GTI
5G + Proximity Network White Paper

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1 Executive Summary

The proximity network, as the last "100 meters solution" between field network and equipment in industries, is the foundation of low-latency transmission, high-precision indoor positioning, and high-reliability local communication system. It is an important component of private network, moreover, a core technology that support digitalization of future industrial applications. In this white paper, we will introduces the understanding and recognition of future industrial proximity network from China Mobile perspective, and propose the comprehensive suggestions of future industrial proximity network based on the research of market, industry, and technology requirement.

2 Abbreviations

Abbreviation	Explanation
2B	To Business
5G	The Fifth-Generation
AFH	Adaptive Frequency Hopping
AGV	Automated Guided Vehicle
AoA	Angle of Arrival
BBU	Building Base band Unite
BIM	Building Information Modeling
CIG	Connected Isochronous Groups
CNC	Computerized Numerical Control
DEM	Digital Elevation Model
DOM	Digital Elevation Model
DTU	Distribution Terminal Unit
eMTC	LTE enhanced MTO
GIS	Geographic Information System
HSS	Home Subscriber Server
IT	Internet Technology
LEPC	low energy power control
LoRa	Long Range Radio
LPWA	Low Power Wide Area
mMTC	Massive Machine Type of Communication
MU-MIMO	Multi-User Multiple-Input Multiple-Output
NB-IoT	Narrow Band Internet of Things
NFV	Network Functions Virtualization
OFDMA	Orthogonal Frequency Division Multiple Access
O&M	Operation and Maintenance
OPC UA	OPC Unified Architecture
OSGB	Open Scene Graph Binary file
OT	Operation Technology
OTA	Over The Air
PDCCH	Physical Downlink Control Channel
PLC	Programmable Logic Controller
pRRU	Pico Remote Radio Unit

QoS	Quality of Service
RFID	Radio Frequency Identification
RSRP	Reference Signal Receiving Power
RSSI	Received Signal Strength Indication
RTU	Remote Terminal Unit
SINR	Signal to Interference plus Noise Ratio
SLA	Service Level Agreement
TDoA	Time difference of Arrival
ToF	Time of flight
TSN	Time Sensitive Network
TWT	Target Wake Time
UPF	User Plane Function
uRLLC	Ultra Reliable Low Latency Communication
UFS	Unified Frame Structure
UWB	Ultra-Wide Band
Wi-Fi6	Wi-Fi6，IEEE 802.11.ax
GPS	Global Navigation Satellite System
GNSS	Global Positioning System

3 References

The following documents contain provisions which, through reference in this text, also constitute provisions of the present document.

[1] EPC Radio-Frequency Identity Protocols Class-1 Generation-2 UHF RFID Protocol for Communications at 860 MHz -960 MHz, EPCGlobal, 2006.06

[2] Theory of Operation for TSN-enabled Systems, AVnu Alliance, Tech. Rep., 2017.02

[3] White paper: TSN - Time Sensitive Networking, Belden, Tech. Rep., 2017.02

[4] 3GPP.3GPP TS 23.501: System architecture for the 5G System Stage 2[S]，2017.

[5] 3GPP.3GPP TR 23.734: Study on 5GS Enhanced support of Vertical and LAN Services[R], 2017.

[6] White Paper on 5G+Industrial Internet Application Scenarios, China Mobile, 2019.12

[7] Industrial Internet Campus Network White Paper, AII, 2019.

4 Introduction of Industry Proximity network

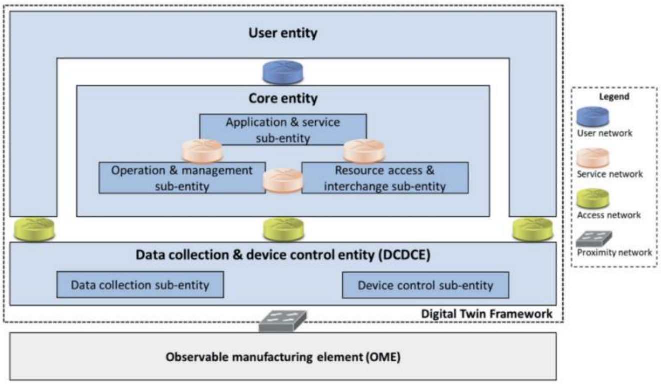
4.1 Characteristics and Features

According to the definition of ISO 23247，the industrial proximity network is a general term for the network access technology of the end-side(of end-edge-cloud framework)equipment. The industrial proximity network connects various terminals, machines, sensors, actuators, and systems of the end-side in order to fulfill diverse requirements of industry, such as sensing, data collecting, positioning, control, and management.

Common industry proximity network technologies include industrial Ethernet (EtherNet/IP, ProfiNet, EtherCAT, etc.), fieldbus (ProfiBus, CC-Link, CAN, etc.), short-range communication technologies such as Wi-Fi, Bluetooth, ZigBee, and narrowband Internet of Things (Narrow Band Internet of Things, NB-IoT), Long Range Radio (LoRa), SigFox and other low-power wide area network communication technologies, as well as Time Sensitive Network (TSN), millimeter wave, passive

Communication technologies such as Radio Frequency Identification (RFID) and Ultra-Wide Band (UWB).

Figure 4-1 Industry proximity network framewotk.(ISO 23247)



4.2 Background

With the global commercialization of 5G technology and rapid development of smart manufacturing, the industry proximity network is facing unprecedented market demand, which also led to technological innovations of industry proximity network.

The development of Industry 4.0 and industrial internet further increase the necessity and urgency of industry proximity network. Intellectualization creating intelligent applications such as equipment data collection, equipment remote control, equipment health prognostics and management, machine vision surface defect inspection, smart robot sortation and packaging, AGV， and remote AR assistant system. Those applications make high requirement for sensing, data, positioning, control, and management. In addition, the special scenarios of different industries, such as network coverage, data transmission, and massive device connection in undermine, nuclear plant, or refinery also requires new capabilities of network.

Unlike 4G technology, To Business (2B) is the main application scenario of 5G technology. The characteristics of large bandwidth, low latency, and large connection of 5G realize the rapid transmission of industrial data and cloud service, and further enable on-site production management, supply chains, collaboration between enterprises, customization, and extend services to become implementable. This also requires that the industry site must break the previous "black box" status, in order to make the equipment, machine and systems become more transparent and intelligent, a powerful and varied network technology is needed.

4.3 Demand and Value Orientation

The development of industry proximity network technology needs to consider the " reusability " of existing systems and equipment in the industry field. In the existing industry field, the equipment communicates with each other through industrial Ethernet, fieldbus, WLAN, Bluetooth, etc., but the traditional industrial equipment has a high degree of specialization, thus the cost of network transformation is high, the enterprises are more sensitive to the benefit and cost, it is nearly impossible to completely abandon the current systems and technologies. The evolution of proximity network technology must be gradually improved based on the existing technology.

From the perspective of typical business applications of intelligent manufacturing and industrial Internet, there is an urgent need for technologies such as deterministic data transmission, extensive equipment information collection, high-precision indoor positioning, high-rate data upload, and massive device connections. For instance, the production remote control requires transmission latency of 1-10ms, the machine vision requires more than 500Mbps bandwidth, the AGV navigation or robotic arm control accuracy is expected to be centimeter level accuracy, and the number of sensors connected at the same time in the factory could be tens of thousands. These application scenarios are key requirements and difficult problems in industrial Internet, and they have also become the first problems that need to be solved in the current industry proximity network technology.

As a cellular mobile communication technology, 5G has the typical characteristics of high speed, large bandwidth, and wide coverage. It can transmit data at a long distance and at a high speed,5G can realize data cloudification, and intelligent coordination between each industrial chain, thus provide high-performance, high-reliability, high-flexibility, and high-security network services for network access and transmission.

According to the current technical status of intelligent manufacturing and the industrial Internet, 5G can be combined with industry proximity networks to reinforce complementary advantages. 5G can be applied to bridge heterogeneous networks in various industry sites, thus create an integrated industry proximity network that integrates short-range, passive RFID, TSN, millimeter wave, positioning, and other technologies to support enterprises "dumb equipment". Therefore, the industry proximity network can carries out network interconnection transformation, supports multiple industrial data collection, promotes the coexistence of multiple networks, improves the interoperability of heterogeneous industrial networks, lowers the technical threshold of network wireless transformation, and develops a 5G+industrial proximity network solution close to the industry field.

4.4 Global Development and Current Situation

Low latency, high reliability, high-precision positioning, low power consumption, anti-interference, and other similar issues are urgent demand of current industry field. In order to solve those problems, technologies such as advanced passive communication, short-distance communication, deterministic network, high-precision indoor positioning have become hop topic of the industrial proximity network technology.

- **Advanced Passive IoT**

RFID technology identifies specific targets through radio signals without mechanical or optical contact, and it currently widely used in warehousing logistics, asset inventory, and intelligent inspection. The RFID industry chain is mainly composed of chip design, tag packaging, reader design and manufacturing, system integration, middleware, and application software. At present, the RFID industry is mainly concentrated in the European and American markets where RFID technology applications are relatively mature. Semiconductor manufacturers such as Philips, Siemens, ST, and TI are monopolizing the RFID chip market; giant companies such as IBM, HP, Microsoft, SAP, Sybase, and Sun occupy the position of RFID middleware and system integration; Alien, Intermec, Symbol, Transcore , Matrics, Impinj and other companies provide RFID tags, antennas, readers and other products and equipment. The development trend of RFID reader design and manufacture is multifunctional, multi-interface, modular, miniaturized, portable, and embedded.

New passive RFID technology are focusing on the research of RFID function separation between read and write, it could solve the problem of complex interference cancellation and short communication distance, therefore reduce the complexity and cost of RFID readers, and dramatically increase the communication distance, and realize the combination of passive RFID and 5G Net coverage.

- **Deterministic Network**

The deterministic communication is widely needed in the industry, and the integration of 5G technology and deterministic network technology has become a research hotspot in the industry. In order to fulfill the requirements of Ultra Reliable Low Latency Communication (uRLLC) scenarios, 3GPP defines 5G technology in R15 stage using 5QI as the basic framework to support flexible frame structures and smaller scheduling. Periodic Mini-Slot, flexible physical downlink control channel (Physical Downlink Control Channel, PDCCH) configuration and edge computing technology to sink the user plane function (User Plane Function, UPF) to the user side; in the R16 stage, 3GPP further proposes a low-latency enhancement solution for uRLLC, which uses uplink authorization-free configuration, HARQ feedback enhancement, and supports time-sensitive network TSN and 5G network docking.

