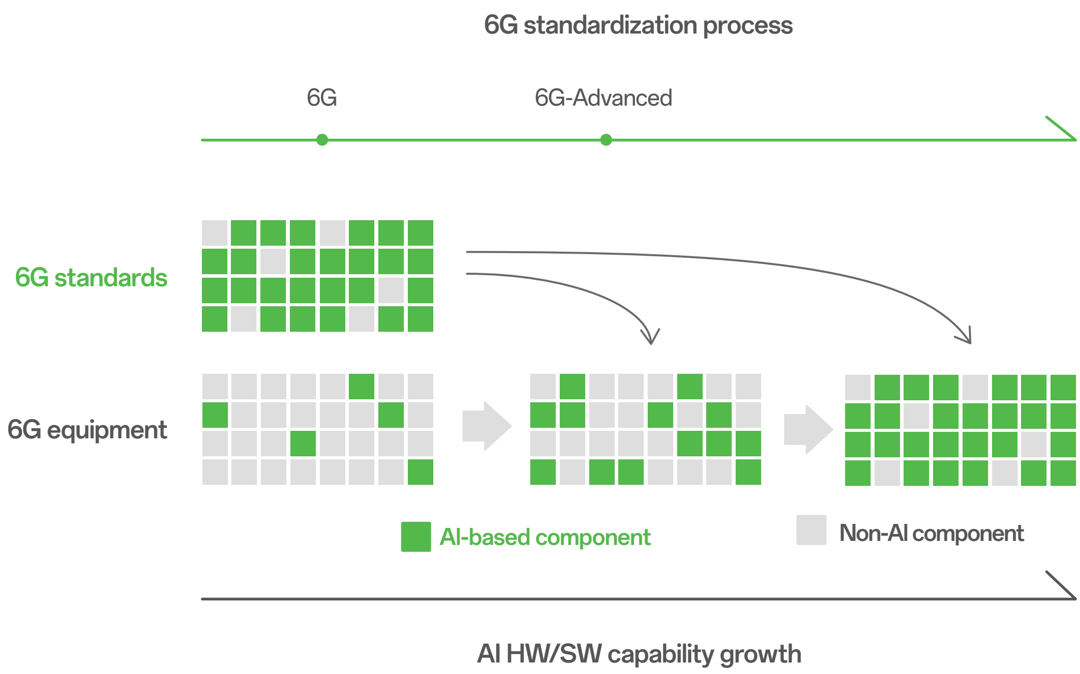

Figure 1-11: Fast “AI-zation” for 6G

From the current perspective, fast AI-zation is a more reasonable route to achieve 6G Mobile AI. At the same time, the working mechanism of AI algorithm also objectively provides the possibility of fast AI-zation of 6G system. The characteristics of AI algorithms are “black box” inference, data-driven, and model training. This characteristics determine that even if there are various technical problems to be solved, the working mechanisms of AI algorithms are similar, including data collection, model training, model management, model storage, model inference, etc.. The working mechanism is called Life Cycle Management (LCM) of AI models. In the study of 5G Rel-18, a preliminary structure of AI/ML LCM for mobile communication system was formed, as shown in Figure 1-12.

Although the design of 6G AI LCM still needs to be further studied, the preliminary research on Rel-18 5G AI at least shows that the AI LCM mechanisms for different use cases are similar, with only potential differences in detailed parameter configurations and procedures. That is to say, it is expected that a common LCM can be used to implement various parts of a 6G radio access network (RAN), so that there is no need to determine whether AI algorithms need to be supported one by one, thus the standardization workload of 6G AI will not increase significantly with the increasing number of AI-zed use cases. On the other hand, we can observe that the AI LCM used in 6G RAN is actually similar to that used in other AI industries (in fact, the 5G Rel-18 LCM is designed by learning from other AI industries). Therefore, we can even try to share the common LCM mechanism between "AI for 6G" and "6G for AI" to achieve the converging design of "AI for 6G" and "6G for AI". That is, one common LCM mechanism can be used for AI data collection, model training, model management, model storage, and model inference in 6G RAN, as well as for data collection, model training, model management, model storage, and model inference in 6G Mobile AI services. In this way, an AI-zed 6G system can achieve software/hardware resource sharing between 6G Mobile AI services and AI-powered 6G RAN processing, unlike in non-AI-zed 6G systems where RAN processing and AI services can only use separate software and hardware resources.

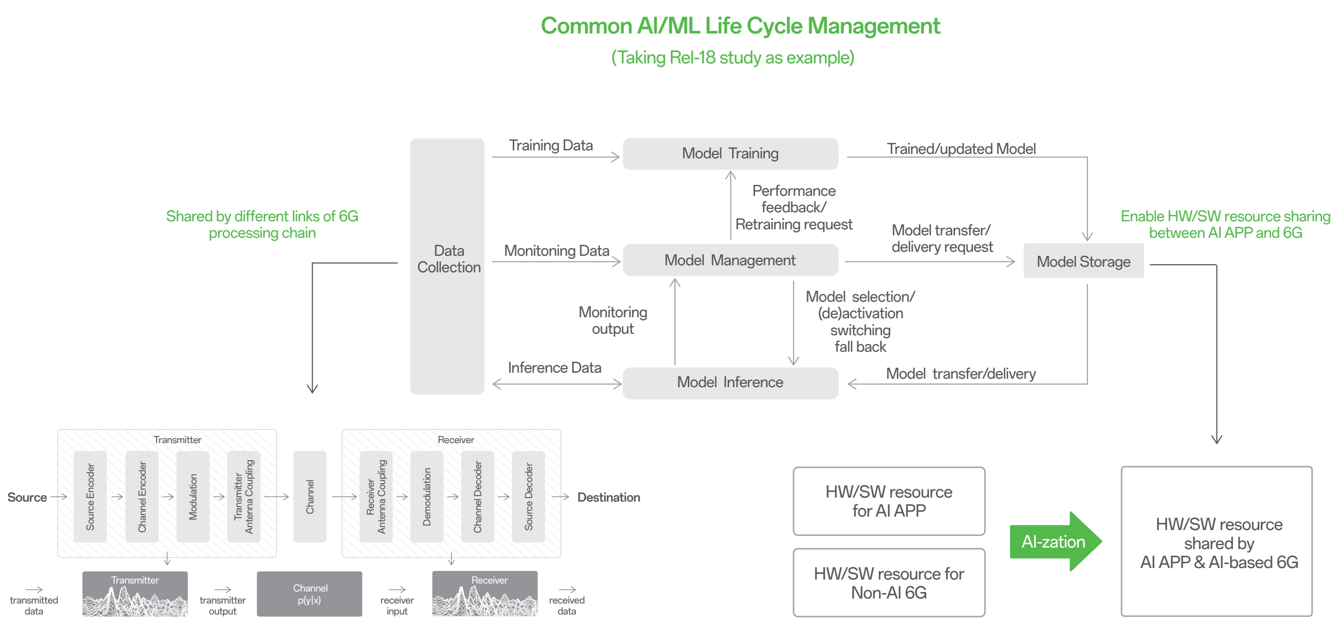

Figure 1-12: Common LCM provides the possibility for fast AI-zation of 6G

Versatile 6G with Minimized Kernel is the way to Mobile Metaverse

1.6

As the other billion-user-level market of 6G, the Mobile Metaverse will also bring challenges to the design of 6G system: How can a cost-controllable 6G system have market competitiveness in each of the five usage scenarios with vastly different requirements?

Challenge:
How to make 6G be competitive in each of the 5 diverse usage scenarios, meanwhile with affordable cost?

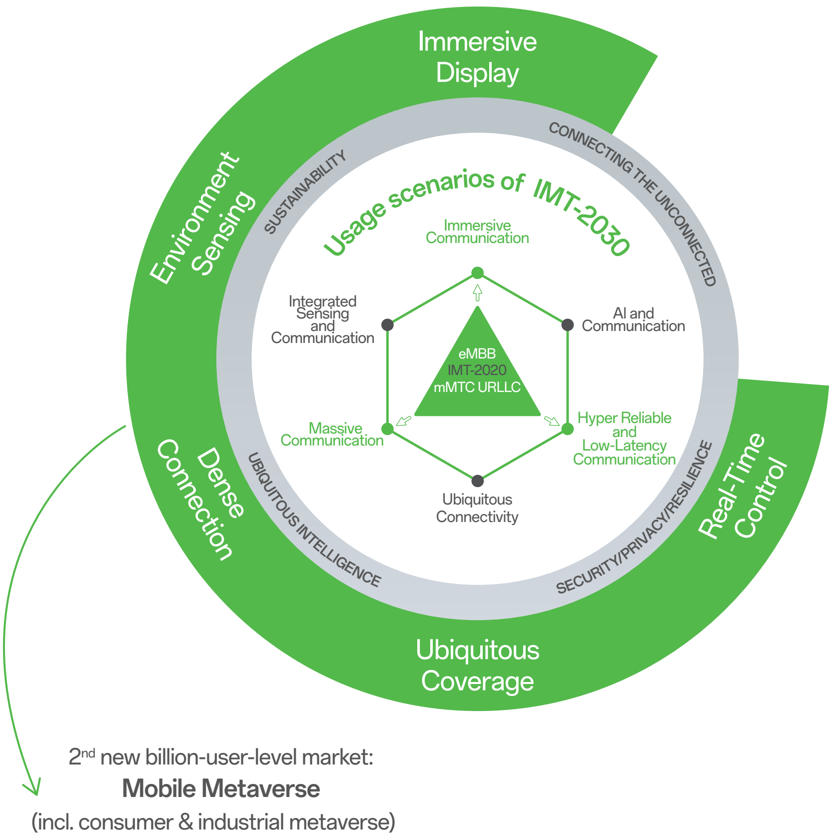

Figure 1-13: Challenges brought by the Mobile Metaverse to the 6G system design

In fact, the 5G system design has already faced this challenge. 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 usage 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.

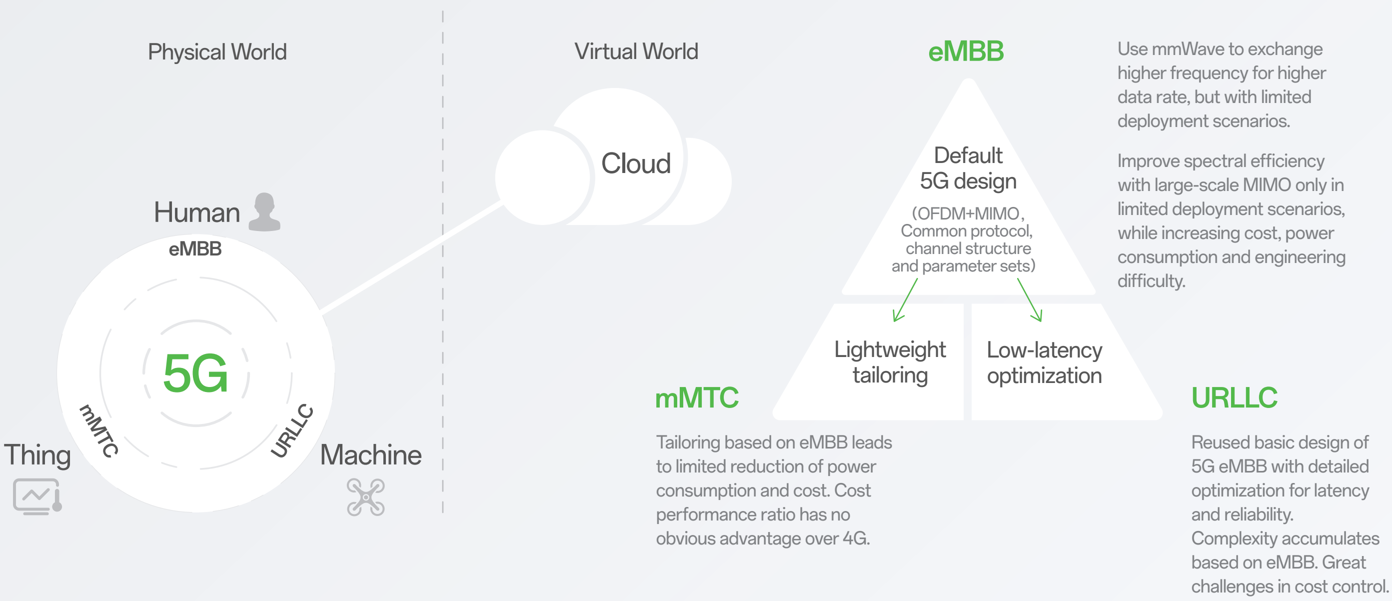

Figure 1-14: Lessons learned from 5G system design

Targeting the emerging Mobile Metaverse market, 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 capabilities of ubiquitous connectivity and the sensing 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 “Mobile Metaverse” 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, further expand to the new usage scenarios, e.g., Integrated Sensing and Communication, Ubiquitous Connectivity, 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 Mobile Metaverse, 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 of air, from land to space and sea. 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 usage 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".

