# GTI
# Digital-Intelligent Base Station Site Technology White Paper

# *GTI Digital-Intelligent Base Station Site Technology White Paper*

| | |
|---|---|
| **Version:** | v_1.0 |
| **Deliverable Type** | ☐ **Procedural Document**<br>☑ **Working Document** |
| **Confidential Level** | ☐ **Open to GTI Operator Members**<br>☐ **Open to GTI Partners**<br>☑ **Open to Public** |
| **Program** | 5G/6G Program |
| **Project** | Technology Evolution |
| **Task** | 5G-A New Tech Application |
| **Source members** | CMCC, HUAWEI, ZTE, CICT Mobile |
| **Support members** | NOKIA, Comba, Ruijie Networks, AsiaInfo, Veenzhen |
| **Editor** | Lei Cao (CMCC), Guizhen Wang(CMCC), Yan Bu(CMCC), Ye Xing (CMCC), Yurong Tang (CMCC), Peiqi Wu (CMCC), Yulu Zhang (CMCC), Kang Xu (CMCC), Bangrui Zhu (CMCC), Yana Zheng (CMCC), Qingling Wang (CMCC), Yushu Jiang (CMCC), Nairong Jiang (CMCC), Wei Yang (HUAWEI), Song Deng (HUAWEI), Qinghua Lan (HUAWEI), Wei Ren (HUAWEI), Zhanghuan Li (HUAWEI), Gaozhen Qi (HUAWEI), Xiwen He (ZTE), Cheng Guo (ZTE), Jingyu Zhang (ZTE), Jianhua Chen (ZTE), Keke Su (ZTE), Gang Zhang (ZTE), Yanrui He (ZTE), Enqiao Li (ZTE), Lewei Hu(CICT Mobile), Mingyu Xu(CICT Mobile), Yi Chen(CICT Mobile) |
| **Last Edit Date** | |
| **Approval Date** | |

# Document History

| Date | Meeting # | Version # | Revision Contents |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |

# Table of Contents

# 1 Executive Summary

Amid the deepening integration of 5G-Advanced (5G-A) and artificial intelligence (AI), wireless networks are undergoing a transition from fundamental "connectivity" services to advanced "intelligent" services. As the core carriers of wireless networks, base stations—through their developmental forms and technical capabilities—not only directly determine the upper limits and value boundaries of network service capabilities but also serve as the critical foundational support for the deployment of new services, the exploration of new scenarios, and the incubation of new capabilities.

In response to this development trend, the white paper has innovatively proposed the "One Infrastructure, Three Layers, Three Domains" digital-intelligent base station site technology architecture. Vertically, it builds a three-layer progressive structure of "perception-decision-application". Horizontally, it forms a three-domain collaborative model covering "operation and maintenance, energy efficiency, and services", creating an integrated system where digital and intelligent technologies are deeply integrated. Supported by a digital-intelligent infrastructure foundation, this architecture enables precise perception of various site elements, provides on-demand deployable and elastically scalable computing resources, and delivers cross-layer, cross-domain scenario-specific solutions. This drives the evolution of base stations into comprehensive nodes that integrate "connectivity, sensing, computing, and intelligence". To date, it has applied several key technologies in practice, effectively improving network operation and maintenance efficiency and user experience while significantly reducing site energy consumption, setting an industry benchmark for the continuous evolution of wireless networks.

This white paper aims to provide advanced insights and references for the industry, foster consensus on collaborative development, accelerate the innovation of research and development, as well as large-scale deployment of digital-intelligent site technologies, lay a solid foundation for the evolution of 5G-A networks and the development of future 6G.

# 2 Abbreviations

| Abbreviation | Explanation |
|---|---|
| 5G | The 5th Generation Mobile Communication Systems |
| 5G-A | 5G-Advanced |
| 6G | The 6th Generation Mobile Communication Systems |
| AAU | Active Antenna Unit |
| AI | Artificial Intelligence |
| AR | Augmented Reality |
| ASIC | Application Specific Integrated Circuit |
| BBU | Baseband Unit |
| CCU | Central Computing Unit |

| | |
|---|---|
| OTDR | Optical Time-Domain Reflectometer |
| QoS | Quality of Service |
| RRU | Remote Radio Unit |
| RAN | Radio Access Network |
| VR | Virtual Reality |
| XR | Extended Reality |
| O&M | Operation and Maintenance |
| NMS | Network Management System |