Time Sensitive Network (TSN) is a real-time Ethernet standard based on IEEE 802.1. It can ensure that information moves from one point to another within a fixed and predictable time. It has feathers of low jitter, low latency, and deterministic transmission, which can meet the application scenarios with higher requirements for transmission reliability and delay.

5G+TSN can solve the deterministic unified communication problem of the network transmission layer, and can replace or extend the wired network in the factory through 5G NR wireless, making industrial production more flexible.

At the beginning of the R17 phase, 3GPP has begun to define that 5G systems can be deployed independently to achieve deterministic communication without external TSN networks. This will further enhance the flexibility and applicability of independent deployment of 5G in industry proximity networks. 5G will continue to improve the ability of deterministic networks in independent deployment scenarios.

The new generation OPC Unified Architecture (OPC UA) standard launched by the OPC Foundation unifies the interoperability interface of the industrial protocol layer, which can solve the problem of interconnection and intercommunication of the industrial protocol at the business layer and the semantic layer, and further improve the interoperability between devices. The integration of 5G and TSN and OPC UA can enable intercommunication from communication to application, which has become an industry research hotspot.

- **High Precision Positioning**

High-precision indoor positioning technology has a wide range of application requirements in employee management, asset supervision, remote monitoring, and machine navigation. Nowadays, Bluetooth and UWB-based positioning technology are more widely used. Bluetooth positioning generally uses the triangulation method. Three Beacon devices can enable the calculation of the accurate position. UWB positioning uses anchor nodes and bridge nodes with known positions to communicate with newly added blind nodes, and uses triangulation or "RSSI fingerprinting" methods to determine the position. UWB positioning accuracy can reach 0.1m-0.5m.

5 Industry Proximity Network Technology

5.1 Architecture

While 5G is broadly empowering conventional industries, it also proposes higher requirements for network capacity, latency, positioning, and reliability. 5G needs to be combined with industry on-site networks that connect industry businesses and applications. Play a greater role and value in the industry scenario.

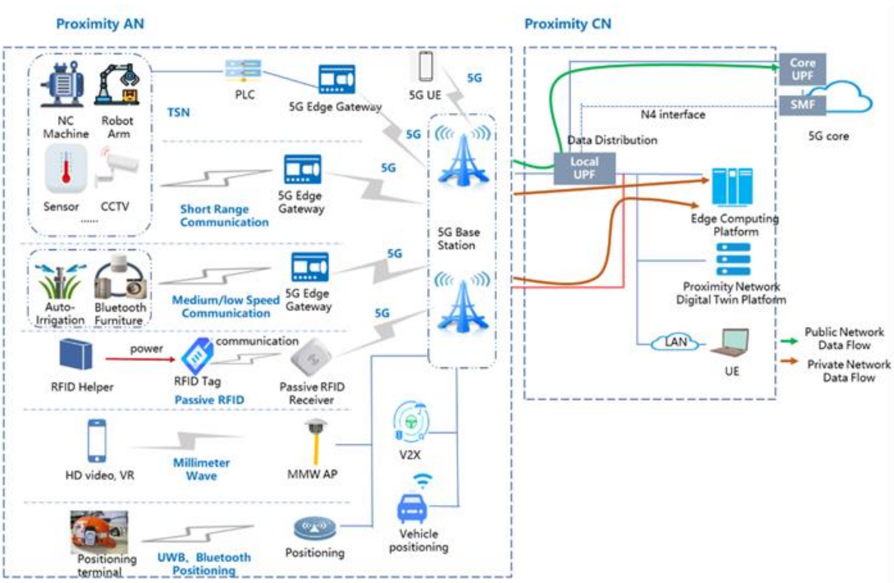
The industry proximity network includes two parts: the industry proximity access network and the industry proximity core network. The industry field access network can bridge heterogeneous industry proximity networks, such as passive communication, short-distance communication, Bluetooth, TSN, etc. The industry proximity core network mainly refers to the UPF deployed on the edge of the industry field, which performs data distribution and enable proximity network management of the industry field.

The industry proximity access network has five core technologies, including 5G+ deterministic network technology, 5G+short-range communication, 5G+ advanced passive communication, 5G+UWB/Bluetooth high-precision positioning. Among them, 5G+ advanced passive communication adopts a system architecture that separates read and write. Tag powered by radio frequency, and both control command and information reply through 5G network, which improves the performance of RFID networking and realizes high reliability of information; 5G+short-range communication is based on a new wireless radio design, it can meet the needs of ultra-low latency, high reliability, precise synchronization, high concurrency, high efficiency and high security while achieving peer-to-peer communication; 5G+ deterministic network has both the advantages of deterministic network and 5G, while meeting the requirements of high reliability and deterministic in communication, it also solves the problem of on-site wiring; 5G+UWB/Bluetooth high-precision positioning can guarantee large bandwidth, low latency, and wide connectivity, in addition, it solves the problems of low accuracy of traditional positioning and poor adaptability to the environment, and meets the needs of high-precision positioning in scenarios such as synchronous collaboration between equipment.

The industry proximity core network deploys UPF network unit on the edge of the industry field to perform distribution and local processing of local data to meet the needs of industry manufacturing such as ultra-low latency. The service perception capability based on the core network UPF can further enhance the service scheduling efficiency of the UPF and on-site access network. In addition, 3GPP has defined the 5G-LAN networking function in R16, which can support the layer2 networking of the industry proximity network through the core network without the need for additional gateway.

In addition to the requirements of on-site network integration and data localization, industry users also makes higher requirements for the O&M of complex network systems. The industrial scenes are complex, which coexist heterogeneous networks. Traditional network management and agent maintenance teams cannot meet the needs of industry network operation, maintenance and management. Digital twin-based network services in the industry proximity network technology can realize network visibility, manageability, and control through information modeling, intelligent O&M, and digital twin proximity network service platforms, reduce field O&M costs, and improve industry proximity network Service efficiency.

Fig 5-1 5G + proximity network architecture



5.2 Advanced Passive IoT

- **Concept**

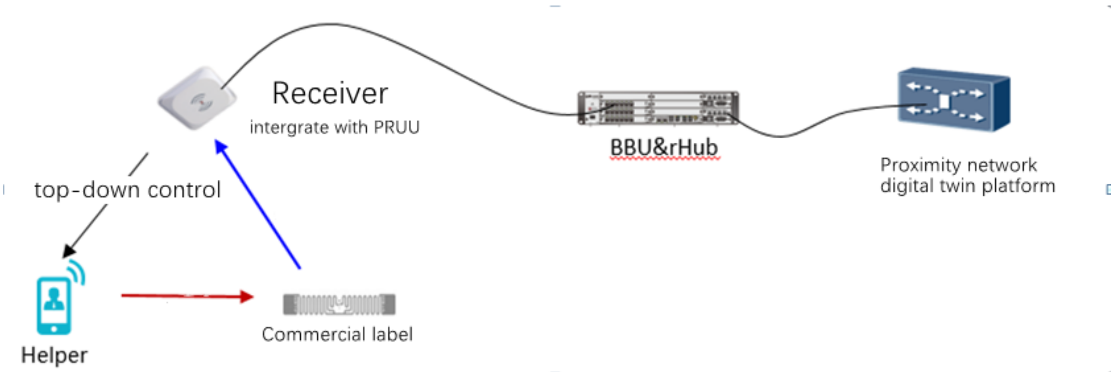
Most factories demand for regular inventory of assets, but current management methods are still based on man power. A few companies try to use RFID for inventory, such as automatic inventory in the warehouse, but the actual reading performance is poor and cannot be used on a large scale.

The basic idea of the new passive communication innovation scheme is to separate the conventional RFID integration framework into independent read and write,improve the performance of RFID networking, and achieve high-reliability reading in industrial scenarios. This solution has two features: the tag can still be commercial RFID tags, which can quickly deploy into commercial implementation in the industry; the network uses cellular 5G uplink and downlink decoupling, multiple antennas and other innovative ideas to improve traditional RFID networking performance.

- **Architecture and key technologies**

Traditional RFID readers integrate read and write together, thus the communication distance is short and the cost is high due to the interference cancellation. Distributed RFID separates tag read and write, avoids complex interference cancellation, which can reduce Helper costs, and improve Receiver's reading performance.

Figure 5-2 Advanced Passive IoT architecture



The separation RFID architecture innovation program has been systematically tested and verified in automobile factories and logistics warehouses, it satisfies all industrial requirement such as accurate inventory, fast transmission, and accurate positioning. By integrate with MIMO technology and multi-Helper collaboration framework, it can achieve 99.99% reading success rate in warehouse management. For the scene of multiple passage in the warehouse, one Receiver can carry multiple Helpers, and the detection accuracy of asset moving direction can be achieved by 99% through the time sequence relationship of the tags being activated by the Helper. And because Receiver can coordinate management and scheduling of multiple Helpers,, there is no need to install screen doors at the entrance and exit crossings, and it can also effectively solve the problem of label information cross-reading between multiple crossings.

- **Separated Architecture of RFID**

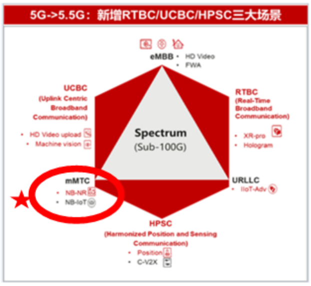
The new passive communication architecture can be well integrated with indoor small cellular base stations. After separation, the receiver's receiving sensitivity can reach -105dBm, and the actual test distance in the factory indoor scene is 20-30 meters, which is equivalent to the coverage of small cellular base stations. Receiver is integrated with remote radio unit (Pico Remote Radio Unit, pRRU) on the hardware, this integration provides pRRU transmission resources to reduce the cost of enterprise network deployment.

- **Future Development**

The future development direction of new passive communication move from indoor to outdoor, enabling outdoor base stations to perform passive IoT capabilities, becoming the next hope of 5G Massive Machine Type of Communication (mMTC). The key challenges of passive communication is to break through the long-distance communication. If the distance can be more than 100 meters, and integrate with the temperature and humidity sensing, passive communication could be a comprehensive solution for various industry.