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, flexible spectrum management and minimal processing kernel.**
- **Separate optimization is made for four different capabilities, including: Immersive communication and AI (optimized for high data rate), Massive communication and ubiquitous connectivity (optimized for coverage, low power consumption and low cost), HRLLC (optimized for low latency and high reliability), Sensing (optimized for sensing accuracy).**
- **One or multiple subsystems are designed for each capability. Key technologies can be selected independently according to usage scenarios, spectrum, topology, etc., and hardware and software can be designed separately for different subsystems. For example, it can be divided into: Broadband cellular, Broadband D2D, Cellular HRLLC, D2D HRLLC, Positioning & sensing, Massive IoT, Non-terrestrial networks (NTN), etc..**
- **Determine how much common air interface technology and design to share between Broadband cellular subsystem and other subsystems, respectively according to the specific requirements of the subsystems.**
- **Different subsystems can adopt different standard evolution cycles according to different market requirments, and may not all update the standard to new release every 15-18 months. Standardization can also output relatively independent specifications for some subsystems, making the 6G specifications more friendly and readable for vertical industries.**
- **The 6G system achieves flexible, low-cost, and low-power support for multiple subsystems by fast switching between the "Minimal processing kernel" in the minimized kernel and the "Complete processing core" of each subsystem.**

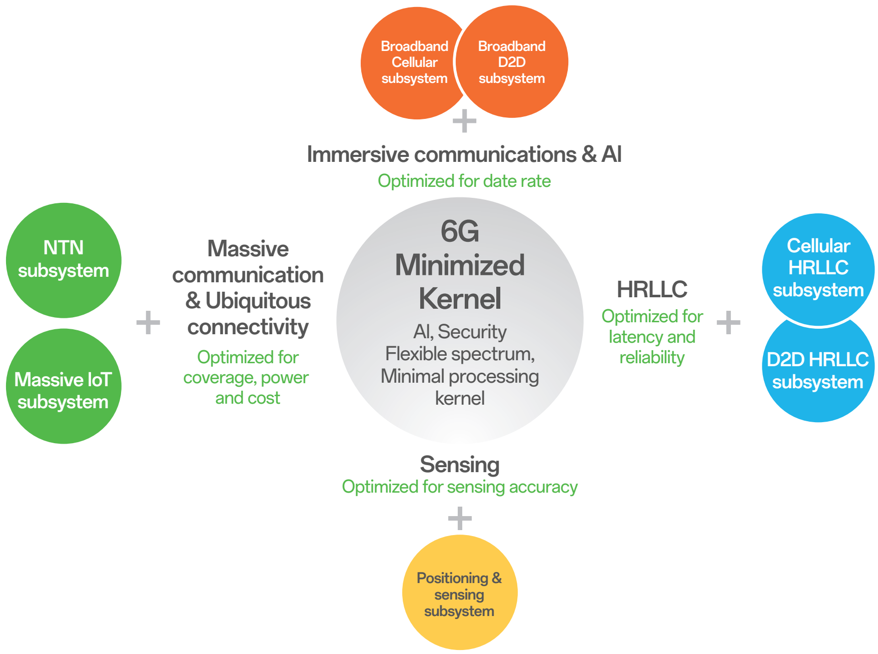

Figure 1-15: 6G = Minimized Kernel + N subsystems

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 usage 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 usage scenario. In the following sections of this white paper, we will respectively introduce our preliminary consideration of the 6G minimized kernel and each subsystem.

For a 6G system that requires support for multiple usage scenarios, the functionality of multiple subsystems can be simultaneously implemented through subsystem aggregation. Here, as an example, we will explain the aggregation of broadband D2D subsystem and perception subsystem.

A typical bi-static scenario of device-based collaborative sensing is: Device A sends sensing signals and Device B receives sensing signals. If a device needs to support this type of sensing, it needs to have both the functions of the sensing subsystem and the D2D subsystem, because in this scenario, the sensing subsystem needs to aggregate with the D2D subsystem to achieve higher layer procedures (such as connection setup, authentication, sensing-related configuration, sensing node selection, etc.) and physical layer procedures (such as synchronization, scheduling or resource selection, power control, and interference coordination, etc.). It can be seen that in the device-based collaborative sensing scenario, the sensing subsystem has a strong dependence on the D2D subsystem, and it is necessary to aggregate the two subsystems within the same device. That is, in the sensing subsystem, there is no need to support synchronization, resource selection, control signaling and data transmission, but to reuse the corresponding functions of the D2D subsystem. The sensing subsystem only needs to implement the sensing processing function.

Specifically, there are two potential solutions: Partial aggregation (as shown in Figure 1-16) and High-level aggregation (as shown in Figure 1-17). With partial aggregation, the sensing subsystem and the D2D subsystem only share the radio resource. But sensing processing and D2D data transmission are designed separately and work independently. With high-level aggregation, the D2D communication signals can be used for sensing simultaneously, thus D2D data transmission and sensing processing can be combined into a integrated design.

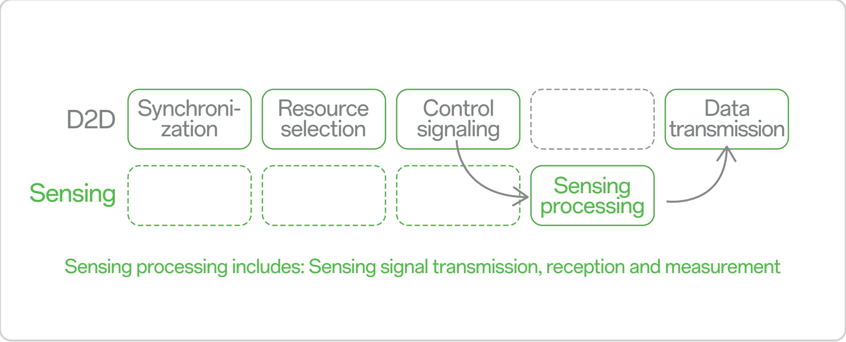

Figure 1-16: Partial aggregation between D2D subsystem and sensing subsystem

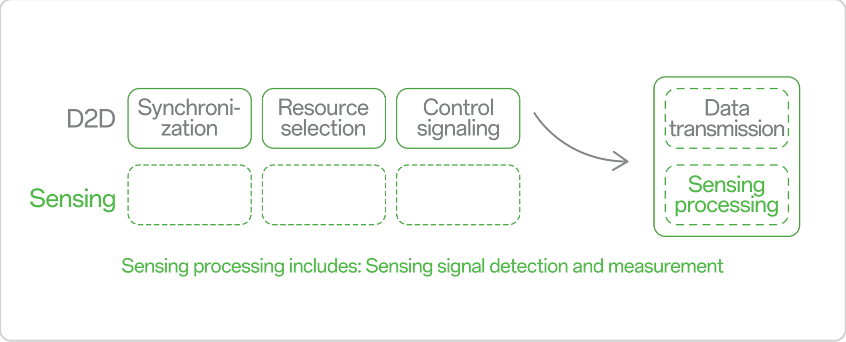

Figure 1-17: High-level aggregation between D2D subsystem and sensing subsystem

However, in order to overcome the channel blocking or ensure continuity of sensing, collaboration is also required between multiple mono-static links, as shown in Figures 1-18. In this scenario, it is still necessary for the device to simultaneously support the sensing subsystem and the D2D subsystem, as the sensing subsystem needs to obtain the position, status, and sensing range of the sensing node through the D2D subsystem. In this case, there can be a low-level aggregation between the D2D subsystem and the sensing subsystem, meaning that the two are relatively independent. The sensing subsystem can also achieve autonomous synchronization and resource selection, but there is coordination between the sensing subsystem and the D2D subsystem for resource selection, as shown in Figure 1-19.

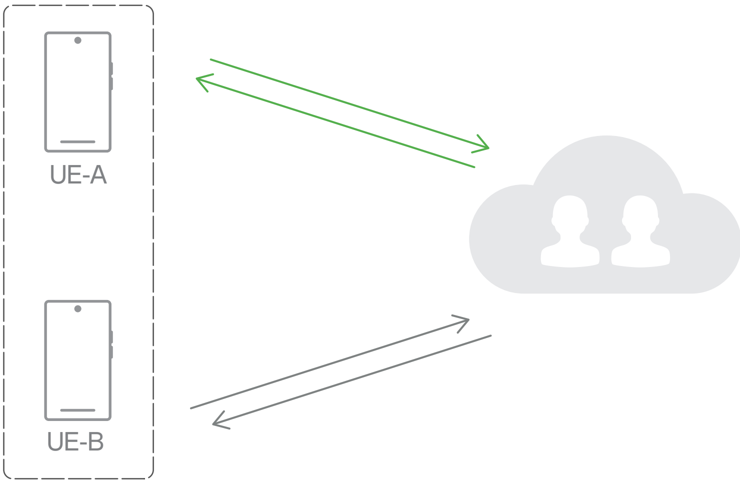

Figure 1-18: Collaborative sensing with multiple mono-static links

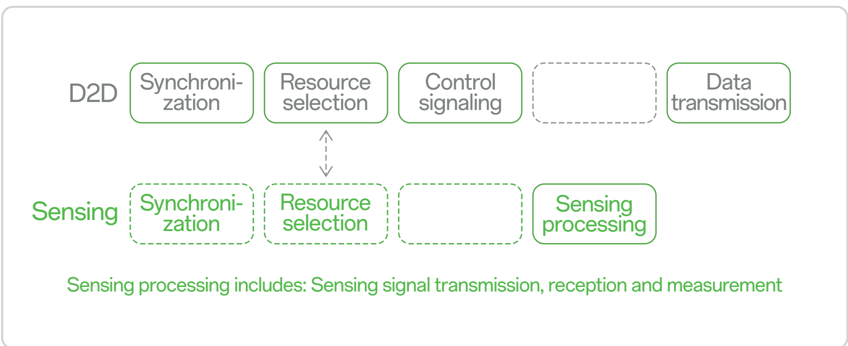

Figure 1-19: Low-level aggregation between D2D subsystem and sensing subsystem

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 four capabilities: Native intelligence, Security, Flexible spectrum management and Mininal Processing Kernel, which will be respectively introduced below.