# 3 Overview of Digital-Intelligent Base Station Site

## 3.1 Current Challenges

As AI technology becomes deeply integrated with the Radio Access Network (RAN), wireless networks are evolving from basic connectivity services to advanced intelligent services. As the core carrier of wireless networks, the digital-intelligent level of base stations serves as a crucial foundation for building high-level autonomous networks. Aiming for the development goals of ultimate experience, simplified operation and maintenance, and ultra-low energy consumption, traditional sites still face challenges in resource allocation, operation and maintenance modes, and energy efficiency management:

**Resource Allocation:** New services such as the Metaverse, embodied AI, and AI assistants are continuously emerging. These services are diverse, rapidly evolving, and highly dynamic. The traditional single-site fixed resource model struggles to adapt to dynamically changing computing power demands, and cannot achieve on-demand resource allocation and elastic scaling based on service dynamics. When faced with varying resource requirements and development uncertainties, this often leads to redundant resource allocation and inefficient utilization, driving up construction costs.

**Operation and Maintenance Mode:** Site equipment includes main equipment as well as multiple types of supporting facilities such as antenna and feeder systems, transmission, power supply, and clock links, resulting in a complex equipment system. Currently, each piece of equipment is maintained independently, making unified management and coordinated decision-making impossible. It is difficult to dynamically optimize network element configurations based on real-time data such as network status, load capacity, and user distribution. Meanwhile, passive devices cannot sense topological relationships or fault locations in real time. Operation & maintenance and fault handling rely on manual intervention, and overall operation and maintenance efficiency needs improvement.

**Energy Efficiency Management:** There is a lack of coordinated interaction between base station equipment and the power supply system, making it difficult to achieve optimal energy savings while ensuring service experience. Existing energy-saving measures mostly involve shutting down some RF channels, carrier frequencies, or putting entire sites into sleep mode during low-traffic periods. More precise energy-saving control is needed, taking into account multi-standard, multi-band network characteristics, differentiated service scenarios, and user demands, so as to enhance low-carbon site operation and carbon reduction capabilities.

## 3.2 Evolution Drivers

In response to the above challenges, there is an urgent need to improve site resource utilization, operational agility, and green development capabilities to build a new generation of digital-intelligent infrastructure. Driven by service demands, and technological innovation, the digital-intelligent evolution of sites has become an inevitable trend.

**Service Demands:** The digital transformation of various industries is accelerating, with new services and scenarios constantly emerging, placing higher demands on wireless networks and driving the evolution of sites toward intelligence, service orientation, and integration. Emerging services such as XR/Metaverse immersive interaction, embodied AI applications, low-altitude intelligent connectivity, smart transportation systems, and remote industrial control pose stringent challenges to bandwidth and latency. There is an urgent need for sites to build near-end computing power pools that integrate access, computing, and intelligence, enabling local data rendering and intelligent reasoning to guarantee low-latency, high-reliability immersive service experiences. Emerging services develop rapidly and change frequently, placing higher demands on resource elasticity, intelligent scheduling, energy efficiency, and deployment efficiency. This forces the innovation of traditional site architectures and operation models, driving the construction of new infrastructure that is flexibly reconfigurable, intelligently schedulable, green, and efficient, thereby supporting the large-scale, high-quality development of digital applications.

**Technological Innovation:** Cutting-edge technologies such as artificial intelligence, environmental sensing, and digital twins are being increasingly integrated into communication networks, continuously injecting momentum into the digital-intelligent evolution of sites. The deep integration of AI with the radio access network not only optimizes network performance but also empowers capabilities such as site traffic prediction, resource scheduling, and fault self-healing. Environmental sensing technology enables real-time collection of multi-dimensional data including equipment,antenna and feeder systems, energy, transmission, and environmental conditions providing a complete data source for intelligent analysis. Digital twins, by creating virtual mirrors of physical sites, enables state mapping, policy simulation, and continuous optimization, driving the transformation of operation and maintenance models from passive manual handling to active predictive autonomy, thereby comprehensively enhancing the intelligence level and operational efficiency of sites.

## 3.3 Core Objectives

Digital-intelligent base station sites aim to create intelligent infrastructure featuring full situation digital perception, flexible computing deployment, intelligent resource orchestration, endogenous intelligent decision-making, and open collaborative capabilities. They will gradually build a site-level digital twin system to enhance network operational efficiency, reduce operating costs, and empower service innovation.