The implementation of long-distance passive communication requires the design of a new type of passive tag. Compared with NB-IOT, the biggest feature of the new type passive tag is battery-free, and the cost is also an order of magnitude lower than that of NB terminals. The newly designed radio waveform and protocol will enable the passive radio a part of the 5G network NR by slice the time-frequency resource, and take out some sub-carriers for passive IoT services. Indoor baseband processing unit (Building Baseband Unite, BBU), transmission and other processing resources are shared with other services, and there is no need to add new core network elements, and label authentication and security functions are realized through soft upgrades.

Figure 5-3 Power consumption and cost comparison between Passive tag and NB-IOT



	Power consumption	Price
NB-IOT	10mW	1 dollar
NR Passive IoT	100uW	0.1dollar

Typical application scenarios of outdoor passive IoT include energy, agriculture and many other fields. For instance, electric power plant requires real-time monitoring of equipment operating status, fault diagnosis and health monitoring, temperature monitoring at joints and other locations, to prevent fire failures, and in the power grid operating environment, passive IoT is safer. The key to precision agriculture is the need for information perception and interconnection of the growth environment, and only passive battery-free can be discarded and meet environmental protection requirements.

5.3 Deterministic Network

- **Concept**

The proximity deterministic network refers to the network that can guarantee the deterministic bandwidth, latency, jitter, and packet loss rate of the service. The determinism here can defines as the performance can be expected, for example, the deterministic delay is 10ms, and the delay jitter is ±10μs.

The demand for deterministic networks is widespread in the field of industrial communications. Traditional fieldbus technologies such as ProfiBus, CAN, CC-Link, Lonworks, or industrial Ethernet technologies have solved this problem to a certain extent. However, due to the complex communication protocol standards, the communication compatibility between each other is still maintain a problem, which restricts the development of industrial network interconnection and interoperability, and causes the long-term high cost of industrial network deployment. In addition, wired connection methods also have problems of limited application.

The emergence of 5G technology enables ultra-low latency and high-reliability communication, which provides new communication options for the industrial field. If the proximity network can have both the advantages of wired deterministic network and 5G, while meeting the requirements of high reliability and determinism of communication, then the problems that have plagued industrial proximity networks for a long time could be be solved.

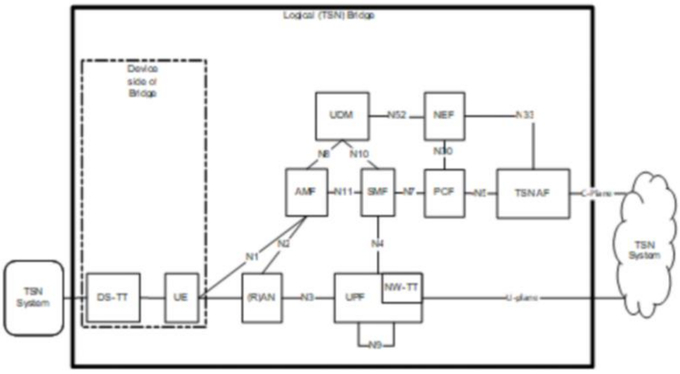
- **Key Technology**

The TSN Bridge architecture defined by 3GPP R16 uses 5G high-precision time/clock calibration technology to solve the connection problem of 5G and TSN networks through the core network. At the same time, the 5G URLLC series technology and the optimization technology of the bearer network gradually enhance the delay certainty are also an important future direction of 5G+TSN network. The following chapters specify and introduce the key technologies of the proximity deterministic network.

1) Deterministic 5G+TSN Bridge Technology

In order to meet the demand of interconnection for deterministic industrial network, 3GPP R16 has considered and defined the 5G system as the architecture of the TSN logical bridge to complete the networking and interconnection with the TSN network.5G can be used to extend the coverage of the existing TSN network in the proximity network. The 5G TSN logical bridge architecture is shown in the figure below:

Figure5-5 TSN logical bridge architecture from 3GPP



5G system has extended 3 function module to achieve interconnection between 5G TSN logical bridge and TSN network:

a）DS-TT

Device-side TSN translator，which connect device-side TSN system.

b）NW-TT

Network-side TSN translator，which connect network-side TSN system.

c）TSN AF

The Application Function of TSN，which connect CNC controller of TSN.

In order to implement the functions of 5G TSN logical bridge, 5G system requires below technologies:

First, the 5G system needs to provide the ultra-high-precision time synchronization capability for TSN services. The entire E2E 5G system can defers to the IEEE 802.1AS "time-aware system". UE/DS-TT and UPF/NW-TT need to support IEEE 802.1AS operation to achieve TSN time synchronization with the TSN GM of the DN network. In addition, 5G gNB and UPF also need to provide high-precision time synchronization based on the 5G system clock.

Second, 5G networks need to provide deterministic low-latency flow scheduling capabilities for TSN industrial Internet applications, including: optimized scheduling technology for radio resources, UE/DS-TT and UPF/NW-TT flow scheduling based on the IEEE 802.1Qbv standard AbilThird, the 5G system needs to interact with the TSN network to realize the configuration and management of the 5G system as a TSN logical bridge, including: UE/DS-TT and UPF/NW-TT need to support the LLDP protocol for link discovery. The 5G system can reports the status of the 5G network to the CNC through the TSN AF, and receives the CNC's path planning and reservation for the 5G system.

At the same time, as a deterministic network, 5G can also be directly used as an access technology for the proximity network. In order to further enhance certainty and increase the scope of application, the R17 of 3GPP is defining TSN network that does not require external, and 5G can independently provide deterministic network transmission functions. It is expected that R18, can further enhance the independent deterministic network function. This provides strong support for further simplifying the network architecture of the industry proximity network.

2) Deterministic 5G URLLC Technology

With technologies such as flexible frame structure, Mini-Slot, uplink authorization-free scheduling and PDCP duplication, the network performance delay and reliability are greatly improved by 5G. In order to achieve low latency and high reliability, 5G optimizes and improves the frame structure, and adopts parameters to flexibly configure the unified frame structure technology (Unified Frame Structure, UFS). It can reduce the TTI length, reduces the CP length, and increases the subcarrier spacing. On the other hand, different parameters can be selected for configuration according to different frequency bands, scenarios, and channel environments.

TSN uses the Mini-Slot architecture, which enables uplink and downlink are inconsistent. The downlink can be arbitrarily configured on (2, 4, 7) OFDM symbols, and the uplink can be arbitrarily configured on 1-13 symbols. The number of symbols is the scheduling unit, which ensures the rapid response of the physical layer in the shortest possible time, realizes smaller scheduling granularity, reduces the number of scheduling symbols, and realizes fast transmission, thereby reducing delay and increasing reliability. At the same time, the upper and lower frame scheduling uses fast access authorization-free scheduling, avoiding the use of scheduling application requests and scheduling permissions, quickly The uplink authorization-free scheduling provides a transmission method based on non-dynamic authorization. By activating the periodic authorization of the uplink configuration, multiple uplink transmissions can be performed based on this authorization configuration. Uplink authorization-free scheduling is helpful for delay-sensitive services and control information overhead. In the NR protocol, two types of uplink unauthorized transmission configuration types are defined, which are called Type-1 and Type-2. In the Type-1 mode, parameters such as period, frequency domain resources, time domain offset, modulation and coding are configured through RRC signal. The terminal device, after receiving the RRC signaling, immediately activates the authorization configuration according to the time domain offset. In the Type-2 mode, the periodic configuration is also performed through RRC signaling, and the transmission parameters and authorization configuration indicated by PDCCH activation are used.

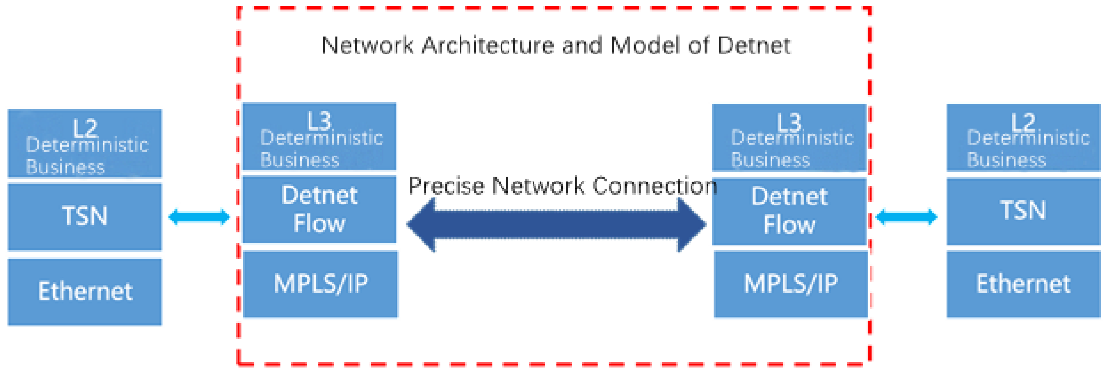
PDCP duplication refers to the PDCP packet is copied to RLC entities of different carriers, and the same data is sent through different radio, which further improves reliability without increasing the delay. The 3GPP R15 standard already supports the PDCP Duplication function, but only supports 2 copies. In the R16 standard proposal, it is recommended to support 4 copies. In scenarios with high requirements for delay, transmission reliability can be improved.accessing the channel, and reducing time delay.

3) Deterministic service bearing technology

For the needs of deterministic business bearing interconnection in proximity network,support TSN + deterministic network bearing solution, that is, UNI side access TSN class deterministic proximity network business traffic, the bearer network virtualized into TSN virtual bridge to provide deterministic and accurate connection.

The carrier network can use different connectivity technologies in the detnet network architecture and model to provide accurate network connectivity (as shown in the figure), which is equivalent to a virtual "fiber" connection from an application perspective, with deterministic forwarding delay and jitter.

Figure 5-6 Network architecture and model of Detnet



Accurate network connectivity supports connectivity technologies that provide different characteristics from physical layer to network layer, including ITU-T MTN technology for TDM hard isolation at Ethernet physical layer, PWE3 emulation technology for soft isolation at Ethernet data link layer, and QoS assurance technology at network layer . Different connection technologies can provide different isolation characteristics, forwarding delay and jitter, and reliability, etc. Users can select the appropriate connection technology according to the differentiated needs of the service, and the selection process can be done automatically through intelligent management. Accurate network connection also supports accurate quality indicator detection, with real-time detection of key indicators such as packet loss, delay and jitter of the connection, to ensure connection quality and simplify O&M.