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 6G network based on native AI

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]:

Compared with traditional AI tasks that are uploaded to the cloud for OTT operation,6G native AI can fully utilize cross-domain resources, including UE, RAN, CN, OAM, Service enabler, OTT Server, etc. In addition to connections, resources also include computing, data and models/algorithms. As shown in Figure 2-2, unlike 5G, which mainly provides connection services, the 6G network will implement QoAIS (Quality of AI Service), including the integration support and management of the four elements of Connection, Computation, Data and Model, so as to realize cross-domain and cross-resource system capabilities, and create a new platform and service with AIaaS (as a Service) exposure capabilities.

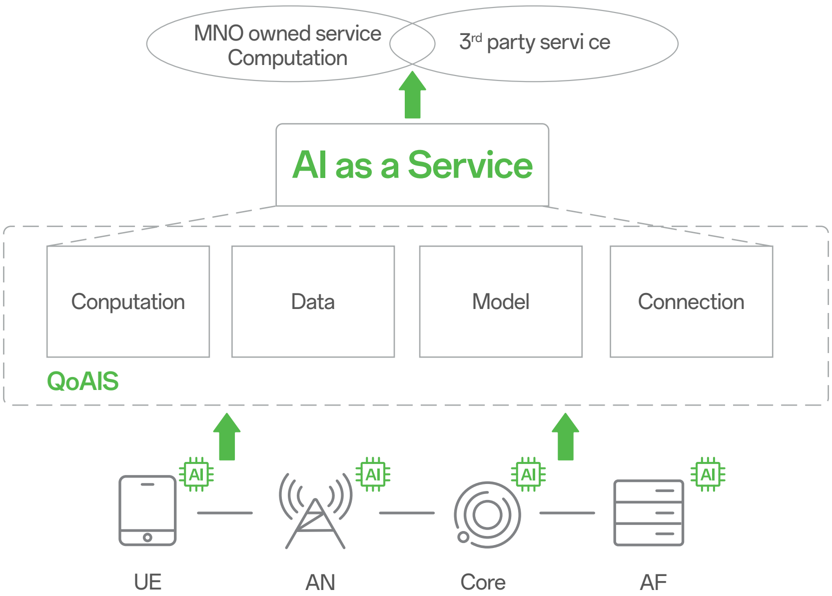

Figure 2-1: AIaaS platform

The specific implementation of the four elements of QoAIS includes the following:

1.Connection

Connection is the most basic feature of 6G Native AI. It is different from the connection capability of 5G. The connection of 6G system must consider supporting

- Differentiated AI data transmission services
- Task-oriented on-demand networking
  Should break the fixed topology as 5G network does (e.g. PDU session)
- Content is perceivable and processable

2.Computation

The 6G network supports the discovery, management and allocation of computing resources (UE, RAN, CN, AS) of cross-domain agents, and allocates them to different AI tasks on demand, including self-owned AI tasks and third-party AI tasks. In this process, the allocation of cross-domain computation resources can realize inference computing operations close to data sources, task sources and end users, and achieve the measurement, management and allocation of computing power at the AI task level. On this basis, the future end-to-end delay should include the sum of the calculation time of each node and the transmission time between each node under each AI task, rather than solely considering the end-to-end transmission delay.

3.Data

The parallel generation of communication data and sensing data is a significant feature of 6G. This feature will lead to diversification of data sources (end-device, base station, core networks, AF, OAM, etc.) and diversification of business types (raw data, Sensing data, IoT data, etc.), diversified content formats (intermediate results, point clouds, anonymization/regularization/aggregation, etc.).

In order to support the data characteristics in the endogenous intelligent system, the 6G system needs to have the following functions:

- Ubiquitous data: Centralization -> Distribution
- Data collaboration (collaborative data): single domain data -> cross-domain data
- Data as a asset: Clarify the data subject and data consumer
- Data timeliness: a key driver for expanding real-time AI business

4.Model

The model management of the 6G network can make full use of the infrastructure resource advantages of the operator's network. The unified storage, management, distribution and sharing of models in the 6G network is an important form of supporting its own business and third-party business, creating an "AI model" Store (AI model library)" new capabilities.

Model training requires massive amounts of data, computing power and connection resources. In order to maximize the efficiency of 6G endogenous intelligent work, the opening and sharing of AI models is the key to improving 6G business efficiency. AI models need to consider the following factors in different businesses and scenarios:

- Model accuracy: A 100% accurate model is extremely difficult and requires a very high price. Reasonable model accuracy needs to be determined on demand.
- Model compatibility: The compatibility of models on different platforms is an important challenge for model opening.
- Model generalization: On-demand adjustment of the model is crucial. Use pre-training fine-tuning to improve model training efficiency.
- Model timeliness: The training and update of the model are subject to timeliness. Models in real-time scenarios have higher requirements for timeliness.

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 "minimalist 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 large models

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 scenario 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 reasoning 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.

  Since the aforementioned four elements of QoAIS (i.e., connection, data, computation, and model) are interrelated, when one element changes, it will always affect other elements to change accordingly. For example, when the sub-model of a specific task changes between node 1 and node 2, the computing power configuration of node 1 and node 2 also needs to be reallocated, and the amount of intermediate data transmitted by the connection will also change, thus affecting the transmission. KPI set values will also change.

  In order to reasonably allocate QoAIS four-element resources, they are deployed in the 6G system in the form of 3GPP context and policy. For a specific task, it is often necessary to comprehensively consider the allocation of various elements of resources based on the actual scenario and network conditions to achieve the optimization of task-level performance and global performance. Therefore, the use of large models to achieve reasonable mapping of scenario requirements to network configuration parameters is the key to the 6G era. An implementation worth considering.

In particular, the functions included in the minimized kernel are the basic mandatory functions on the standardization protocol. For example, 3GPP must standardize the content and capabilties, and then map the personalized functions of different subnets according to the scenario 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 2-3, Among them, a major feature of 6G network on-demand networking is the mapping relationship from scenarios to network characteristics. Here we define the tasks in each scenario to be composed of three major elements: communication, cognition and computing, and make qualitative or quantitative requirements. The model can achieve reasonable generation and composition of parameters related to network characteristics according to the requirements of the input scenario tasks, and then further instantiate it into the 6G network..

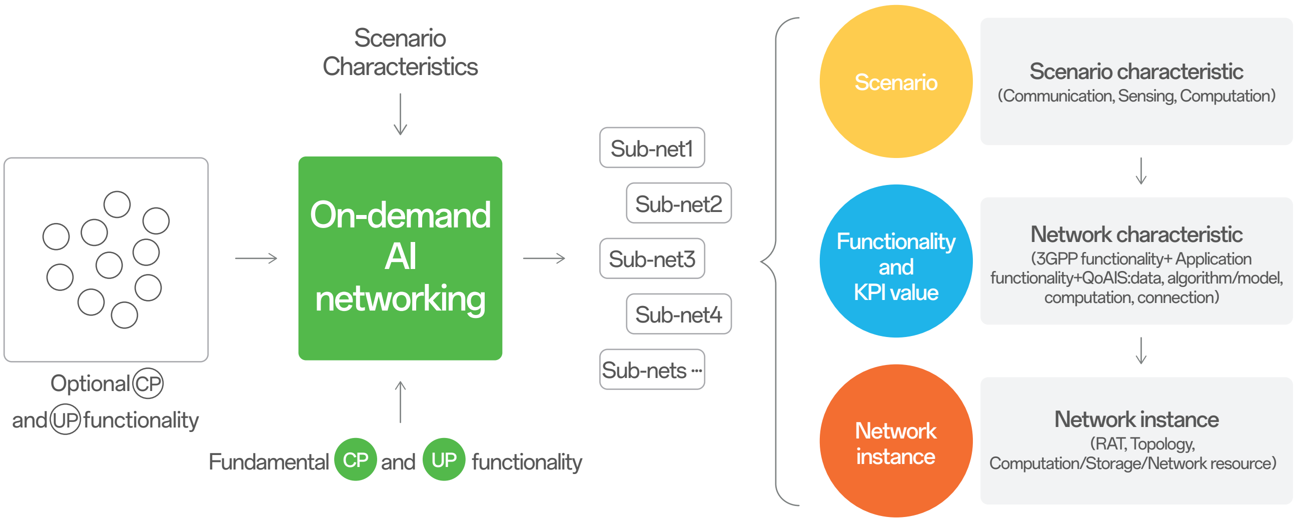

Figure 2-2 : On-demand networking based on native AI of minimized kernel

2.1.3 AI-zation of 6G network based on 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.

AI-zation 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, transmission, activation, selection, switching, configuration and reasoning. 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.

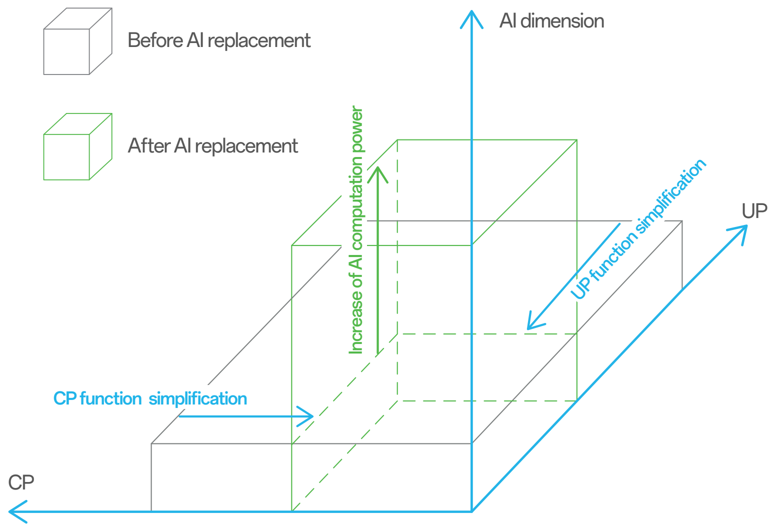

Figure 2-3: Replace some CP and UP functions with AI computation

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.

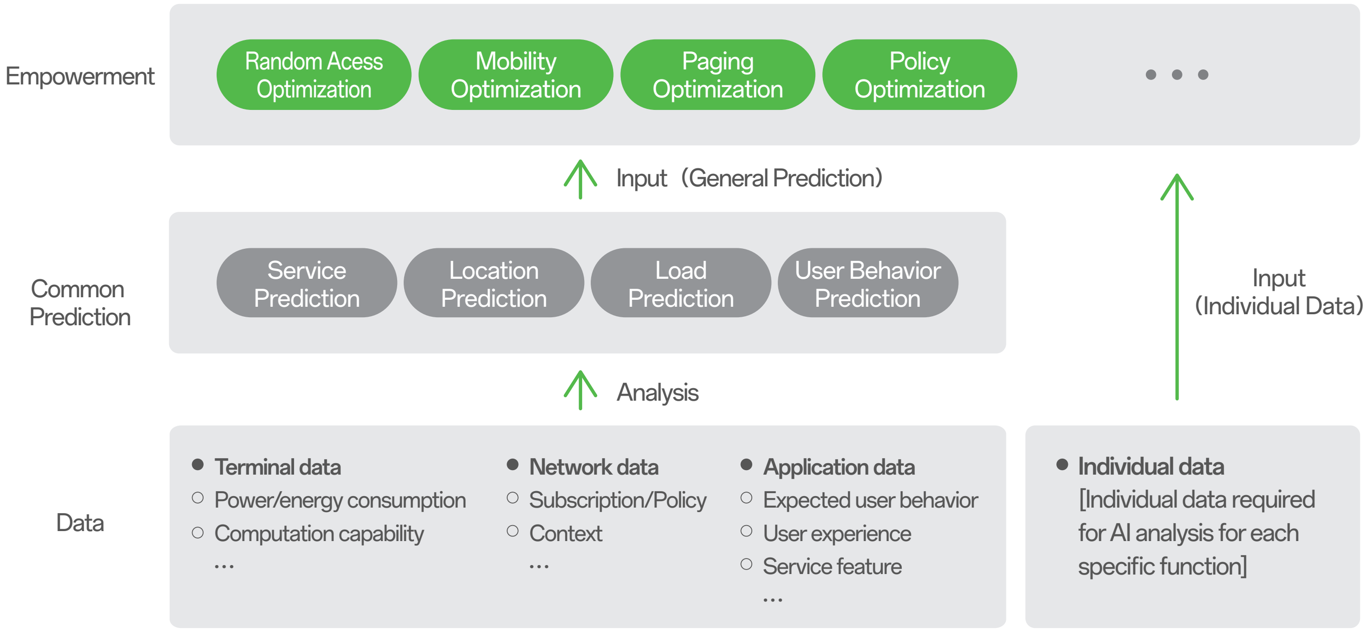

Figure 2-4 : Simplify CP functions through intelligent replacement

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 reasoning 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.