**Full Situation Digital Perception:** Through smart sensors and hardware equipment, achieve accurate data collection and fusion analysis of all site elements—including base station equipment, energy, transmission, antenna and feeder systems, and environmental conditions—breaking down data silos and enabling visualized intelligent operations and maintenance.

**Flexible Computing Deployment:** Build a hierarchical, scalable wireless computing foundation that enables the pooling of computing resources across multiple base stations and the centralized deployment of AI capabilities. This ensures efficient deployment of various services and enables flexible scheduling and on-demand allocation of computing resources.

**Intelligent Resource Orchestration:** Establish dynamic, adjustable, and reconfigurable capabilities ranging from software parameters to hardware resources. Enable on-demand, dynamic, and fine-grained scheduling of network resources based on actual service requirements, maximizing spectral efficiency and resource utilization.

**Endogenous Intelligent Decision-Making:** Support sites in autonomously performing parameter optimization, fault prediction, root cause localization, policy generation, and other operations, thereby improving overall site operation and maintenance efficiency, energy utilization efficiency, and network operational stability.

**Open Collaboration and Sharing:** Expose "atomic capabilities" of sites—such as sensing data, computing resources, and scheduling authority—to upper-layer platforms. This enables flexible invocation and unified orchestration of capabilities, empowering more innovative applications.

# 4 Digital-Intelligent Base Station Site Architecture System

## 4.1 Overall Architecture

Digital-intelligent base station sites take digital-intelligent infrastructure as the foundation. It forms a system with a vertical division of perception, decision and application layers, and a horizontal coverage of operation and maintenance, energy efficiency and service domains. Real-time multi-dimensional data collection is realized via full situational perception. By enabling comprehensive perception, it collects multidimensional data in real time and leverages cross-layer and cross-domain data fusion analysis to generate intelligent optimization and decision-making, transforming analytical outcomes into executable service applications. In the operation and maintenance domain, predictive maintenance and automated closed-loop management are implemented to improve system reliability and stability. In the energy efficiency domain, smart energy conservation and low-carbon operation are achieved to cut energy consumption throughout the entire processes. In the service domain, the system supports experience optimization and service innovation, so as to enhance network quality and user experience.

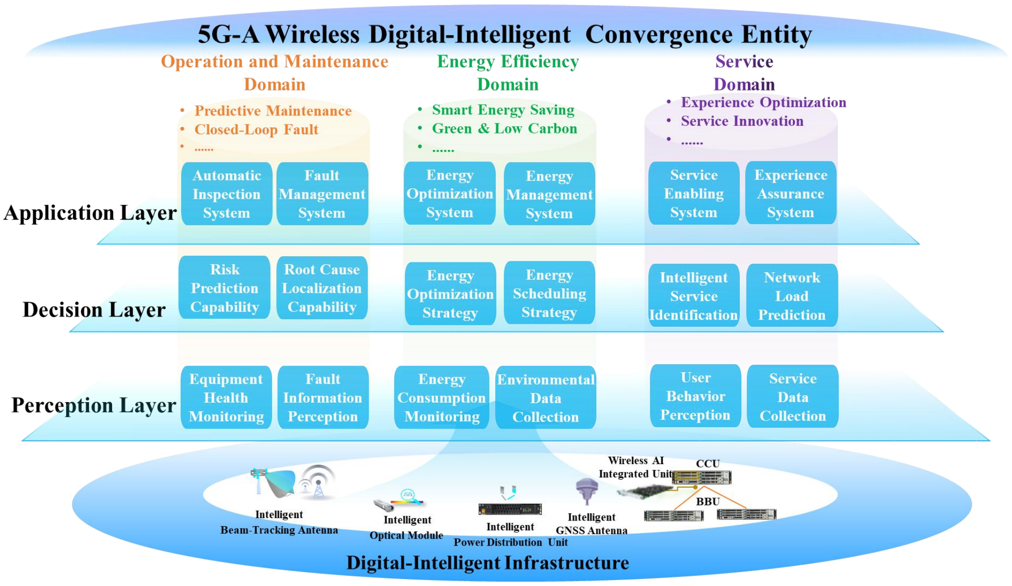


Figure 4. 1 Digital-Intelligent Base Station Site Overall Architecture

## 4.2 Vertical Three Layers

### 4.2.1 Perception Layer

As the system's "eyes" and "nerve endings", the perception layer is responsible for acquiring and monitoring comprehensive data from site elements—including equipment status, clocks, power, and optical links, providing a reliable data foundation for the decision layer. It serves as the essential support for achieving intelligent operations and maintenance and refined management.