Bearer network slicing technology is the basic ability of the proximity network, based on the unified bearer network infrastructure, network slicing can be used for the differentiated bearing needs of the proximity network, providing suitable and guaranteed network resources for industry applications, and then providing guaranteed virtual private network services for deterministic bearer of industry application requirements.

- **Evolutionary Trends**

While 5G and TSN solve the problem of deterministic unified communication in terms of network transport, OPC UA (Unified Architecture), a new generation OPC standard introduced by OPC Foundation, unifies the interoperable interface at the industrial protocol layer, making information available to every authorized application and every authorized person at any time and any place; OPC UA is independent of the manufacturer's original application, programming language and operating system, can solve the interoperability problem of ubiquitous industrial protocol service layer.

The combination of 5G with TSN and OPC UA provides a complete industrial communication solution that is real-time, highly deterministic and truly independent of the equipment manufacturer. As the 5G and TSN industry chain matures, the solution is expected to gradually become a best practice for industrial field communications.

5.4 Highly accurate indoor positioning

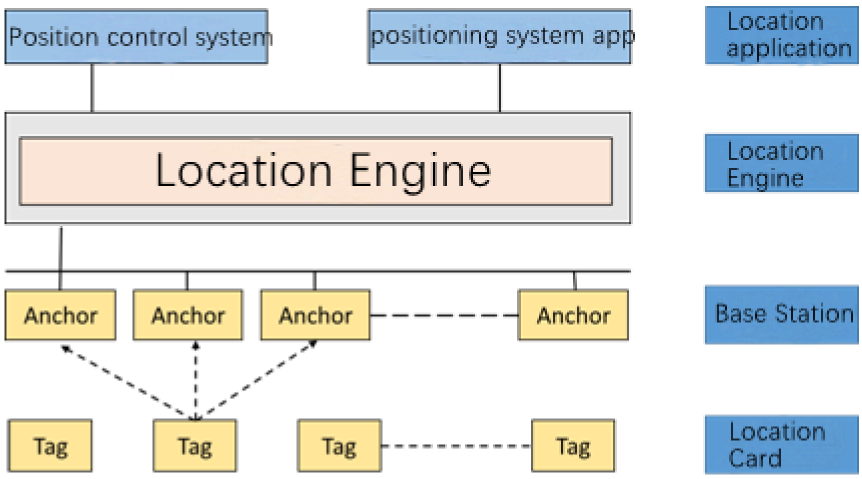
- **The concept and overall technical framework, key technologies**

The traditional positioning method used in the proximity network is the signal carrier strength based technology, i.e. RSSI (Received Signal Strength Indication) to do triangulation, which is characterized by low accuracy and poor adaptability to the environment, but relatively simple to implement, such as RSSI based on Wi-Fi signal, or RSSI based on Bluetooth iBeacon signal with an accuracy of 1/3 or 1/4 of the base station spacing for rough positioning. Over the past period of time, there has been a growing need within the industrial industry for the detection and management of people, movable assets and equipment. Several types of high precision positioning needs have emerged in the industry such as high precision electronic fence, high precision trajectory, and three dimensional positioning. In response to these needs, two technology directions have been proposed.

2) UWB(Ultra-WideBand)

UWB is a new communication technology that is very different from traditional communication technologies. It does not require the carrier of traditional communication systems, but transmits data by sending and receiving very narrow pulses with nanosecond or picosecond levels or less, for that reason, it has GHz-level bandwidth. Compared with traditional narrowband systems, ultra-wideband systems have the advantages of high penetration, low power consumption, good anti-multipath effect, high security, low system complexity, and can provide precise positioning accuracy. Therefore, ultra-wideband technology can be applied to indoor stationary or moving objects and human positioning tracking and navigation with high measurement accuracy. The ideal situation in the laboratory can achieve a high accuracy positioning of about 10cm, and the accuracy of the actual environment can reach sub-meter level.The framework of the UWB positioning system is as follows:

Figure5-7 UWB positioning system architecture



Each positioning tag sends data frames to surrounding base stations in repeated and uninterrupted UWB pulses.

Each positioning base station use a high-sensitivity short pulse detector to measure the time at which the data frame from each positioning tag arrives at the receiver antenna .

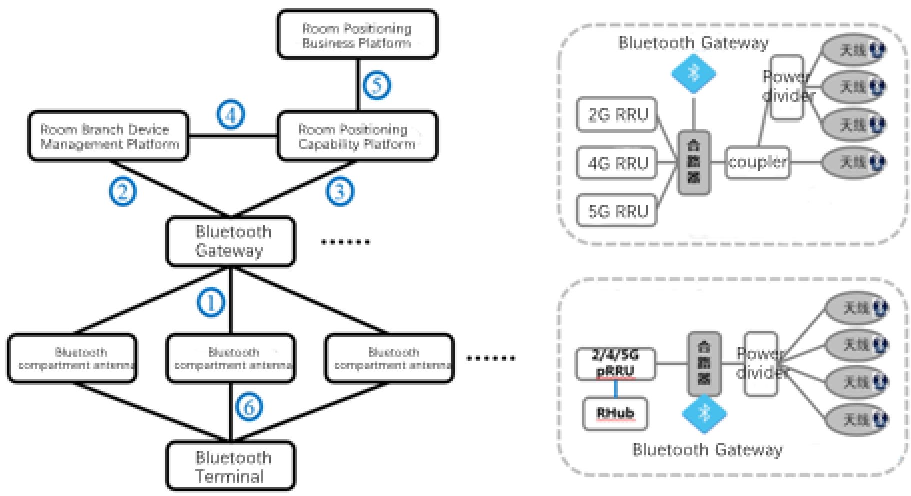
The positioning engine determines the time difference between the tag reaching different positioning base stations according to the calibration data sent by the tag, and then uses the ToF or TDoA algorithm to calculate the tag position.

3) Bluetooth

Angular positioning based on antenna array (AoA/AoD), represented by Bluetooth, is a high-precision positioning solution based on angular measurement between transceiver signals. Based on the phase difference between different antenna links on specially designed antenna arrays (ULA uniform line array, UCA uniform circular array, URA uniform square array) at the base station or terminal, the relative angle between the signal transceiver and transmitter can be obtained according to the phase MUSIC algorithm, and the positioning accuracy is able to reach sub-meter level under ideal circumstances. Thanks to the maturity of the Bluetooth industry chain, the angle positioning based on Bluetooth has more cost advantages in a certain accuracy range. The framework of Bluetooth high-precision positioning system is similar to UWB, the only difference is that the final position is calculated by the angle information generated by different base stations, rather than the time information used in UWB.

The indoor distribution system with integrated Bluetooth positioning technology is shown in Figure 1, including Bluetooth room antenna, Bluetooth gateway, room device management platform, indoor positioning capability platform and indoor positioning service platform.

Figure 5-8 Indoor distributed positioning system with Bluetooth



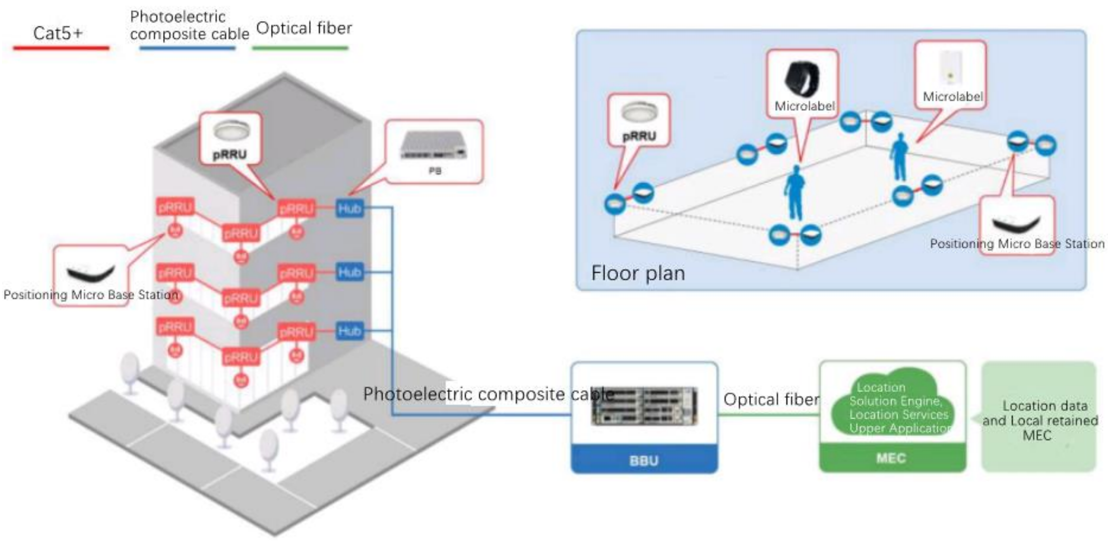
- **5G + high accuracy positioning**

5G technology greatly improves the performance of mobile networks, provides large bandwidth, low latency, wide connectivity network connectivity, provides the necessary technical guarantee for the digitalization of vertical industries. Bluetooth, UWB high-precision positioning can reach centimeter-level positioning accuracy, combined with the needs of the proximity network for communication and positioning, indoor positioning solutions that 5G integrates high-precision indoor UWB, Bluetooth AoA come into being.The solution mainly considers the joint deployment of positioning base stations and 5G distributed pico base stations. The positioning base stations reuse the site resources, power supply resources and transmission resources of 5G pico base stations, while combining leading technologies such as edge computing and big data to provide sub-meter level positioning accuracy to meet various positioning service requirements in indoor scenarios such as smart parks, transportation hubs, industrial intelligent manufacturing and large exhibition halls.

In the 5G integrated UWB/Bluetooth AoA positioning solution, the positioning base station is connected to the cascade port of the 5G smart room sub-base station to obtain power resources, while the data from the UWB/Bluetooth AoA base station passes through the 5G smart room division system (BBU, PB and PRRU) and is finally transmitted to the positioning decoding service deployed on the MEC.

The integration system consists of four parts: hardware layer, network connection layer, data resolution layer and application layer. 5G fusion UWB/Bluetooth AOA positioning scheme networking architecture is shown in Figure.

Figure 5-9 Converged Network Architecture with 5G, UWB and Bluetooth



- **Future Development Direction**

1) Integration of multiple positioning technologies

5G NR has proposed positioning scenarios and needs from the beginning,in 3GPP R16, a positioning standard of 3m indoor and 10m outdoor level was proposed, and R17 will propose a positioning requirement of less than 30cm, but the difficulty of implementation and chip maturity are significantly higher than the current UWB implementation. In the future, it is also possible to apply UWB's extremely narrow pulses with an accuracy of nanoseconds or picoseconds to 5G or 6G to enable the operator's network has the ability to locate with high accuracy.