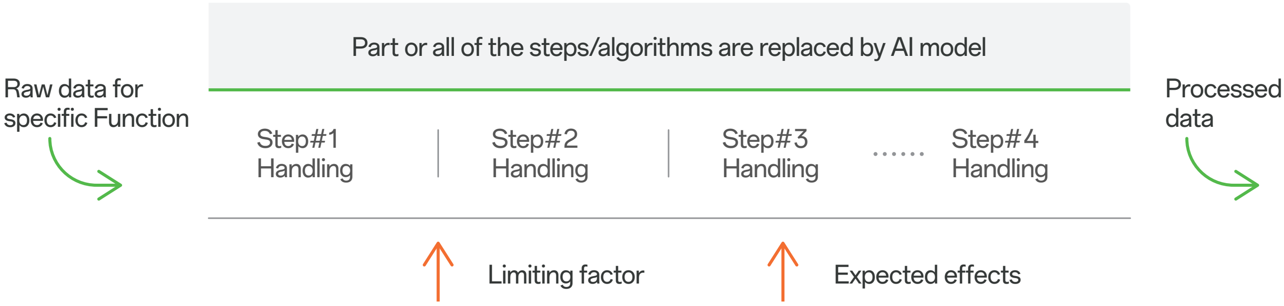

Figure 2-5 : Simplify UP functions through intelligent replacement

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, light-weight 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.

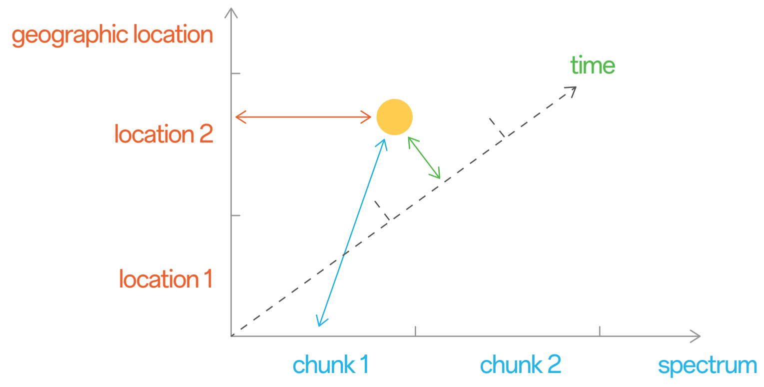

Figure 2-6 : License to spectrum utilization according to time, spectrum, geographic location

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.

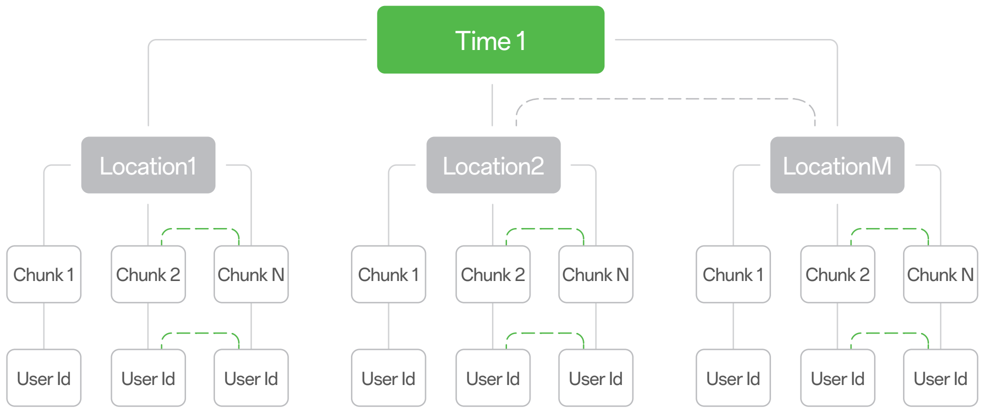

Figure 2-7 : Data structure for flexible spectrum sharing based on blockchain

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.

Minimal processing kernel of Minimized 6G kernel

2.4

In terms of 6G air interface processing, the Minimized kernel should provide a low-complexity and low-power "Minimal processing kernel". The Minimal processing kernel can provide the common parts of multiple subsystems. On the one hand, the 6G device designed for subsystem A does not need to provide the functions of subsystem B except for the "Minimal processing kernel", which can avoid unnecessary functional overlap between subsystems and minimize the complexity of each subsystem. On the other hand, the devices of a certain subsystem do not need to always work in the "full functional state" of the subsystem. When there is no service or only fundamental service, the system can fall back to the "Minimal processing kernel" and enter the "low functional state" with low-complexity and low-power.

If we consider the "full functional state" of a subsystem as a processing kernel, then this processing kernel can be regarded as a "Full processing kernel". **In this way, in a Versitile 6G system with Minimized kernel, the switching from the Minimized kernel to a subsystem can be achieved using the "Small kernel-to-big kernel" operation, as shown in Figure 2-8. The "Small kernel-to-big kernel" operation has the following characteristics:**

- **Different subsystems have different "Full processing kernels", and the equipments and devices of each subsystem work in the "complete processing core" when they need to work in the "full functional state";**
- **When an equipment of the subsystem can work in a "low functional state", it falls back to the "Minimal processing kernel". The Minimal processing kernel supports the most fundamental functions such as initial access, minimum control signaling, basic data types and basic measurement, and has the basic performance such as full coverage, basic data rate, and basic mobility;**
- **Support fast switching between "Minimum processing kernel" and "Full processing kernel".**

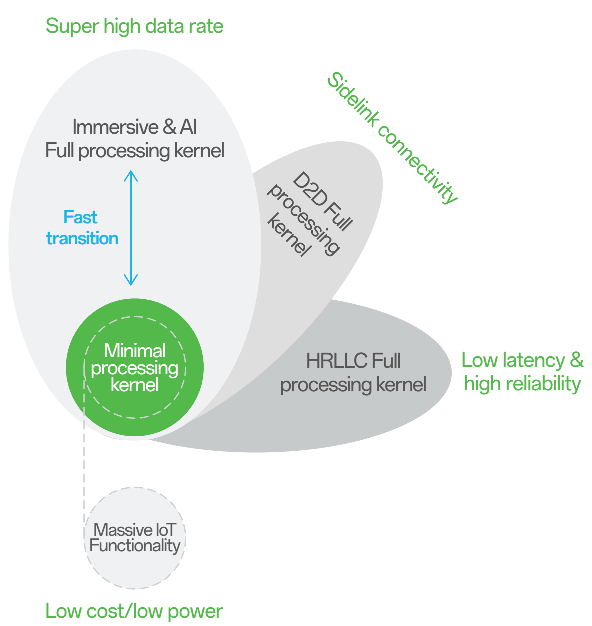

Figure 2-8: Achieving switching from the Minimized kernel to a subsystem with "Small kernel-to-big kernel" operation

Figures 2-8 shows examples of three "Full processing kernels" and the "Minimal Processing kernels": the "Immersive and AI" Full processing kernel, the D2D Full processing kernel, and the HRLLC Full processing kernel, while the Minimal processing kernel can cover the functionality of Massive IoT subsystems. Taking the switching between the "Immersive and AI" Full processing kernel and the Minimal processing kernel as an example, when the "Immersive and AI" device has two processing kernels, it can work on the "Immersive and AI" Full processing kernel when it has Immersive communication or high-speed AI service. When the device has no Immersive communication or high-speed AI service, it can quickly fall back to the Minimal processing kernel, and work in a “low functional state” to effectively save power consumption.

If we want to achieve such fast switching, we should effectively embed a Massive IoT subsystem into a Broadband cellular subsystem design from the beginning of 6G standardization, rather than as in 5G system design, first designing an all-in-one 5G system for eMBB and then doing functional tailoring for RedCap. By treating eMBB as a baseline of 5G, the minimum device capability defined in the first release of 5G NR was too high. Therefore, the functional tailoring based on 5G eMBB can never achieve the desired level of power saving and complexity reduction.

If supporting the Minimal processing kernel in the equipments of various subsystems from the beginning of 6G system design, we can achieve the subsystem aggregation by switching between the Full processing kernel of each subsystem and the Minimal processing kernel. For the "Small kernel-to-big kernel" operation, the key is to support the fast switching between "big kernel" and "small kernel". The switching procedure should consume as little energy and few steps as possible, and be integrated into the conventional procedure.

3.0 6G Broadband Cellular subsystem

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

KPI requirements of 6G Broadband Cellular

3.1

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, meanwhile to enable Mobile AI as a new service. mainly including:

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

We believe that the 6G broadband cellular subsystem should meet the requirements as shown in Figure 3-1.

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 broadband multimedia and Mobile AI services. For a small number of usage 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.

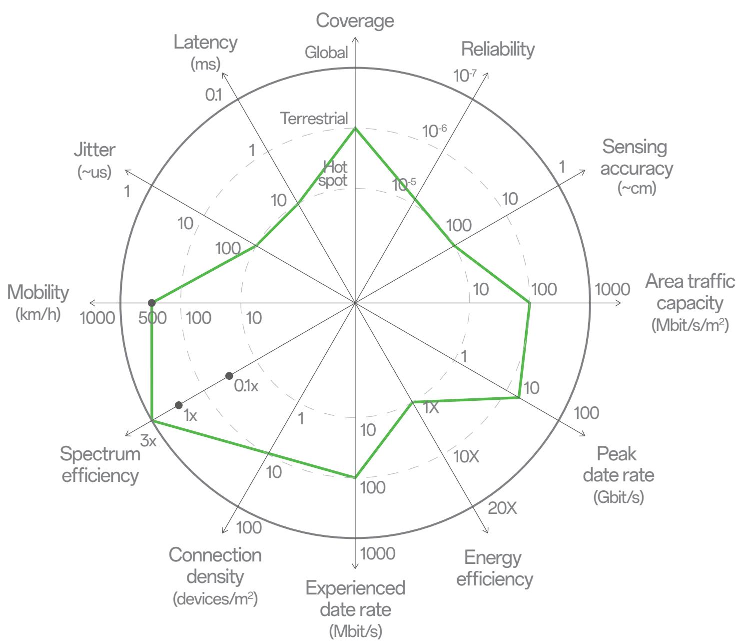

Figure 3-1: KPI requirements of 6G Broadband Cellular subsystem

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 HRLLC 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 HRLLC 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 in1.5 and 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, 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, technology trends, 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.