The details are shown in the figure 4.2 below, primarily including the following aspects:

- **Clock subsystem**: Sensing clock signal data, clock topology, clock synchronization status, etc.
- **Power subsystem:** Sensing electrical indicators such as voltage, current, power, as well as power supply topology information, etc.
- **Fronthaul subsystem:** Sensing optical link signal strength, device type, operating status, quality assessment of optical modules, etc.
- **Antenna feed subsystem:** Sensing engineering parameters such as azimuth, latitude and longitude, as well as the operating status of the subsystem.
- **Environmental subsystem:** Sensing the temperature, humidity, smoke, access control, water leakage of equipment room, etc.

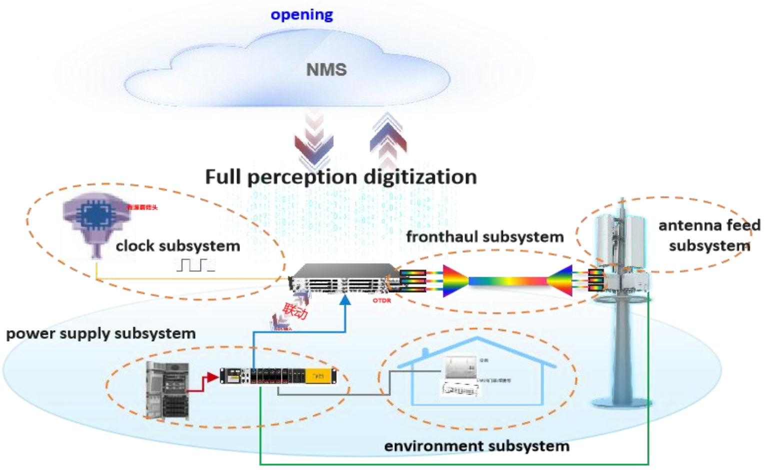


Figure 4. 2 Perception Layer Subsystem

### 4.2.2 Decision Layer

The decision layer acts as the "brain" of the system, undertaking tasks such as aggregating massive data, conducting AI computations and making intelligent decisions. It possesses the ability for autonomous analysis and optimization, and can operate flexibly in base stations, intelligent boards, wireless intelligent hubs, and network management systems.

In the domain of operation and maintenance, it integrates multi-dimensional state perception data of the sites, uses intelligent algorithms to achieve precise demarcation and location of the root cause of faults, and predict potential risks in advance. After the system outputs decision instructions, it can continuously regulate and iteratively optimize, significantly enhancing operation and maintenance efficiency and system reliability, and effectively supporting the transformation to intelligence.

In the energy efficiency domain, it real-time senses the dynamic relationship between service load and energy efficiency indicators, builds site-level and device-level energy efficiency models, combines AI technology to predict service load and energy demands, formulates optimal power scheduling and energy-saving strategies, such as device actives as needed, carrier frequency sleep, and refined backup power functions, achieving refined energy management and continuously reducing site energy consumption and operational costs.

In the service domain, based on real-time and historical data, such as service traffic, user behavior, operating status, time periods, etc. Combined with preset rules and machine learning algorithms, it generates the optimal strategy, driving the network to operate autonomously and continuously optimizing the service.

### 4.2.3 Application Layer

The application layer acts as the "limbs" of the system, mainly responsible for converting the processing results from the perception layer and the decision layer into solutions applicable in actual application scenarios. It provides one-stop services for operation and maintenance management, energy efficiency optimization, and service innovation. At the same time, it integrates an APP interface with data visualization, real-time monitoring, and remote operation functions. This further enables the high-precision positioning, computing power, and other capabilities of the site to be made available through the application layer for external services, achieving value creation.

In the domain of operation & maintenance, relying on the intelligent operation and maintenance center, a closed-loop processing of fault prediction, diagnosis, decision-making, and recovery is achieved. Combined with intelligent algorithms, the root cause is accurately located and self-healing strategies are executed, significantly reducing the cost of manual intervention and improving the automation level and system reliability of operation and maintenance.

In the domain of energy efficiency, through the energy efficiency management platform, it supports the coordinated scheduling of multiple energy sources (utility power, batteries, green power, etc.) and the issuance of device-level energy-saving strategies. Through visualization management and remote control functions, it realizes the refined management and dynamic optimization of site energy efficiency, effectively reducing energy consumption and carbon emission levels throughout the entire life cycle.