With the continuous development of the 5G industry chain, specific positioning technologies may be used in specific scenarios in the future to extend the applicable area for high-precision positioning and reduce the overall coverage cost, such as UWB to provide indoor positioning and base stations or differential GPS to provide outdoor positioning.Another example: the combination of time of flight and antenna array, although we have not yet seen commercial products, but some chip manufacturers have reserved the ability in hardware. In the future, the position can be solved by combining signal's time of flight and angle information, the accuracy and the jitter of the positioning system will be further optimized, and the system's environment adaptability will become stronger.

2) Combination of GIS technology and high-precision positioning on the operational layer

Current manufacturers doing high-precision positioning usually do not have map technology, the front-end interface of the positioning application simply relies on the calculation results of the positioning engine for location mapping, which has inherent deficiencies in dealing with occasional point jumps, road attachment and track optimization.

5.5 Virtual proximity network based on Digital Twin

- **Value and Significance**

Application scenarios of proximity network are complex, heterogeneous and customized. Traditional network management systems and maintenance teams cannot meet the operation and management needs of industry networks. Relying on digital twin technology, we can provide differentiated services at the stages of delivery, management, operation and optimization of industry networks to achieve low-cost trial and error, high-quality operation and intelligent auxiliary decision-making, and improve user experience. Operators need to change their thinking on network O&M as soon as possible, evolve from traditional large network maintenance to O&M management of heterogeneous proximity networks, and provide customer & business-centered visualization, automation and intelligent O&M capabilities through digital twin technology to enhance O&M efficiency, improve customer experience with the network, culminating in a high-value network O&M management system.

1) Unifying heterogeneous industry networks

Industry networks have diverse application scenarios and diverse terminal forms, and its networking and configuration solutions are highly customized with complicated architectures.First, the network architecture is diverse, and the topology is complex as different kinds of 5G industry-specific networks are integrated with short-range communication, passive IoT, mm-wave and other proximity networks. Second, the network configuration is customized, because network slicing, frequency, quality of service (QoS) and subframe ratios and other parameters should be configured on demand based on service. Third, the network functions virtualization (NFV) and micro-service architecture result in network module decoupling in layers, and large number of network element modules makes it difficult to locate and delimit network faults.

2) Meet the diverse network requirements

The network is the foundation for industry customers to realize informationization, and customers need a way to perceive network quality at any time and get timely response when network failure occurs.First, network awareness: intuitive, real-time, three-dimensional display of customer understandable and perceptible network performance indicators and operational status. Second is the Service Level Agreement (SLA) guarantee: there are many industry scenarios, and the SLA of different business scenarios have different requirements for network performance, so it is necessary to do fine management and deterministic guarantee of SLA. Third is the fault response: the first time to notify O&M personnel when a network failure occurs, the troubleshooting process can be tracked in real time to further achieve fault prediction and prevention before it happens.Third is the fault response: the first time to notify O&M personnel when a network failure occurs, the troubleshooting process can be tracked in real time to further achieve fault prediction and prevention before it happens.

3) Optimize network operation and maintenance

The traditional O&M team and non-automated process model cannot meet the industry network requirements.First, the O&M system is fragmented: the O&M system is independent of each other, and the data between the systems are isolated, so it is difficult to troubleshoot. Second, reactive O&M: After a fault occurs, the period from complaint to on-site investigation is long. The previous experience with large network O&M is difficult to cope with the new problems of 5G industry networks, and troubleshooting takes a long time.Third, low level of automation: The industry network lacks automated O&M tools, which leads to low efficiency and high labor costs.

- **The composition of the digital twin technology of the proximity network**

According to the problems of heterogeneous networks management and low efficiency of network O&M, a "end-edge-management-cloud" architecture should be constructed, in order to develop a comprehensive service solution for proximity network, thus improve the capabilities of network O&M management and service. There are four main categories of technologies that compose the digital twin system for proximity networks:

1) Data collection based on service quality probe

The end-side probe is developed for the needs of service deployment and refinement O&M of proximity network, which can effectively carry out the network SLA guarantee by providing monitoring, analysis and alarm services of equipment status, network coverage, service quality and other key network information.

2) Information model-enabled proximity networks

First, the identification system, which refers to the identification coding and identification parsing technology of the physical objects of network. It maps the physical object’ s description information of heterogeneous identification to a unified information model for the construction of digital information model.Second, the information model, which refers to the digital definition of the proximity network infrastructure and the description of the logical relationship between devices.It's a Prerequisites for realizing the unified management of wireless and wired network devices in each area of the factory.

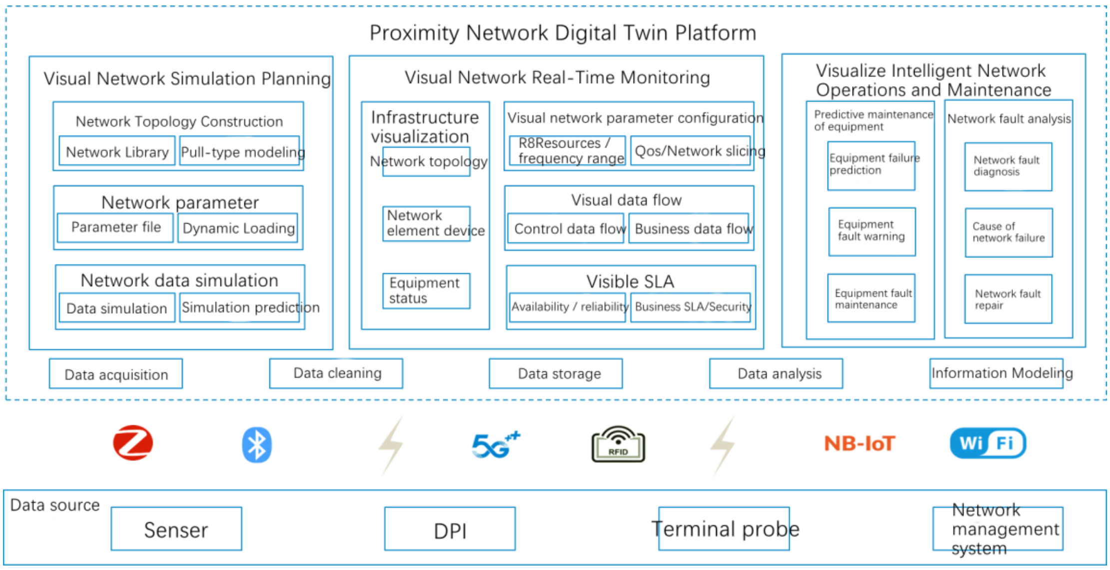
3) Intelligent O&M

Smart O&M refers to the deep integration of digital twin information model and data based on AI technology for proximity network to achieve efficient and intelligent network monitoring, O&M analysis, resource provisioning and configuration optimization to ensure the orderly operation and management of network systems.

4) 3D visualization

It provides a three-dimensional visual display interface and integrates various types of charts to facilitate customers to be aware of the network topology, network performance data, network fault information, etc.

Figure 5-13 Virtual proximity network architecture based on digital twin



- **IoT service quality probes provide field-level O&M**

For industry customers' 5G/IoT service deployment and O&M needs, the IoT Service Quality Probe SDK is deployed on 5G gateways or modules to provide monitoring, analysis and alerting services for key information such as field-level device status, network coverage, service quality, etc. It can also be deployed on an industry network O&M platform on demand.The main types of data detected by operational quality probes are:

1) Data collection of terminal

(a) Basic gateway information, including gateway SN, gateway model, etc;

(b) Gateway status information, including CPU occupancy rate, remaining memory, location information, Wi-Fi connection status, etc;

(c) Sub-device information, including device type, device name, etc.

2) Service quality monitoring

(a) Detection capability, including heartbeat packet, speed measurement, Ping function;

(b) General service quality information, including delay, rate, etc;

(c) Service quality information of video scenario, including resolution, fidelity, etc;

(d) Service quality information of remote control scenario , including delay, jitter, deterministic transmission.

3) Network coverage detection

(a) Network signal quality parameters, including Reference Signal Receiving Power (RSRP), Signal to Interference plus Noise Ratio (SINR), etc;

(b) Throughput performance parameters, including peak rate, average rate, etc;

(c) Cell-related information, including cell ID, slice ID, etc.

- **Identification system achieves information sharing of full element and procedure**

The identification system identifies all objects throughout the whole life cycle of network planning and design, network construction, O&M, and optimization. It can provide the information query and sharing of the whole elements and procedures of the proximity network, and is the hub of cross-regional, cross-industry and cross-enterprise information interoperability.

- **Information model provides standardized data semantics**

It provides a unified device information model, standardizes the data semantics between proximity network terminal devices and network management platform, provides unified access, unified parsing and unified access to heterogeneous proximity network access devices, and provides the data needed for digital twin. which mainly includes two major parts. One is the management plane data model, which mainly covers parameters such as device information, software management, alarm management, log management, time management, GPS management, network management server configuration, backhaul port configuration, performance file configuration, MR file configuration, etc. The second is the service plane data model, which mainly covers the configuration parameters of base station services, including carrier-related parameters, core network parameters, link parameters, channel parameters, neighboring cell parameters, and mobility parameters.

- **AI and digital twin achieve intelligent O&M**

Based on AI technology, the digital twin model and data of proximity network can be deeply integrated, which can carry out real-time monitoring, O&M analysis, resource provisioning and configuration optimization monitoring, analysis and resource provisioning of the network condition, thus ensuring efficient and intelligent operation and management of the whole life cycle of the network system. It can further guarantee the efficient and intelligent O&M of the whole life cycle of network system. AI enables four functions of proximity network digital twins:

1) AI-based network information monitoring

Using AI technology to realize the processing and statistical analysis of massive network data, real-time monitoring of network operation status, diagnosis of abnormalities and faults, and ensure the orderly operation of the digital twin system of the proximity network。

2) AI-based Heterogeneous Network Collaboration

Industry site network structure is complex, large scale, and there are a large number of heterogeneous devices, AI technology can realize task allocation, information interaction and capability collaboration among multiple nodes to further meet the hierarchical and intelligent network management needs.