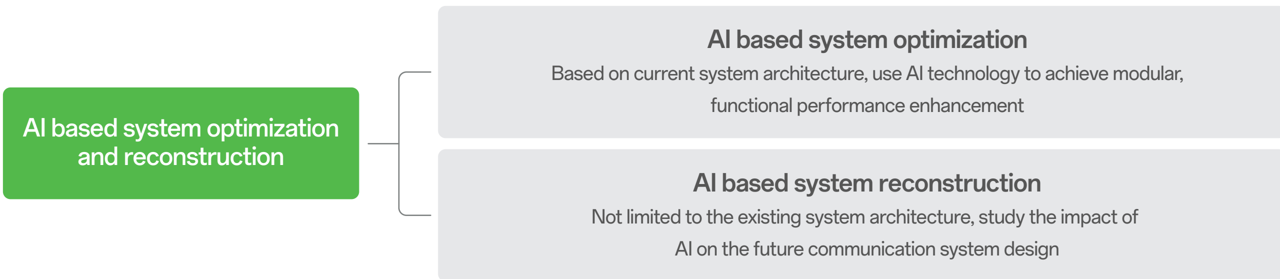

Figure 3-2: AI-based system optimization and AI based system reconstruction

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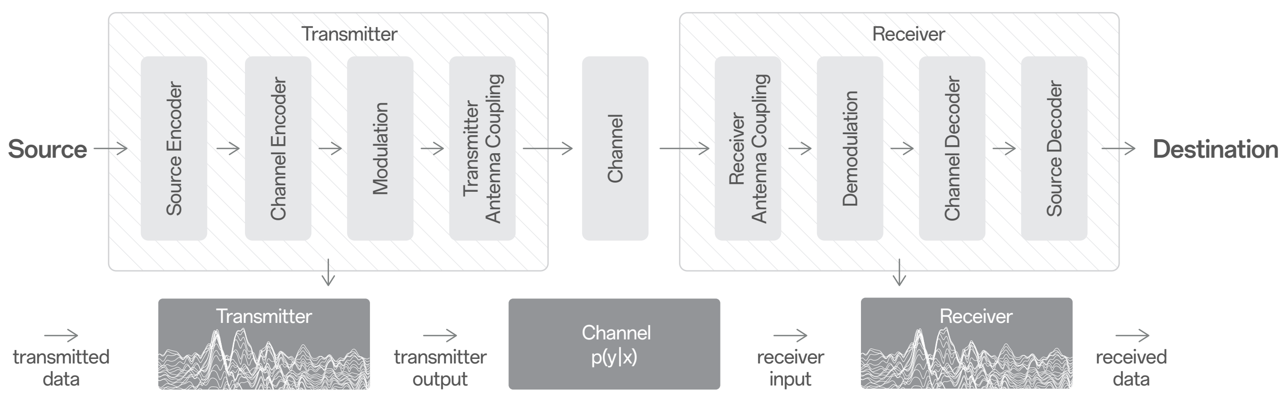
The intelligent 6G air interface consists of two levels, i.e. AI based system optimization and AI based system reconstruction. As shown in Figure 3-2, the intelligent optimization for wireless communication system will first improve the performance of a single module or a specific link relying on data 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.

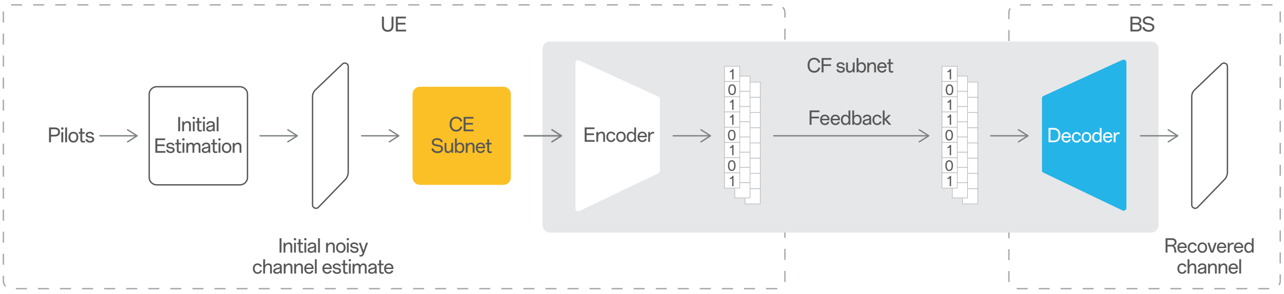
The research on the intelligent 6G air interface will not only do the repair and optimization evolution on the specific wireless use cases, but also carry out the in-depth analysis of the common basic problems of wireless AI from the perspective of system reconfiguration, including:

- **Integrated and systematic design,**
- **Novel air interface enabled by advanced AI receiver,**
- **Scenario adaptation and online updating,**
- **Intelligent data modeling and virtual data reconstruction.**

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

In the research of 6G AI, it is essential to leverage the core advantages that AI technology can offer. The development of AI technology has re-examined numerous complex problems that were previously difficult to solve. In the near future, the iteration speed of AI technology is expected to be much faster than that of traditional communication theory, potentially changing the relationship between communication transmission schemes and corresponding post-processing schemes. In traditional wireless communication systems, a significant shortcoming arises from the limited receiving algorithms and post-processing capabilities, often necessitating special pre-processing on the front-end (e.g., orthogonalization and linearization) to simplify the processing required on the back-end. Recently, with the assistance of AI technology, the effectiveness and efficiency of AI receivers in various tasks have been demonstrated. This makes it feasible to design a system with a powerful back-end and a simplified front-end. For instance, unnecessary orthogonalization and linearization pre-processing can be simplified to reduce system design complexity while maintaining or even further improving system performance through corresponding AI solutions. Currently, for some use cases studied in 3GPP (e.g., CSI and beam management), the introduction of AI solutions on the back-end has already reduced the system's dependence on pre-processing from the front-end transmitting. Looking ahead, the integration of advanced AI receivers is anticipated to have a further impact on front-end transmission simplification and back-end performance optimization in more fundamental communication issues such as pilot design, modulation, coding, waveform, etc,.

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 researchs and works. 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 scenario adaptation and online updating under small sample conditions

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.

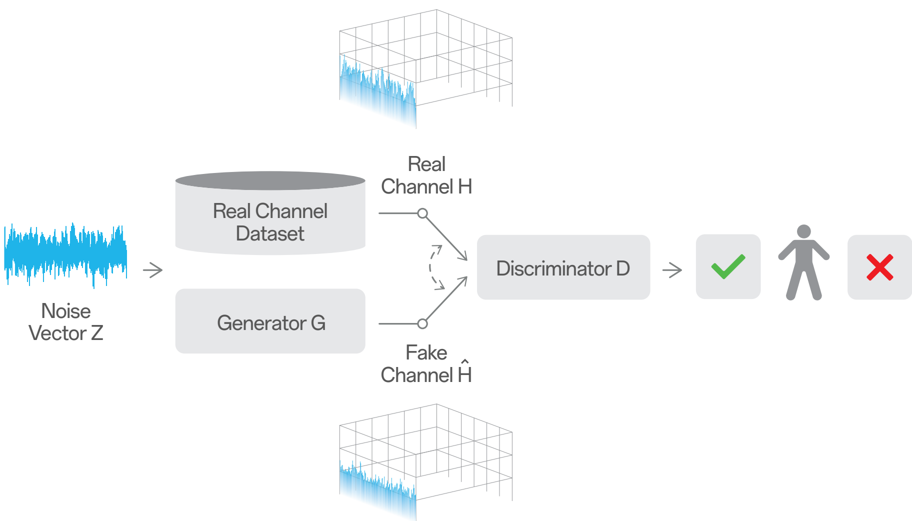


Figure 3-5: Intelligent channel modeling and virtual channel reconstruction.

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

KPI requirements of 6G D2D

4.1

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

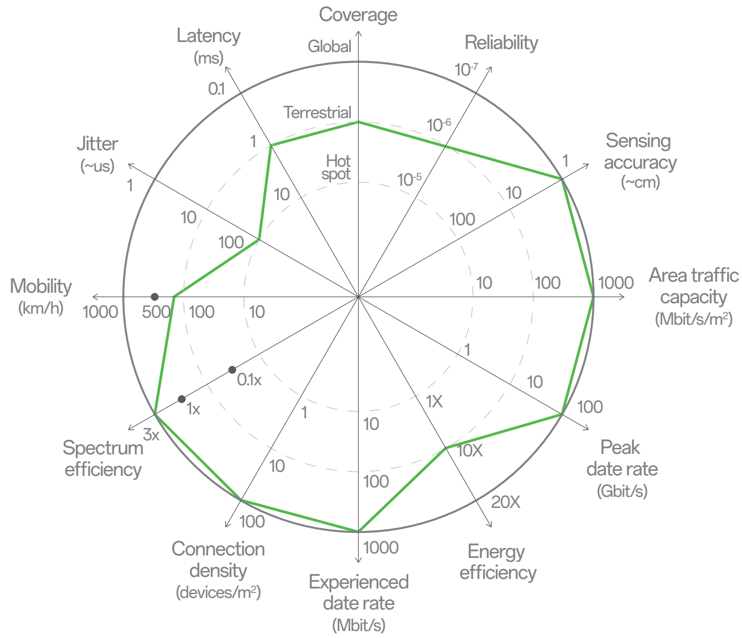


Figure 4-1 : KPI requirements of 6G D2D subsystem

Coverage:

The 6G system requires seamless coverage in Ubiquitous connectivity scenario. Howerver, in a 6G system using higher-frequency bands, the coverage range of 6G base stations will be limited and have out-of-coverage areas. Through D2D relay-based technology, coverage can be extended, allowing remote devices or devices outside cell coverage to connect to the network, and minimizing the out-of-coverage areas. In addition, through UE aggregation technology, multiple devices with low-capability can be connected to the network. This can actually extend the cell coverage and improve the transmission performance.

Peak rate and data rate:

The 6G system considers the transmission technology with higher frequency bands, such as mmWave, 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. mmWave, terahertz communication and visible light communication are more suitable for 6G D2D sub-system, 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 sub-system 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.
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 sensing 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

Device to Device (D2D) technology has many advantages, such as improving data rate, reducing latency, increasing energy and spectrum efficiency, and offloading from cellular networks. D2D communication will continue to play a key role in 6G network. **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 D2D subsystem can be applied in the scenarios such as coverage extension, Personal Access Network (PAN), smart home, V2X, Industrial Internet of Things (IIoT), sensing, positioning, etc.

- **D2D system for extending network coverage**

The 6G system is required to support ubiquitous connectivity covering Space-Air-Terrestrial-Sea, enabling all devices to be connected to the network (i.e. connect everything). On the other hand, in order to support a higher data rate, 6G system need to use higher frequency bands and larger bandwidth. However, the higher the frequency band, the smaller the network coverage. One way is to meet the demand for full coverage is to increase the number of sites. But this will greatly increase the cost of network deployment. In addition, in some special scenarios (such as underwater environment), it is also difficult to deploy base stations, making it difficult to achieve seamless coverage. By using D2D relay-based technology, more devices can be connected to the network, achieving the goal of extending network coverage and even seamless coverage. D2D relay technology includes U2U (UE to UE) relay and U2N (UE to network) relay, and supports single-hop and multi-hop relays, allowing devices located in remote areas or even outside cell coverage to connect to the network through U2U relay or U2N relay. The device can connect directly to the network or through a relay, thereby maintaining multiple connection paths with the network and improving the reliability of the connection.