In the service domain, with the service enabling platform as the core, based on key information such as traffic prediction, resource scheduling, and user analysis generated by decision-making, dynamic resource allocation is achieved to ensure the efficient and stable operation of the service; personalized services and customization functions are provided to enhance user experience, drive service innovation and value growth.

## 4.3 Horizontal Three Domains

### 4.3.1 Operation and Maintenance Domain

In the current operation and maintenance system of the base station site, a large number of "dumb devices" have formed information islands due to lack of sensing capabilities. They are unable to report parameters or abnormal alarms in real time and only rely on manual inspections to respond to faults passively. At the same time, various emerging services are driving the base station site to evolve towards multi-band and multi-standard integration, making the network topology and device coupling increasingly complex. Site faults exhibit characteristics of "multiple sources, concealment, and chain linkage". The traditional solution relies on manual positioning, which is inefficient and difficult to accurately trace the cause, unable to meet the "high reliability, low latency" services requirements. This has led to an increase in operation and maintenance complexity and poses severe challenges to system reliability. The digitalized site uses "hardware blind spot supplementation + software empowerment" as a dual drive to build a full-dimensional, high-precision data perception and intelligent operation and maintenance system.

For the hardware, the focus is on "completing the perception shortcomings". By deploying intelligent sensors on existing "dumb devices" or integrating intelligent sensing units into newly constructed devices, comprehensive and real-time collection of key operational data such as electrical parameters, environmental indicators, and network performance of the devices is achieved. At the same time, intelligent network elements with computing capabilities are deployed on the upper-level platform to conduct real-time aggregation, intelligent processing, and multi-modal fusion of the massive sensed data.

For the software, through multi-dimensional correlation analysis, the underlying operating patterns and potential correlations of the devices are mined. Relying on intelligent diagnostic algorithms, the health status of the devices can be quickly identified, fault risks can be predicted, and trend predictions can be conducted based on long-term data accumulation, providing support for the optimization of equipment operation strategies, dynamic resource allocation, and future expansion planning. Ultimately, precise perception of the operating status, rapid diagnosis of abnormal situations, and prediction and warning of potential risks are achieved, thereby building a closed-loop capability from perception to decision-making, and comprehensively enhancing the intelligence level and proactive operation capabilities of the system.

### 4.3.2 Energy Efficiency Domain

Under the background of the large-scale deployment of 5G networks and the acceleration of digital transformation, the demand for data traffic continues to rise, the network load significantly increases, and the power consumption problem of base stations becomes increasingly prominent. With the continuous growth of power costs for base stations, saving electricity has become an important means to reduce the operating costs of telecommunications. Traditional energy-saving measures for base stations are carried out the shutdown process in a straightforward manner, such as closing some radio frequency channels, carrier frequencies, or shutting down the entire station during low-traffic periods. However, due to objective factors such as multi-system multi-band networking, complex service scenarios, and differences in user perception requirements, it is difficult to implement energy-saving solutions in a "one station, one time, one strategy" manner for precise and efficient implementation.

Digital-intelligent base station sites, through full situational perception and intelligent algorithms, can significantly reduce energy consumption, improve overall energy efficiency, and achieve efficient collaboration between services and the entire station. By integrating the dynamic matching among power supply, energy storage, energy consumption and service loads, it is possible to intelligently adjust resource allocation based on real-time service loads, achieving "energy following service", comprehensively enhancing energy utilization efficiency, reaching the optimal energy efficiency of the entire site, and building an efficient and green future base station site.

### 4.3.3 Service Domain

Under the background of new services integration and the continuous evolution of 5G-A, the cross-industry digitalization process is continuously deepening, driving fundamental changes in users' demands for services domains. Current demands are evolving towards intelligence, integration, guaranteed experience, and high flexibility. The traditional base station architecture centred on communication services is unable to cope with the challenges of diverse scenarios. Relying on the intelligent foundation platform, the digital-intelligent base station sites have achieved cross-domain integration of computing resources and intelligent elastic deployment, which can effectively support various high-real-time and quasi-real-time services at low cost, providing basic capability support for experience optimization and service innovation.