3) AI-based network predictive maintenance

Based on the operational data collected by the digital twin system in real time, AI technology enables diagnosis and prediction of network faults by monitoring the network operation condition and diagnosing or predicting network faults, which is conducive to advance planning and timely provision of network O&M.

4) AI-based network intelligent decision-making

Based on the predictive analysis of the network operation status, it provides intelligent decision-making assistance for network administrators to achieve optimal allocation of network resources and scientific and efficient closed-loop management of twin systems.

- **3D-visualization supports efficient display and interaction**

With the help of graphic means and technologies, 3D visualization processes basic information, and through real-time rendering of 3D scenes and data modeling, it makes the presentation of proximity network data more intuitive and provides a good human-computer interaction environment for the digital twin system.

Visualization is one of the basic functions of the digital twin. There are differences in the characteristics and applicable scenarios of various types of visualization technologies, and each manufacturer has its own advantages and disadvantages in technology and products. Facing the demand of 3D visualization in the process of human-computer interaction in the industry, suitable visualization technology strategy is selected, and at the same time combined with the information of GIS map of proximity network, real-time visualization presents the space, power consumption, ports and environment of the site network, which is an important means to support business planning and network maintenance.

The data types of 3D visualization technology corresponding to proximity network based on digital twin mainly involve: vector type data (GLG vector data, CAD design drawings), model type data (Building Information Model BIM, tilt photography OSGB), dynamic data (IoT real-time data), point cloud data (LiDAR), raster type data (digital elevation model DEM, digital orthophoto DOM). Processing types include: dynamic scene graphics creation, digital entity rendering design, and scene data semantic processing. Support functions include: network/device state awareness, network device unified management, 3D spatial analysis, service co-simulation, network state prediction.

6 Typical application scenarios of proximity network

6.1 Smart Machinery Manufacturing

Construction machinery manufacturing is an important branch of China's manufacturing industry, it can directly affect the efficiency and quality of national infrastructure construction. However, limited by the complexity of the scene and network technology, the current manufacturing process still accounts for a large proportion of manual. The introduction of proximity network technology can penetrate into scenarios that are beyond the reach of traditional networks and promote intelligent machinery manufacturing.

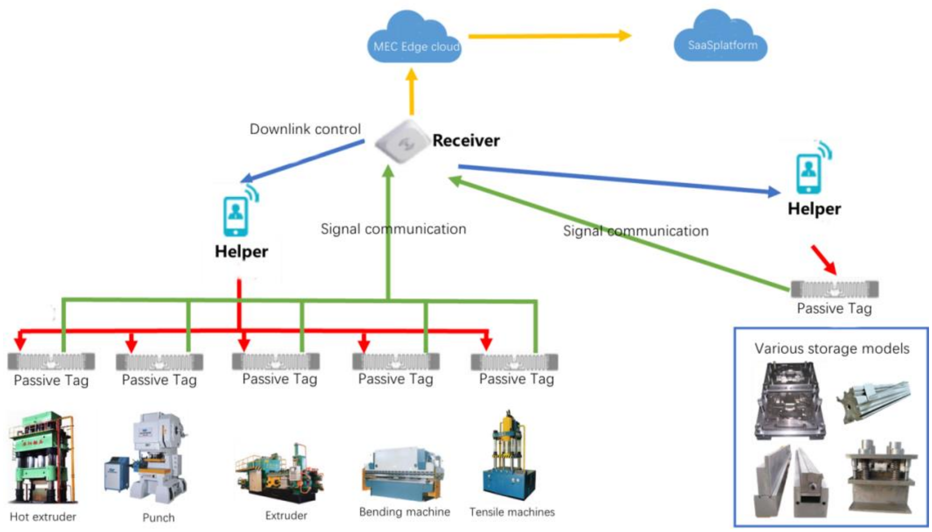
Taking the mold management as an example, mold is the main production resource of a manufacturing enterprise, which needs to frequently record important information such as mold loading time, molding cycle, mold opening and closing times, and abnormal downtime. However, the traditional mold inventory adopts the manual search and manual record way, which is time-consuming and prone to errors, and will interfere with the management's judgment on various aspects such as real production capacity, operation process, personnel performance, and even the strategic decision of the whole enterprise in the later feedback. Therefore, through 5G + RFID can realize the information management of molds, reduce the error of manual records and improve the efficiency of inventory.

In addition, in the machinery manufacturing park, more metal equipment leads to serious signal loss, 5G signal in complex terrain can only cover 200 to 300 meters, and because of its expensive counterfeit, it is difficult to deploy 5G module for each mold. Although the signal loss of traditional network small but it can not support tens of mold equipments in a wide range of connections. RFID tag cost only 0.3 cents per tag, in the same deployment density can effectively reduce costs. At the same time, passive RFID tags rely on the radio frequency signal emitted by the reader to stimulate power supply, it can support ten years of ultra-long standby, to avoid the replacement of batteries resulting in network post-maintenance costs. Passive, lightweight characteristics can also support RFID tags can be used to paste, rapid deployment. Modes management data transmission has low requirements for latency and bandwidth, and the performance parameters of 5G, Bluetooth, Wi-Fi and other networks are much higher than the demand, resulting in wasted resources, and the high power consumption of such network base stations will increase the power cost of later operation.

Existing passive RFID technology has been able to meet most of the application requirements. However, because of its one architecture with excitation and data receiving, resulting in RFID tags need to be powered in a really close distance by reader. Most cases still need manual handheld reader sweep RFID tags. The tags’ uplink signal-to-noise ratio is low, resulting in the reader being unable to demodulate the tag signal when distance between tags and reader is far. Therefore, the industry has proposed a new passive RFID architecture that breaks the constraints of the traditional RFID technology communication distance too close. The new passive RFID technology splits the reader into Helper and Receiver, realizing the separation of excitation and communication, avoiding the interference of sending and receiving signal to eliminate, and Helper can improve the excitation distance of the tag to 50 meters, communication distance can improve to 200 meters.

The factory can deploy the Helper on the top of the warehouse, through the receiver to give instructions to send the excitation signal to the RFID tags at regular intervals, the tags will be stimulated to immediately feedback the signal containing mold data to the receiver, through this way the receiver can periodically read and refresh the current position of the mold, the number of times the mold is closed, the molding cycle, the use of materials and products and other information, completely replacing the manual scanning code, and the receiver control the Helper between time and frequency scheduling resources, high-density seamless coverage.

Figure 6-1 Mould Management solution based on new passive RFID



The new passive RFID technology can also be combined with CPE to further extend the communication distance using CPE as an active transit node. This solution reports data to the edge cloud through RFID tags, which can meet the localized processing and security requirements of business in manufacturing production areas. Through the data on the cloud can effectively break the data barrier between the whole production line, each workshop and each plant, forming a unified asset management SaaS platform, realizing the management of the whole life cycle of molds from acquisition, use, maintenance, scrapping and their disposal.

6.2 Smart mining

The mining industry occupies an important position in China's national economy, and the annual output value of the mining industry exceeded 6 trillion yuan in 2018, accounting for 7% of the national GDP, which is the main industry category in China's industry. Along with the development of communication technology and a new generation of Internet of Things technology, the mining industry is given the basis for intelligent information collection, transmission and control, relying on the relevant technical capacity support of the industry's proximity network to meet the different needs of the application scenarios for the mining industry.

In the smart mining application architecture, the proximity network plays an important role in the enterprise network, and proximity network is the last part of the network in the industry park, which runs through the whole network layer. The proximity network for smart mining adopts a distributed, multi-layer architecture, which is divided into display layer, application layer, platform layer, network layer and access layer from top to bottom, totaling five layers, as shown in the figure below, and the existing digital twin platforms of smart mining are designed with this architecture as a reference.

Figure 6-2 proximity network architecture for smart mining

In the mining industry, the mining process can be divided into two types of operations, open pit mining and underground mining, depending on the mining method. The application scenarios, business needs, network requirements and industry site network integration points in these two mining operations are different. Taking unmanned mining in underground mining as an example, unmanned mining is achieved by installing remote control system, monitoring equipment and sensing equipment on mining machinery, and realizing remote operation and control of mechanical equipment through the console.

Remote control equipment in smart mining includes, but not limited to, scraper conveyors, reloaders, crusher control systems, forward operating face diggers, etc. The current underground mining operation process relies heavily on manual operation, and the manpower is mainly concentrated on the operation of digging machine, conveyor belt and underground gas sensor data viewing, which leads to a series of problems such as difficult management, high cost, high risk and low efficiency of enterprises due to the very high dust and harmful gas during operation, and the harsh and dangerous environment, which urgently needs unmanned remote control equipment technology with low time delay, high reliability and wide range of connection to replace on-site manual operation and help mining enterprises to produce safely and efficiently.

In terms of communication, the current underground communication method is relatively backward, mostly using wired way to transmit information. A large number of video monitoring equipment and sensors are installed on the hydraulic support of the working face, with many and mixed cables. Due to the complex underground environment and the fact that communication is mostly by fiber optic and power cable carrier technology, the use of the process is easy to cause cable breakage and data interruption, which leads to a large workload of O&M. In addition, industrial Wi-Fi, 3G/4G and other wireless communication means can not meet the requirements of the mining industry applications, such as industrial Wi-Fi and underground Bluetooth, Zigbee, etc. are in the same frequency band, which is easy to be interfered with when operating equipment remotely, while the use of 5G network slicing technology can effectively guarantee the isolation of remote operation services. The ultimate realization is to liberate operators from dangerous underground workplaces and realize remote and safe control of mine operation processes. For example, the sensor information collection service requires high reliability and large bandwidth and is not sensitive to latency and upstream and downstream rates, while the remote control application requires high reliability and ultra-low latency. The bandwidth and high upstream and downstream rates are required for downhole video monitoring and downhole communication.

As the last step of the enterprise network, priximity network provides guarantee for the intelligent development of mining industry. The SLA classification of proximity network for smart mining can meet the requirements of reliability and realize the centimeter level accurate positioning through the synergy of multiple positioning methods. But there are still many limitations on the development of the mining industry, such as 5G explosion-proof and intrinsically safe certification of communication equipment, the limits of communication power, reliability and deterministic transmission of wireless networks, and other issues are still in the communication technology for technological breakthroughs.