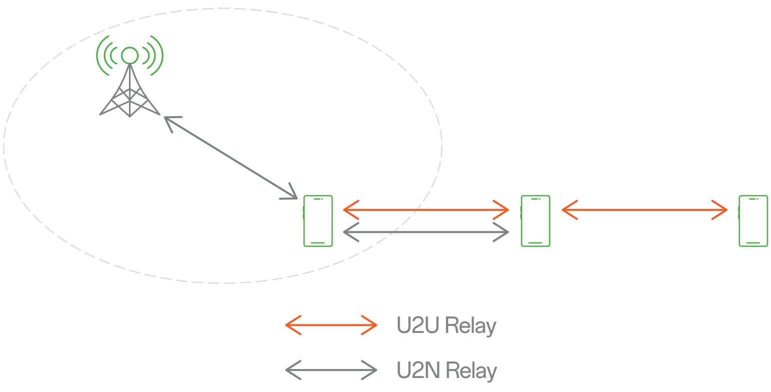


Figure 4-2： D2D subsystem for coverage extension

For some low-capability (Redcap) devices, due to their limited hardware capabilities and transmission power, it is difficult to connect to the network or have high transmission performance. By using UE aggregation to aggregate the capabilities of multiple terminals and transmit data to the network, transmission performance can be improved (e.g. increasing data rate, reducing transmission power, improving reliability, and reducing latency).

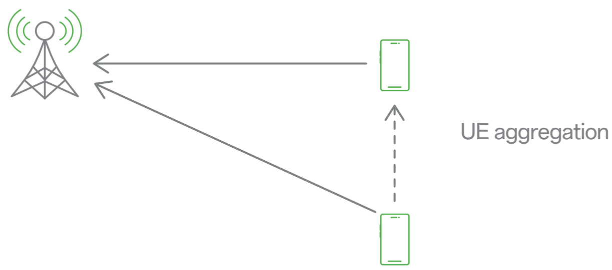


Figure 4-3： D2D subsystem for UE aggregation

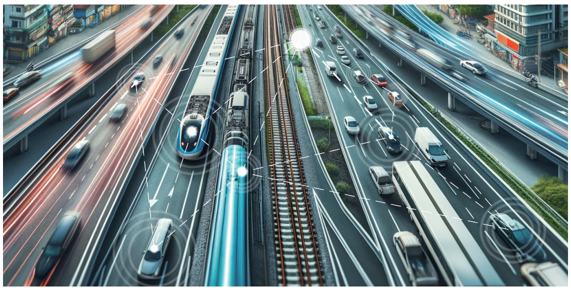
In order to allow more devices to connect to the network, a self-organizing network can be set up through multi-hop interconnection between devices, known as Mesh networks. The research topics of Mesh network include network discovery, routing and forwarding, and network maintenance. In future, intelligent devices may be in a fusion world of both physical and virtual, with a more complex surrounding environment. At the same time, they may be in a high-speed moving status. Therefore, intelligent devices in Mesh networks need to quickly join the network to establish communication connections, quickly make decisions to adapt to the fast-changeing environment, update and maintain the network topology, to maintain an efficient and stable communication operation. However, legacy 5G devices may not have such powerful prediction and decision-making capabilities. In 6G era, in an AI-empowered D2D subsystem, and intelligent devices serve as a node of edge cloud computing and distributed AI computing. Intelligent devices act as a center to leverage the powerful AI computing to implement the Mesh networking, helping Mesh network deploy in a wide range of usage scenarios.

- **D2D system for Internet of Vehicles**

6G system will be required to support autonomous driving, which brings challenging requirements on reliability, communication distance and data rate. With the rapid development of smart vehicles, the number of vehicles supporting autonomous driving will rapidly increase in the future. The emergence and development of technologies such as 3D display, holographic control display system, brain-computer interface, immersive entertainment, and in-car entertainment system have higher requirements to communication data rate, reliability and latency.

The major use case of 5G NR sidelink technology is Internet of Vehicles. With technical enhancements, D2D technology can also be used in 6G system to support autonomous driving and in-car communication. The enhancement over 5G D2D system can include the following aspects:

- **Higher data rate: Support higher frequency bands (FR2-1/FR2-2) and carrier aggregation technology;**
- **Higher reliability: Low er SCI payload design, transmission mode based on central scheduling, new QoS parameter design;**
- **Lower latency: Larger subcarrier spacing, resource granted prioritized processing;**
- **Inter-RAT scheduling: 5G D2D transmission scheduled by 6G Uu interface;**



(a) V2X communication

(b) In-car communication

Figure 4-4: D2D applications in Internet of Vehicles

- **D2D system for Industrial IoT (IIoT)**

In the IIoT scenario, direct communication between programmable logic controllers (PLCs) and sensors is required, or direct communication between multiple collaborative cargo handling robots [7], to meet the requirement of low-latency and high-reliability communication. Therefore, D2D-based direct connection is required in the IIoT scenario. In addition, in some IIoT scenarios, the devices need to support positioning function even outside the network coverage. Therefore, the D2D-based positioning is also an important feature for IIoT.

In the IIoT scenario, a combination of Wide Area Network (WAN) and Micro Area Network (MAN) can be used for networking:

- **WAN: Provide full coverage with and mobility management with network coverage**
- **MAN: Support low-latency, high-reliability and low-power communication based on D2D communication.**

In order to meet the requirements of low-latency and high-reliability IIoT communication, the D2D subsystem need to be enhanced accordingly, e.g., improving reliability, reducing latency, high-precision time synchronization mechanism, U2U/U2N relay group switching mechanism and sidelink-based positioning mechanism.

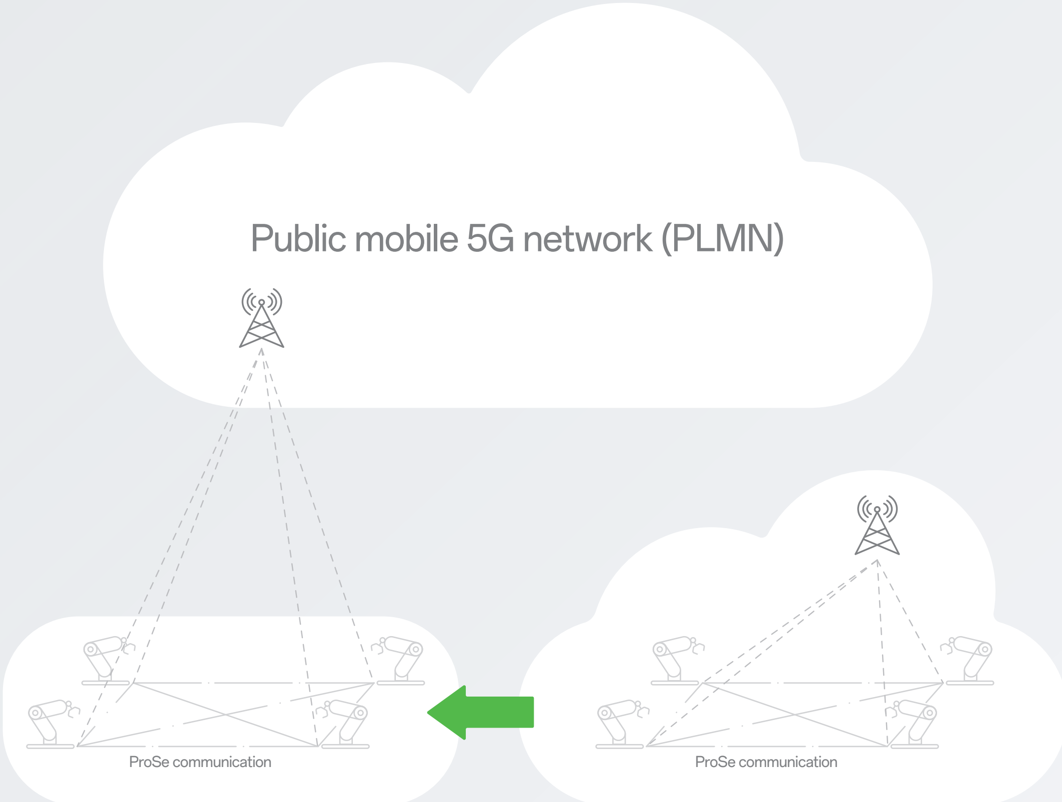


Figure 4-5： D2D subsystem for Internet of Vehicles

- **D2D system for sensing and positioning**

To meet the requirement of Mobile Metaverse, the 6G "Integrated sensing and communication" usage scenario would require an ubiquitous sensing capability, i.e., capturing environmental details of the physical world, and reconstructing the environment in the virtual world. For some indoor application scenarios, such as indoor intrusion detection, health detection, gesture recognition, mobile monitoring, parking space recognition, industrial Internet of Things, there is usually no or weak network coverage. In this case, device-based sensing and positioning is an attractive solution. The inter-device cooperation can be used to complete the sensing and positioning task of the surrounding environment. Therefore, device-based sensing or positioning capability is an important feature in 6G systems. Having communication, sensing and positioning functions at the same time will be the capability trend of 6G terminals.

The work modes for D2D-based sensing and positioning include:

- **Collaborative sensing and positioning between base stations and devices: The base station sends sensing signals. The device receives sensing signals, or vice versa;**

- **Device-based sensing and positioning: Mono-static (A device sends and receive the sensing signal) or bi-static (i.e., Device A sends the sensing signal and Device B receives the sensing signal).**

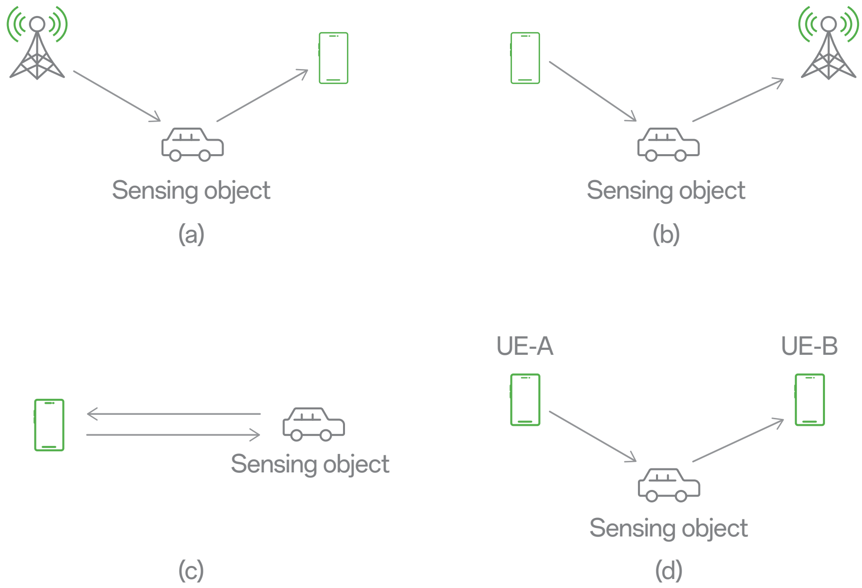


Figure 4-6： D2D subsystem for sensing and positioning

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

5.0 6G HRLLC subsystem

Low latency high reliability (URLLC) scenario is introduced by 5G, which 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 HRLLC subsystem will also become an important part of the 6G system. 5G URLLC has been initially supported in Rel-15, and is 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 HRLLC 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 usage scenarios and improve the competitiveness of 6G in the horizontal market.

KPI requirements of 6G HRLLC

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, and the performance of any business cannot be truly optimized. The 6G HRLLC subsystem should be optimized according to the needs of target services.

In order to satisfy the efficiency, precision and reliability requirements of industrial automation dynamic control, the delay needs to be 0.1ms, 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 10^6 devices/km2.