In terms of service experience, it is necessary to shift from the traditional "do one's best" model to a "guaranteed certainty" model. New services require that the service domain possess the ability to perceive and guarantee end-to-end experience. Relying on the wireless intelligence-based foundation platform, global dynamic scheduling of wireless resources and multi-domain collaborative optimization are achieved, significantly enhancing the system-level throughput and certainty service capabilities. By relying on real-time perception of massive data, including user plane XDR data and MR measurement reports, the network can respond and optimize independently within milliseconds for complex services requirements, significantly improving resource utilization efficiency and service reliability, and providing a stable and high-quality wireless environment for high-concurrency and multi-type industrial applications.

In terms of the service model, it is necessary to complete the transformation from "standardized packages" to "personalized and integrated solutions". Users are no longer satisfied with a single connection service, but urgently need integrated solutions that are tailored to specific scenarios. The services domain should be based on AI and big data analysis capabilities, accurately identify and understand the user behaviors and services characteristics of different industries, generate fine-grained service precise identification, and accordingly dynamically construct an " connection + computing power + application" integrated customized service plan, achieving intelligent matching of resources and real-time distribution of strategies. Through the end-to-end data loop, continuously evaluate and iterate strategies for service experience, and continuously improve the service quality and satisfaction of users throughout their entire life cycle.

# 5 Key Technologies of Digital-Intelligent Base Station Site

## 5.1 Digital-Intelligent Foundation Technology

### 5.1.1 Digital Foundation Technology

#### 5.1.1.1 Digitalization of Power Supply

The traditional power supply system of a base station site is usually composed of "dumb devices" such as air switches, rectifier modules, and backup batteries. The system lacks intelligent perception, collaborative analysis, and remote management capabilities, resulting in a lack of efficient energy management, limited energy-saving effects, and difficulty in pinpointing the specific cause when the system fails. Moreover, the capacity and health status of the backup batteries cannot be monitored in real time, making it impossible to formulate precise backup strategies, which affects the duration of critical service operations.

To address these pain points, the digital power system should possess capabilities such as topology perception, potential risk prediction, and fault location:

- **Power topology perception capability:** It mainly consists of two parts. One is power supply topology perception, which is to identify the power supply relationship between the power supply and the base station. The other is distribution topology perception, which is to identify the connection relationship between the load equipment and the distribution ports.
- **Power supply risk prediction capability**: It includes micro-fault detection, deterioration trend prediction, and services resilience estimation, etc.
- **Power fault detection capability:** This includes detection of power outage from the mains supply, detection of abnormalities at power and distribution ports, and detection of abnormal line length and diameter.
- **Backup power status monitoring capability:** The power system is required to interface with the backup battery through a standard communication protocol, enabling real-time monitoring of the type, remaining capacity, temperature, charging and discharging status of the backup battery.

To match the aforementioned digital power capabilities, the digital power system is centered around the distribution unit. By introducing multiple functional modules at the hardware of the distribution unit, it achieves the required functions:

- **Data interaction module:** It supports real-time data interaction with the background network management system, backup power unit, green power equipment, and AAU/RRU load equipment, enabling precise collection of information such as power supply status, battery capacity, and photovoltaic power generation, as well as the issuance of instructions.
- **Multimode sensing module:** It deploys multiple high-precision temperature, humidity, current and voltage sensors at the power distribution ports, key contacts and inside the intelligent power distribution unit to monitor the transmission status in real time. It supports temperature over-limit alarms for the ports and automatic power-off protection, and can

intelligently regulate the rotational speed of the cooling fans to effectively prevent overheating risks.

- **Intelligent control module:** It not only supports the execution of remote timed power-on/off strategies and intelligent switching of multiple power input channels, but also enables coordinated power distribution with the backup battery, allowing it to automatically select the optimal power supply path based on service peaks and troughs and electricity price strategies, thereby improving energy utilization efficiency and operational economy.
- **Protocol integration module:** It supports standard communication protocols to interface with backup power batteries of different platforms. By obtaining backup power information, it enables the battery to cooperate with the backup power system for power distribution, thereby enhancing the efficiency of the backup power battery usage. Currently, backup power batteries of different platforms cannot communicate with the power system due to the lack of communication standards. A unified standard communication protocol will be introduced in the future.