6.3 Smart Grid

- **Requirements of smart grid typical applications**

A typical proximity network application scenario in smart grid industry involving deterministic network requirements is distribution network differential protection. In order to improve the reliability of power supply, it is required that the highly reliable power supply area can realize uninterrupted and continuous power supply, shorten the accident isolation time to millisecond level, and realize regional non-stop service. The distribution network differential protection sinks the processing logic of the original master station to the intelligent distribution terminal in a distributed manner, and realizes intelligent judgment, analysis, fault location, fault isolation and restoration of power supply in non-faulty areas through peer-to-peer communication among terminals, thus realizing fully automatic fault processing, minimizing the time and scope of fault outage, and increasing the distribution network fault processing time from the minute level to the second or even millisecond level.

Basic principle of differential protection in distribution network is: Distribution automation terminal unit (DTU) regularly sends current vector values to other terminals on the same distribution line, and the DTU terminal compares the current vector values of two or more terminals at the same time, determines that a fault has occurred when the current difference exceeds the threshold value, and performs the corresponding differential protection action locally; each protection terminal sends the electrical measurement data of its end to the other end through the communication channel and receives the data sent by the other end and compares them, determines whether the fault location is within the protection range and decides whether to start the fault removal. Each protection terminal sends its electrical measurement data to the other end through the communication channel, and receives the data sent by the other end and compares them to determine whether the fault location is within the protection range, and decides whether to start the fault removal.

Table 6-1 requirements of communication network for distribution network differential protection

U-BW	D- BW	E2E communication delay	Timing accuracy	Communication frequency	Num /connections	Safety isolation area	Reliability	Other requirements
⩾ 2.5M	⩾ 10M	⩽ 15ms	10us	0.833ms	10-100 pieces / km^2	Safety production zone I	99.999%	Support MAC based layer 2 and IP based layer 3 multicast

- **Current situation and problems**

Differential protection has high requirements for E2E communication delay, and only fiber optic communication can meet the requirements before. According to IEC61850 protocol, the E2E communication delay of fiber optic communication is ≤10ms, which can fully meet the communication delay requirement of differential protection. However, due to the high deployment cost of fiber optic communication, long engineering cycle and difficult coverage of special terrain, it was decided that the differential protection service was previously only deployed on a large scale in the main power network. And for the distribution network scenarios with complex and differentiated scenarios, the differential protection based on fiber optic communication has only been verified in a small number of pilots in a small area, and no large-scale deployment has been realized.

Since 2018, with the promotion of 5G+ smart grid pilot demonstration projects in State Grid Corporation of China and China Southern Power Grid, the pilot verification of network differential protection based on 5G has been gradually completed. Based on the characteristics of 5G such as large bandwidth, ultra-low latency, ultra-high reliability and massive access, combined with 5G's unique network slicing, MEC edge computing and other differentiated solutions, it provides a ubiquitous, flexible, secure, reliable and low-cost communication solution for the entire distribution grid with full domain coverage, which can better match the digital needs of the grid industry. In order to adapt to the delay uncertainty of the 5G access network, the distributed processing software built on DTU terminal adopts fault-tolerant processing by increasing the message packet timestamp, enlarging the message packet reception buffer, providing survival time messages, and packet loss retransmission protection mechanism, at the expense of service processing performance and increasing terminal cost, to reduce the sensitivity and dependence on 5G network delay and jitter to a certain extent.

- **Evolution direction**

Based on wireless network, 5G deterministic network provides deterministic transmission performance for specific applications, that is, bounded delay and low jitter, high reliability, and end-to-end high-precision time synchronization, so as to truly realize the transformation from "application adaptation network" to "network adaptation application".

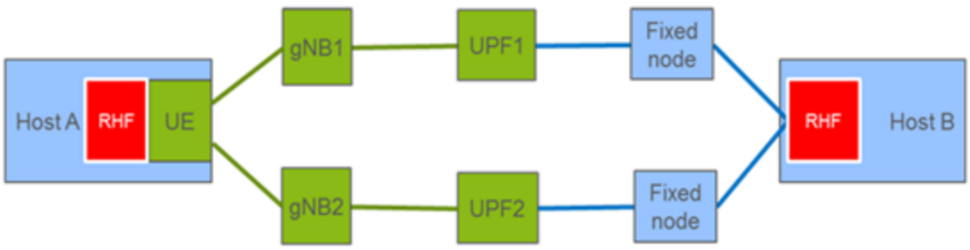
1) Bounded delay and low jitter

5g system (5GS) adopts black box scheme to integrate with TSN system and manage logical switching nodes to realize the mapping of deterministic requirements of application layer to 5G QoS model; meanwhile, the user side guarantees deterministic transmission of TSN streams and eliminates transmission jitter in the wireless network by reserving cache and bandwidth resources for TSN streams and using enhanced forwarding scheduling and other mechanisms.

2) Extremely high reliability

Provide highly reliable transmission through E2E redundant paths.

Figure 6-3 Highly reliable transmission architecture



3) End-to-End High Precision Time Synchronization

The differential current calculation for differential protection requires comparison of current sampling values at the same moment on both sides, requiring synchronized sampling and consistent transceiver time delay.

5GS acts as a transparent clock to synchronize TSN clocks to downstream devices, as defined by 802.1AS, it supports timestamp mechanism, multi-clock domain optimal clock source selection, TSN domain and 5G domain clock offset determination, clock synchronization frame information calibration, etc., thus providing us-level high precision clock synchronization timing function.

It should be noted that the 5G TSN defined by 3GPP R16 uses the entire 5GS as a black-box switch of the TSN system in a bridging mode, requiring the upstream TSN system to provide corresponding TSN policies (e.g., TSN flow forwarding and scheduling rules) and clock source inputs. It is not applicable for the power industry where no commercial TSN network has been deployed yet. Therefore, we propose to adopt the non-TSN system scenarios studied in the 3GPP R17 initiative, which means 5G TSN technologies and solutions that can be independently implemented by 5GS.

6.4 Smart steel

China is the largest country in steel production and attaches great importance to the digitization of the steel industry. The 14th Five-Year Plan has put forward clear requirements for the digital transformation of the steel industry relying on new information technology. But limited by the steel production process, network technology is highly complex, the current steel production in the whole process is still highly dependent on manual. The introduction of 5G + proximity network technology can expand the connection of steel production equipment, achieve highly reliable real-time monitoring, intelligent analysis, to promote the digitalization, networking and intelligent transformation of the steel industry.

Among the steel production processes, the iron-making process has a high degree of process complexity, and the main cost of steel enterprises originates from iron-making. The traditional iron-making process is not highly automated, and the process operation mainly relies on manual experience, with insufficient process synergy, production stability and cost control. Therefore, iron and steel enterprises can realize the automation, unmanned and intelligent production process in the iron area with the goal of comprehensive optimization of economic and technical indicators through the deep integration and innovative application of ironmaking process technology with 5G, big data, cloud computing and other technologies to comprehensively improve production efficiency and reduce potential safety production hazards.

In the iron-making process, the four major vehicles of coking (coal loading car, coke pushing car, coke stopping car, motor car) are the core large mobile equipment. The remote control of coke oven vehicles, remote monitoring of the central control room, automatic and stable operation of unmanned vehicles mainly rely on the assistance of information systems such as automatic positioning system, wireless communication system, ground coordination system, safety control system, remote monitoring system, etc. to meet the needs of the production process that requires collaborative operations. To guarantee the scenarios of remote control, automatic positioning and ground coordination of the four vehicles, the main requirements are as follows:

1) High precision positioning

The positioning accuracy of the four vehicles needs to meet the static positioning accuracy of ±2mm and dynamic positioning accuracy of ±5mm in order to realize remote control to accurately determine the location of equipment and collaborative operation without deviation. At present, 5G positioning accuracy can only reach 5-10 meters, which cannot meet the industry demand. Through 5G+UWB, 5G+POA and other indoor positioning solutions, 5G+GPS and other outdoor positioning solutions are expected to meet the demand for millimeter-level positioning of coking four vehicles.

2) Deterministic networks

The four-vehicle interlocking system requires real-time detection and judgment of interlocking conditions to enable safe stopping of equipment in case of failure or emergency conditions, with extremely high demand for network transmission delay and deterministic transmission guarantee. 5G deterministic network is based on wireless network, which can provide deterministic transmission performance for four-vehicle safety control system, including bounded time delay and low jitter, extremely high reliability, and end-to-end high-precision time synchronization, realizing 5G deterministic network adaptation to safety control scenarios.

6.5 Smart building

Smart building is a new modern building that integrates architecture, communication, computer and control technologies with each other and can adapt to the development needs of information-based society. With the continuous development of the Internet of Things (IoT) technology, it has become an inevitable trend for future development to enhance the construction of smart buildings with the help of IoT technology.

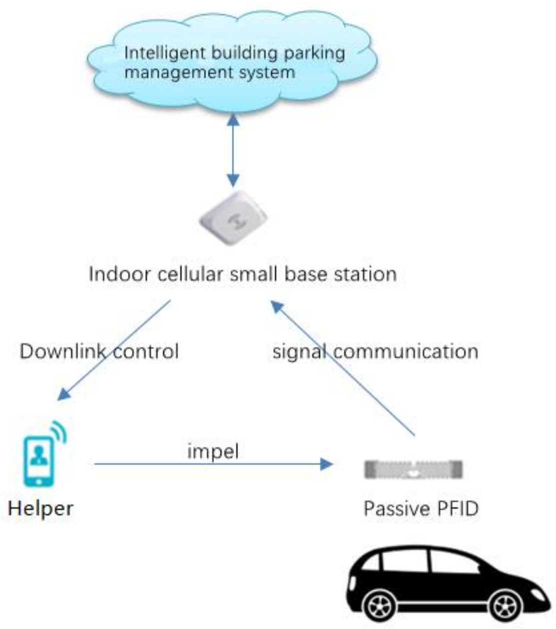
Parking management is one of the typical scenarios in smart buildings. By quickly and accurately identifying vehicle information, it effectively controls vehicle access; by automatically counting the number and location of remaining parking spaces and quickly locating vehicles, it assists parking administrators to get parking information in real time, solving the traditional parking troubles of finding cars.