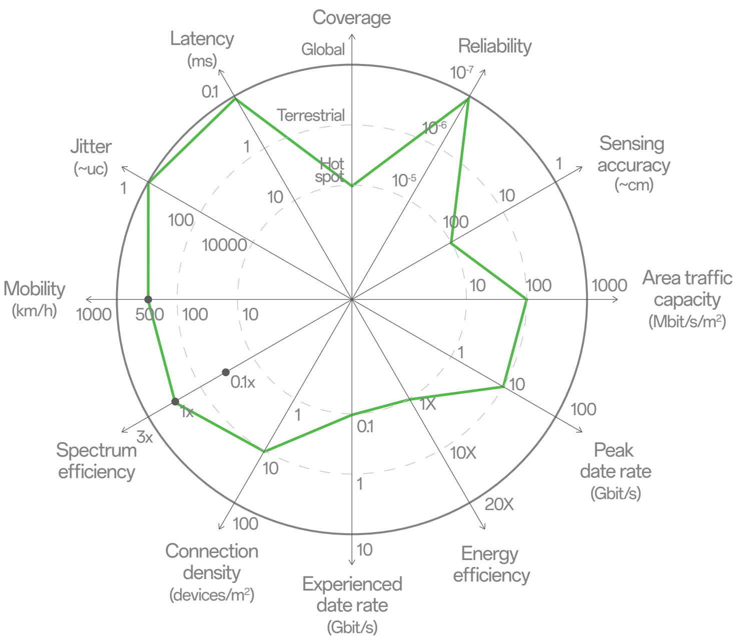


Figure 5-1: KPI for Service Target 1 of 6G HRLLC subsystem

Key technology and system design of 6G HRLLC

5.2

5G system supports diverse frequency bands, flexible slot structure, variable subcarrier spacings, beam sweeping and rich deployment scenarios, and the design of 5G system fully takes into account the above characteristics, as a result, the module of random access is complete, flexible but complicated. As mentioned in Chapter 1, to achieve the goal of "simplicity and versatility", 6G system aims to design multiple application scenario oriented subsystems, and hence for each subsystem, the module of random access can be designed more targeted rather than inclusive. 6G HRLLC subsystem can explore more deterministic design for random access, for example, during the cell search procedure, deterministic parameter set/restricted parameter set, e.g., restricted frequency points, simplified SSB, can be studied to lower the latency of cell search and RRM measurement. For the function of random access, the 2-step RACH in 5G system can be the starting point for design in order to reduce the synchronization latency. Meanwhile, it can be considered to eliminate redundancy in RRC configurations and only retain necessary parameters for RRC configuration to reduce complexity.

In order to satisfy the requirements of high reliability, low delay and high data rate, the 6G system will further explore to support 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 simultaneously, that is, different types of data can be transmitted simultaneously on independent channels, which can improve system efficiency.

For periodic services, a more simplified downlink control signaling transmission mechanism can be considered to achieve high efficiency and reliability while reducing blind decoding of downlink control channel. Additionally, DCI-level repetition can be considered to improve schuedling flexibility with high reliability.For a service with small payload, small data packet transmitted in downlink control channel is beneficial for reducing processing latency, improving system efficiency and reliability.

For a TDD carrier, the HARQ retransmission delay caused by TDD uplink and downlink configuration needs to be further reduced. In the 6G system, XDD can be widely used to provide more uplink and downlink transmission resources in the time domain to reduce scheduling, feedback, and retransmission delays. Furthermore, HARQ retransmission delay can be reduced by adopting cross-carrier retransmission of HARQ process or unified management of multi-carrier HARQ processes when carriers with different uplink and downlink configurations are aggregated.

In addition, **the 6G HRLLC 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 HRLLC 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.**

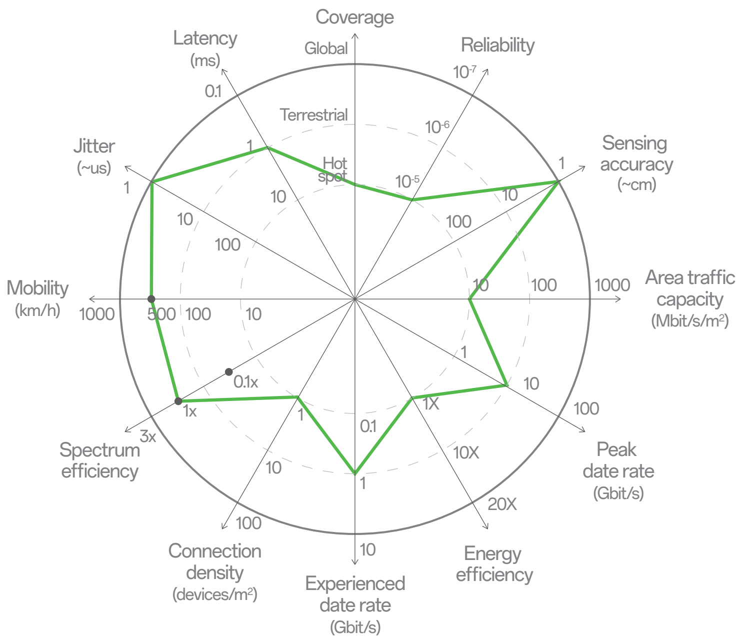


Figure 6-1: KPI requirements of 6G sensing system

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.

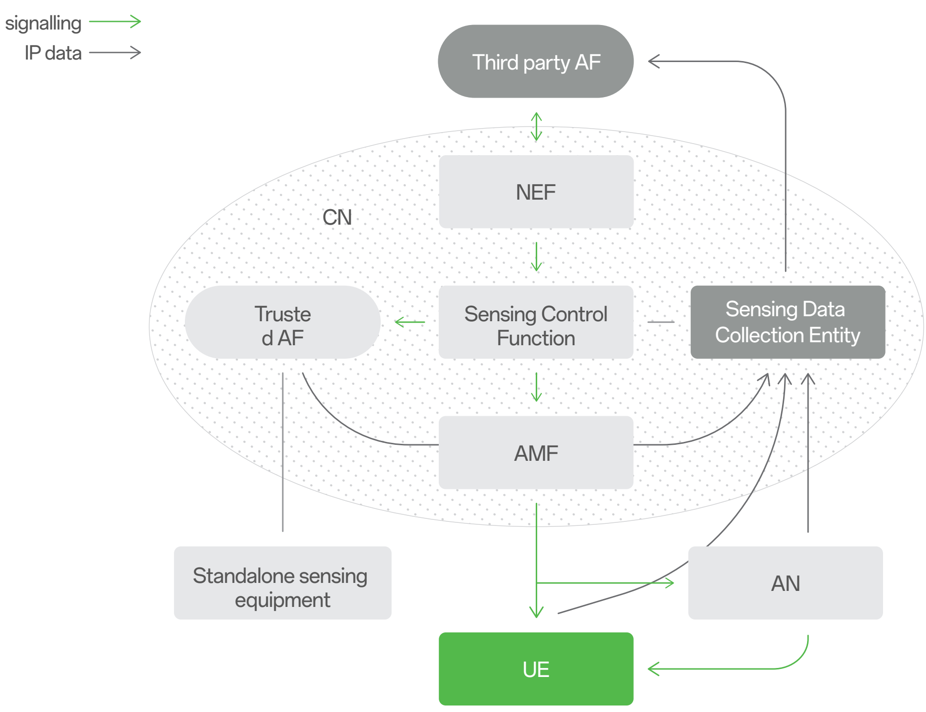


Figure 6-2 : Network architecture of Integrated Sensing and Communication

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 bandwidth,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.**

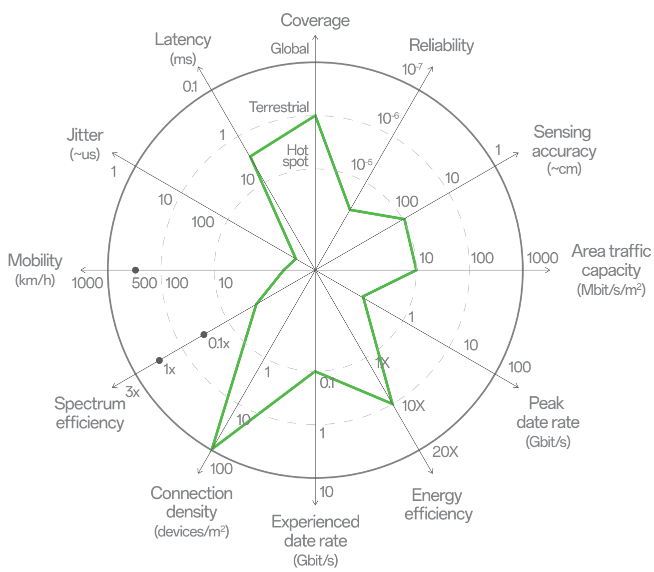


Figure 7-1: KPI requirements of 6G massive IoT subsystem

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.

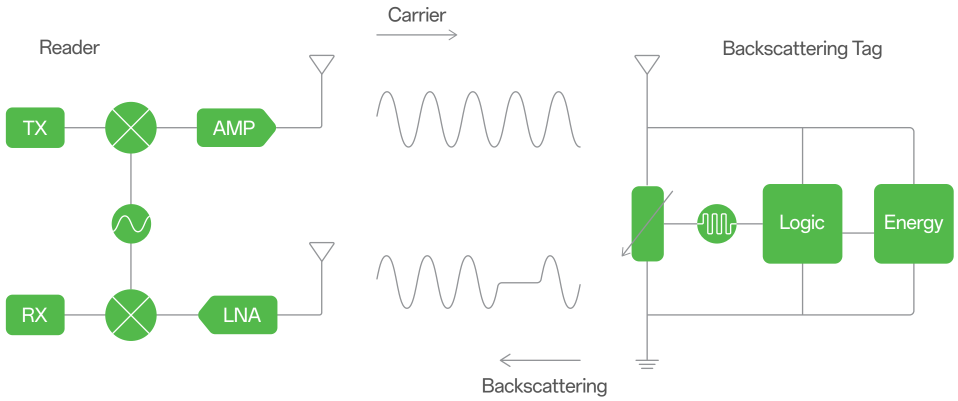


Figure 7-2: Backscattering communication technologie

- 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.

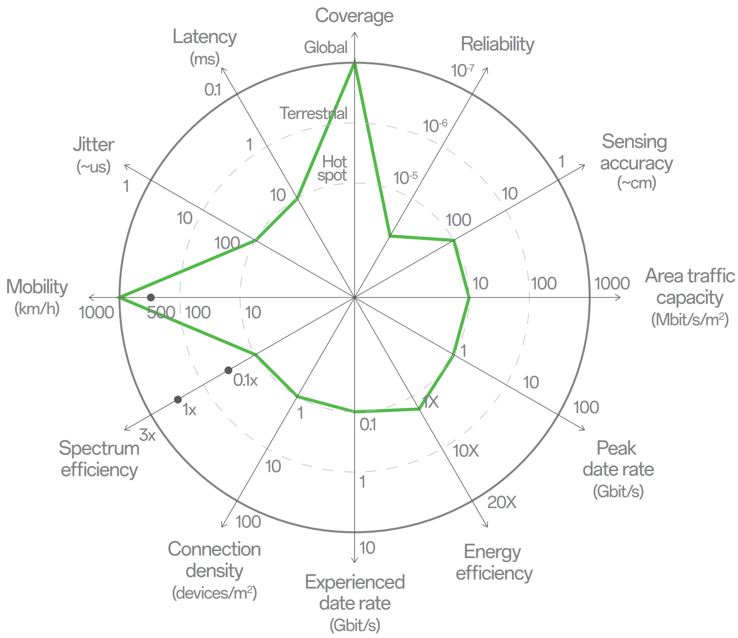


Figure 8-1: 6G NTN subsystem KPI

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.