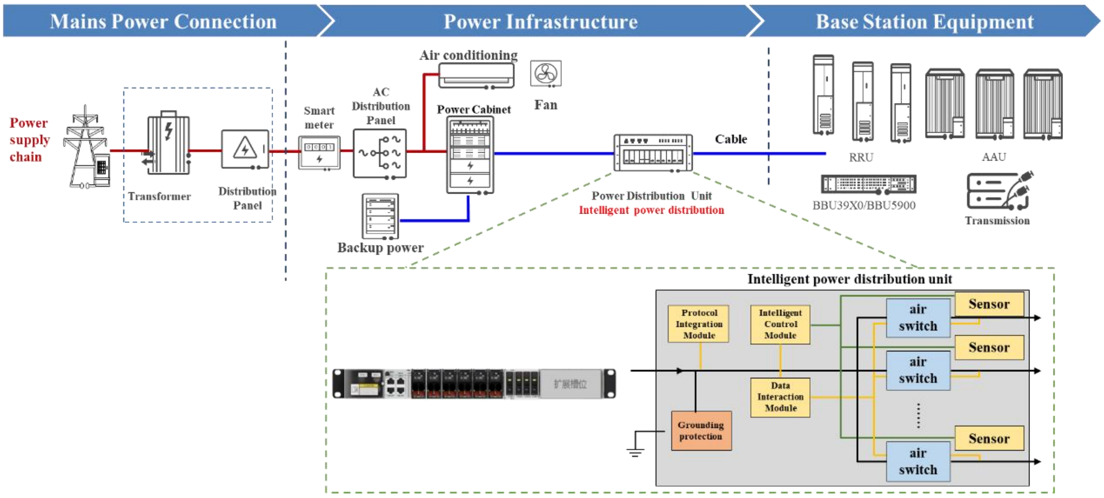
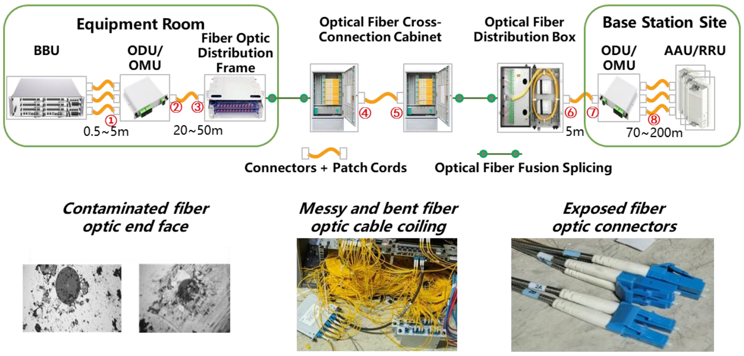


Figure 5.1 Digital Power Supply System

This modification upgrades the power supply from an "energy consumption isolated unit" to a "smart energy core" for the site. By collaborating with the network management platform, it supports the realization of automation in operations and maintenance as well as the goals of green and low-carbon.

### 5.1.1.2 Fronthaul digitalization

The traditional fronthaul network connects BBU with AAU/RRU through passive optical fiber links. The link topology is complex and involves various devices such as optical modules, optical connectors, and optical switching boxes. The core problem lies in the inability to perceive the optical path quality, topology connection relationship, and fault location in real time. This makes the fronthaul network an "invisible and uncontrollable" "black box". In case of poor reception optical power or interruption, it is necessary to manually carry an OTDR device to conduct section-by-section troubleshooting at the station. The fault detection time can last for several hours or even several days, resulting in long-term service interruptions. At the same time, due to the lack of precise data on the fronthaul link, the management of fiber core resources is chaotic and the expansion planning is blind, which greatly restricts the efficiency of 5G network operation and maintenance.



**As the fiber-optic network distance in the CRAN increases, the number of optical cross-connects rises by 2 to 3 hops, the number of fiber splices increases, and non-standard engineering practices lead to a higher failure rate**

**Figure 5.2 Pain Points of Traditional Fronthaul Systems**

In response to these current network pain points, the fronthaul network should have the ability to link fault awareness, topology awareness, network action awareness, etc., to ensure the stable operation of the base station service:

- **Fronthaul fault sensing capability:** the fronthaul system should first have link-level detection capabilities, and have detection capabilities for link-level indicators such as status, transmission rate, QoS, and flicker of the CPRI/eCPRI interface. In addition, in order to reduce the frequency and duration of unplanned outages, the fronthaul system should also support device-level fault detection capabilities, which can detect the status of devices such as connectors, optical fibers, and splitters in the fronthaul link, and perceive the degradation trend of optical modules.
- **Fronthaul topology sensing capability:** the fronthaul system often forms a fronthaul network by multi-hop fiber. For the needs of actual maintenance and management, the fronthaul network topology sensing capability is also a digital essential capability. When the overall link is found to be faulty, according to the forward topology, the optical path node and optical fiber where the problem is located can be quickly located and be repaired. When expanding and changing the equipment, it is also necessary to make accurate adjustments based on the actual topology to avoid unnecessary service interruptions.
- **Fronthaul action sensing ability:** in the process of base station equipment maintenance, the fronthaul network will carry out fault maintenance, expansion and topology optimization. The digital fronthaul system needs to have the ability to detect and record the above maintenance actions, so as to facilitate the confirmation of fault repair and verification, and avoid duplication of work orders in the background. In addition, the basic data of the network runtime can also be used as a reference for the overall network planning to be recorded by the digital fronthaul system.