However, most buildings currently have a low level of parking management and still use traditional access control and parking space monitoring based on IC cards, video recognition or geomagnetic. For IC card identification, it is associated with the vehicle license plate number through contactless way to realize vehicle information statistics. However, in the process of parking and retrieval, users need to swipe the card several times, the operation process is complicated, and there are problems such as missing recognition. For video recognition, the license is identified through camera to realize access management and parking monitoring, but the video equipment is costly and easily affected by environment and shooting angle. In the parking lot, one camera often has to cover multiple parking spaces, and it is difficult to cope with visual dead space and the situation like multiple vehicles entering and leaving the parking space at the same time. For the geomagnetic identification, it can only detect whether the parking space is occupied by a vehicle, and cannot be informed of the vehicle information. At the same time, the accuracy of geomagnetic recognition is low, and there are problems such as strong magnetic interference, adjacent parking space misdetection, geomagnetic drift, etc. It is also difficult to detect the vehicles with high chassis.

Smart building parking management has a strong demand for proximity network, for example, parking space detection requires high positioning accuracy and has certain requirements for network reliability, latency and edge computing capability. At the same time, considering the transformation cost, construction difficulty, the number of parking spaces and other influencing factors, the network needs to have a strong deployment flexibility, support larger connection density, etc. With the passive RFID technology based on proximity network identity recognition, vehicle identification, precise positioning, vehicle access management and efficient parking space monitoring can be realized, solving the problems of difficult parking and management in smart buildings.

The new passive communication technology based on separated architecture to realize smart building parking management is shown in Figure below. Passive RFID tags can be used as the vehicle identification and information transmission equipment, mobile terminals can be used as incentive equipment, indoor cellular small base stations can be used as the receiving equipment. These devices work together can achieve spatial isolation to avoid interference, theoretical communication distance is up to 100 meters, which can improve the efficiency of information transmission. At the same time, passive RFID-based proximity network technology can also greatly reduce the cost of equipment, and with the RFID positioning capabilities to improve parking navigation in the parking lot, reverse car search in the positioning accuracy, the entire process without the user to swipe the card multiple times, greatly improving the efficiency of parking management.

Figure 6-4 Smart building parking management based on passive RFID



In addition to parking management, the proximity network can also provide network capability guarantee for typical applications such as asset management, personnel management, building energy saving, etc.

of smart buildings, meet diverse network requirements, and improve the refinement, intelligent operation and control capability of smart buildings.

6.6 Smart Port

- **Smart Port Demand**

Smart port is a inevitable trend of modern port development, and its main goal is to make full use of IoT technology, sensors, cloud computing, analysis and optimization based on AI and other technical means to predict and sense, connect and deeply calculate the key information of each core link of the port supply chain, realize seamless connection and coordination linkage between various resources and various participants in the port supply chain, respond to port management in a timely manner, and form digital, information, intelligent modern port applications. To realize smart ports, effective processing, integration and data mining of port terminals, logistics equipment, storage operations, freight and other information is required through various information and communication technologies and sensing and positioning technologies.

- **Current Situation and Problems**

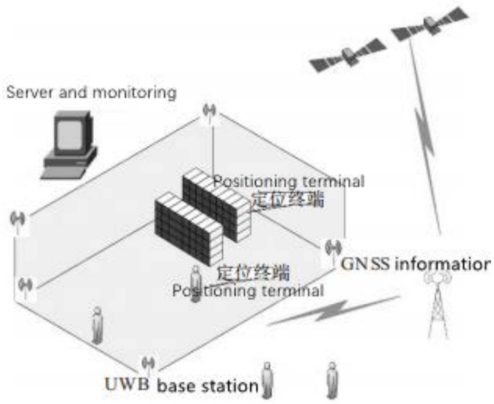
GNSS (Global Navigation Satellite System) is a navigation system that obtains good positioning effect in outdoor unobstructed observation environment, and in the application of GNSS augmentation system, it can provide accurate positioning service for port terminal operation. However, GNSS satellite signals are easily blocked and refracted by buildings, which leads to the reduction of observation satellites' number or multi-path effect, and GNSS positioning technology cannot meet the requirements of integrated indoor and outdoor seamless positioning.

- **Solutions based on proximity network**

With high transmission rate, low power, high resolution, strong anti-interference capability and high positioning accuracy, the ultra-wideband (UWB) technology signal can meet the requirements of seamless positioning of indoor positioning connection points and can effectively solve the positioning problem of GNSS signal in the case of obscured.

The integrated positioning system combines GPS and UWB positioning technologies and requires a mobile positioning terminal that can receive GNSS satellite signals and send UWB pulses. In the integrated positioning system, the GNSS differential reference station sends error correction signals to the terminal, and the terminal corrects the received GNSS data to obtain more accurate real-time positioning data. The core server of the positioning system receives the error correction signal, and then uses the TDOA , differential or other methods to process the UWB signal of the positioning terminal, and transmits the signal to core server through the synchronization controller to get the actual relative position of the terminal. the integrated positioning system of UWB and GNSS is shown in the figure below.

Figure 6-5 Integrated positioning system of UWB and GNSS



Joint UWB and GNSS positioning system requires.:

GNSS is synchronized with the UWB system clock and can use the server to achieve time synchronization control. In addition, due to the difference of GNSS and UWB sampling rates, its observation time can be sampled and unified by interpolation in static and slow scenarios, while in dynamic scenarios, it can be unified by time-stamping the positioning data.

Coordinate unification of GNSS and UWB systems. When positioning the container area in the port, using the container yard information in the terminal operation system, the precise plane coordinate position of each box position can be calculated and mapped to the UWB positioning base station.

- **Value of smart port solution based on proximity network**

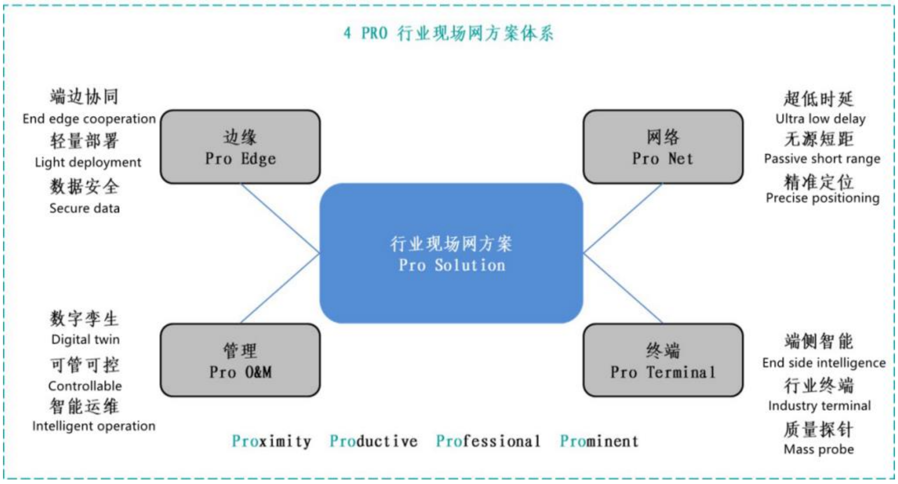
The 5G + proximity network solution will help multiple proximity network convergence and enhance the core ability of operators to empower industry field applications. Through network fusion technology, an integrated network architecture can be built to achieve flexible management of different networks, and meet the diverse demands of industry, transportation and other industries’ sensing, data transmission, positioning, control and management. The high-precision positioning scenario of the smart port is to obtain the precise location of personnel and equipment in the port area in real time through the fusion of GNSS and UWB technology, strengthen the management of personnel, equipment and assets, reduce the safety hazards caused by staff's irregular operation, improve the management level and increase the efficiency of enterprises production and management.

7 Development prospect and trend of proximity network

To meet the diverse requirements of various verticals, enterprise network in the present stage cannot provide optimal solutions in diverse vertical application scenarios, including time delay, power supply, cost, bandwidth, reliability, etc.

As an extension of enterprise network, proximity network can make up for the shortcomings of the current network and to build a complete enterprise network. China Mobile will use its own network capabilities, to achieve network adaptation based on the industry requirements, and build a "4 PRO proximity network solution system".

Figure 7-1 4 PRO system of proximity Network



The 4 PRO proximity network solution system includes Pro Edge (edge), Pro Net (network), Pro O&M (operation and management), Pro Terminal:

- **Pro Edge**

The key technologies of Pro Edge include the collaboration of terminal and edge, lightweight deployment, and data security, etc.

On the one hand, there are a large number of heterogeneous terminals in the industry field, and data cannot be interconnected. Through the collaboration of terminal and edge, device abstraction can be realized, the hardware differences of the device can be shielded. Devices with different protocols and different data formats can be connected and dispatched uniformly, realizing the unified management of devices by proximity network. On the other hand, proximity network is an extension of the enterprise network, making it possible for the services originally deployed on the edge to sink to devices. Lightweight deployment technology uses lightweight virtualized containers to provide an operating environment for the deployment of services on devices. Moreover, with the integration of 5G and industry proximity network, 5G enterprise networks characterized by the sinking of UPF will be widely used in proximity network. UPF deployed on the user side will offload data to the edge computing platform for processing, so that user data can stay in the local side, which ensure the data security.

- **Pro Net**

The key technologies of Pro network include ultra-low latency, passive IoT, short-range communication, precise positioning, etc. Ultra-low latency will combine the short-range communication technology and high-reliability communication technologies such as TSN to solve the application problem of equipment remote wireless control. Passive IoT and precise positioning technology will solve the problems of asset management and equipment and Personnel positioning. These pro net technologies work together to meet the differentiated demands of various scenarios in verticals, and realize the full-process management and control of personnel, equipment, and materials, thus facilitate the informatization of industrial production.

- **Pro O&M**

The key technologies of Pro O&M's include digital twins, manageable and controllable, and intelligent O&M, etc.

There are many application scenarios of proximity network, resulting in network heterogeneity and customization. However, customers have gradually increased their demands for network construction and O&M. Traditional O&M teams and non-automated process models are gradually unable to meet the requirements of proximity network O&M. Therefore, combining digital twin information modeling and intelligent O&M technologies, and researching and developing the proximity network O&M platform based on digital twin can realize the visibility, manageability and control of proximity network, thereby reducing O&M costs and improving efficiency.

- **Pro Terminal**

The key technologies of Pro terminal include device-side intelligence, industry terminals, quality probes, etc.

The flexible deployment and O&M of 5G/IoT services, specialized industry terminals and end-side intelligence will help 5G be more widely used in traditional industrial scenarios, as well as informatization and intelligent upgrades, to meet the diverse requirements of terminal forms and terminal services. And through the IoT service quality probe SDK deployed in 5G gateways or modules, it provides monitoring, analysis and alerting services for key information such as field-level device status/network coverage/service quality, effectively enhancing the end-side value and providing an effective information source for the proximity network O&M platform based on digital twin.