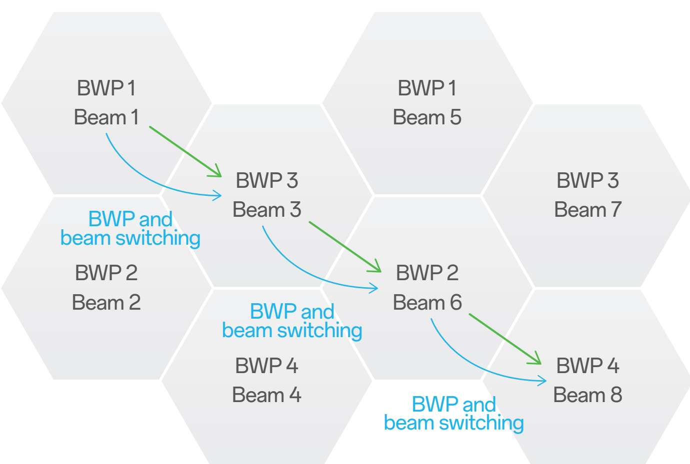


Figure 8-2: Beam management for 6G NTN

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.

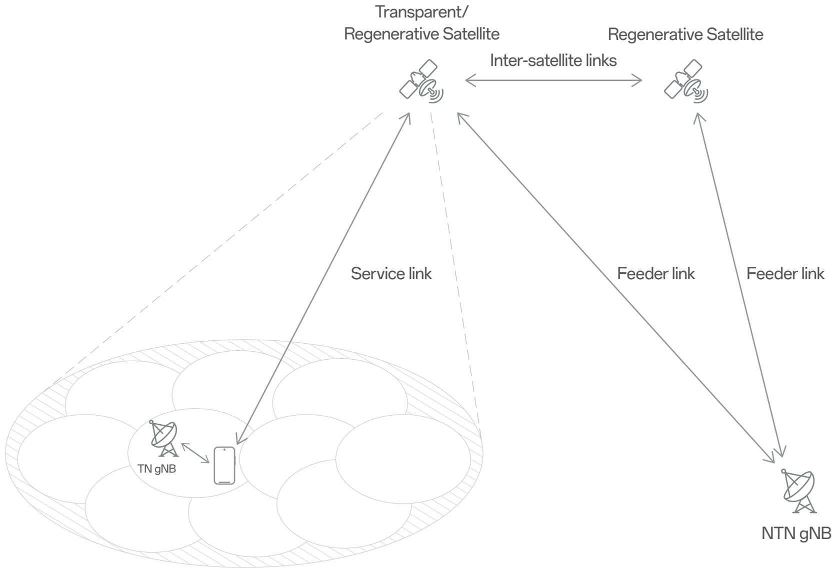


Figure 8-3: Dual connectivity between TN and 6G NTN

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.

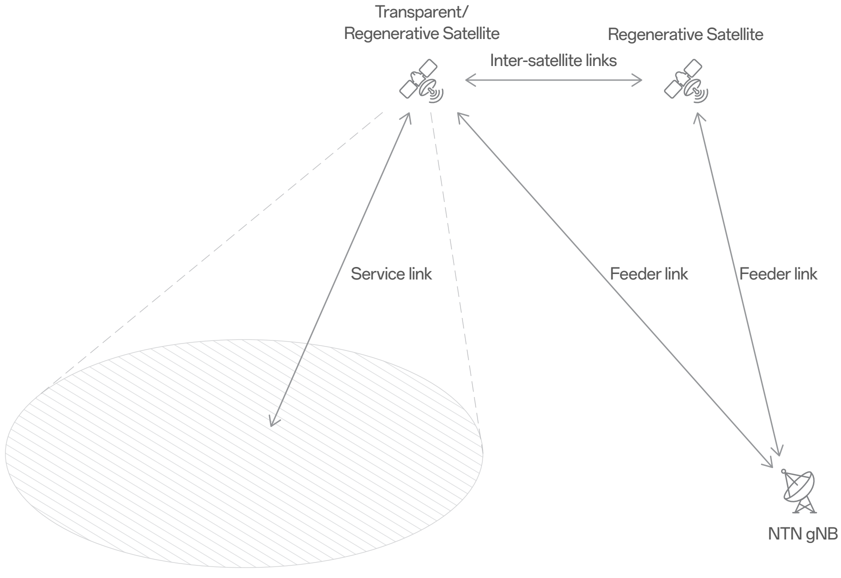


Figure 8-4: Regenerative payload for 6G NTN

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.

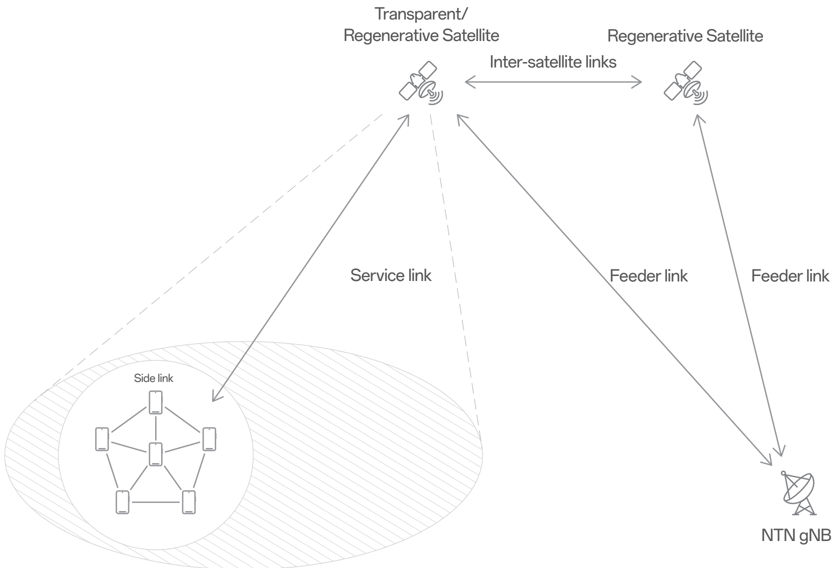


Figure 8-5: Combination of sidelink and 6G NTN

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 mission of 6G is, based on the experience and lessons learned from 5G, to completely achieve the industrial upgrading goal of becoming an infrastructure for inclusive intelligence and metaverse.
- Among the six usage scenarios defined in the IMT-2030 (6G) development framework, AI and Communication is expected to promote the popularization of mobile AI computing, achieve inclusive intelligence through AI computing networks and computing devices, and activate the first new billion-user-level market. The other five usage scenarios are expected to promote the construction of a mobile virtual digital environment, realize the interconnection and integration of the virtual and real worlds through the realization of consumer metaverse and industrial metaverse, and activate the second new billion-user-level market.
- And these two billion-user-level markets will mutually empower and promote each other: Mobile AI Computing can be seen as the brain of the Mobile Metaverse. The Mobile Metaverse can be seen as the body of Mobile AI Computing.
- The "Integrated of AI and Communication" usage scenario of 6G can effectively achieve split AI/ML inference and training, making 6G the key infrastructure of Mobile AI Computing, the emerging billion-user-level market. While promoting inclusive intelligence, it can achieve the third industrial upgrade and market return for communication industry.
- In the era of 6G, if humans are to control and manage the informatized world through AI agents. It is necessary to build a more complete virtual world better corresponding to the physical world. By controlling the digital twin of massive machines and things in the virtual world, we can control the machines and things in the physical world. Building a Metaverse is a feasible method to realize the virtual world.
- The other five usage scenarios of 6G can respectively achieve the three major steps of building a Metaverse: "Sensing the physical world and building a virtual world", "Controlling the physical world from the virtual world", and "Displaying the virtual and real worlds to users". At the same time, "Massive communication" and "Ubiquitous connectivity" serve as the two basic capabilities. The five usage scenarios will make 6G the key infrastructure of Mobile Metaverse, and achieve the third industrial upgrade and market return for communication industry.
- As the first billion-user-level market in 6G, Mobile AI poses a challenge in 6G system design: How to implement an efficient and cost-effective software and hardware design that can simultaneously meet the needs of 6G communication and AI computing on both network and device sides? "AI zation" will provide a feasible path.
- From the current perspective, fast AI-zation is a more reasonable route to achieve 6G Mobile AI. At the same time, the working mechanism of AI algorithm also objectively provides the possibility of fast AI-zation of 6G system.
- As the other billion-user-level market of 6G, the Mobile Metaverse will also bring challenges to the design of 6G system: How can a cost-controllable 6G system have market competitiveness in each of the five usage scenarios with vastly different requirements?

- 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.8ko
- In order to achieve "interconnection and convergence" between the physical world and the virtual world, further expand to the new usage scenarios, e.g., Integrated Sensing and Communication, Ubiquitous Connectivity, 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, flexible spectrum management and minimal processing kernel.

  ——Separate optimization is made for four different capabilities, including: Immersive communication and AI (optimized for high data rate), Massive communication and ubiquitous connectivity (optimized for coverage, low power consumption and low cost), HRLLC (optimized for low latency and high reliability), Sensing (optimized for sensing accuracy).

  ——One or multiple subsystems are designed for each capability. Key technologies can be selected independently according to usage scenarios, spectrum, topology, etc., and hardware and software can be designed separately for different subsystems. For example, it can be divided into: Broadband cellular, Broadband D2D, Cellular HRLLC, D2D HRLLC, Positioning & sensing, Massive IoT, Non-terrestrial networks (NTN), etc..

  ——Determine how much common air interface technology and design to share between Broadband cellular subsystem and other subsystems, respectively according to the specific requirements of the subsystems.

  ——Different subsystems can adopt different standard evolution cycles according to different market requirments, and may not all update the standard to new release every 15-18 months. Standardization can also output relatively independent specifications for some subsystems, making the 6G specifications more friendly and readable for vertical industries.

  ——The 6G system achieves flexible, low-cost, and low-power support for multiple subsystems by fast switching between the "Minimal processing kernel" in the minimized kernel and the "Complete processing core" of each subsystem.

- For a 6G system that requires support for multiple usage scenarios, the functionality of multiple subsystems can be simultaneously implemented through subsystem aggregation.
- 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.

- AI-zation 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, transmission, activation, selection, switching, configuration and reasoning.
- 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 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 block-chain technology.
- In a Versitile 6G system with Minimized kernel, the switching from the Minimized kernel to a subsystem can be achieved using the "Small kernel-to-big kernel" operation, as shown in Figure 2-8. The "Small kernel-to-big kernel" operation has the following characteristics:

  ——Different subsystems have different "Full processing kernels", and the equipments and devices of each subsystem work in the "complete processing core" when they need to work in the "full functional state";

  ——When an equipment of the subsystem can work in a "low functional state", it falls back to the "Minimal processing kernel". The Minimal processing kernel supports the most fundamental functions such as initial access, minimum control signaling, basic data types and basic measurement, and has the basic performance such as full coverage, basic data rate, and basic mobility;

  ——Support fast switching between "Minimum processing kernel" and "Full processing kernel".

- 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.
- 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 design,

  ——Empowered backend and simplified frontend design,

  ——Scenario adaptation and online updating,

  ——Intelligent data modeling and virtual data 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. The 6G D2D subsystem can be applied in the following scenarios:

  ——D2D system for extending network coverage

  ——D2D system for Internet of Vehicles

  ——D2D system for Industrial IoT (IIoT)

  ——D2D system for sensing and positioning

- The 6G HRLLC subsystem should be optimized according to the needs of target services.
- The 6G HRLLC 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.

- 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 HRLLC 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 usage 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, due to the fact that D2D will play a more important role in 6G system than in 5G system, it should be considered that D2D mode is specified from the first release of 6G, at least including the broadband D2D subsystem and D2D mode of the positioning and sensing subsystem.

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