In order to achieve the above capabilities, the fronthaul digital intelligence realizes the deep perception and accurate diagnosis of the fronthaul link by innovatively integrating multiple hardware modules in the optical module:

- **Low-frequency photoelectric modulation module:** a special modulation unit is built in the transmission link of the optical module, which can generate and inject the fronthaul optical path detection optical signal for link diagnosis, and realize the active detection of optical fiber characteristics without affecting the normal service transmission.
- **Feedback detection link:** a high-sensitivity detection unit is added at the receiving end to

specifically collect Rayleigh scattering and non-Neel reflection light signals generated by the fiber, and convert them into electrical signals to provide raw data for subsequent analysis.

- **Micro-optical circulator:** an optical circulator is integrated at the output port of the optical module to ensure that the transmitted detection signal can be directed into the optical fiber, and the reflection/scattering signal is efficiently coupled to the feedback receiving link to achieve one-way circulation and efficient recovery of the signal.
- **Intelligent control unit:** the optical module is equipped with an independent control unit, which can quickly switch between the two modes of "normal communication" and "optical path detection" in milliseconds, so as to realize real-time or regular monitoring of the fronthaul link without affecting the service transmission.

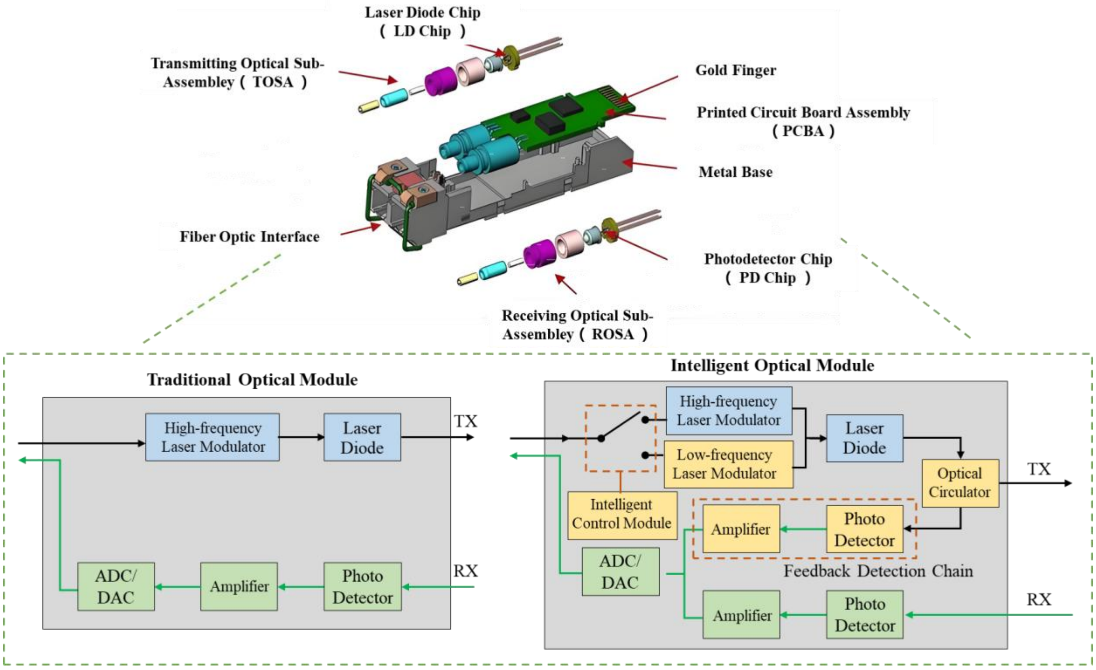


**Figure 5.3. Digital Fronthaul System**

Fronthaul data intelligence upgrades "dumb fiber" to "smart blood" of the network, which not only greatly improves the level of operation and maintenance automation, but also provides a core data base for C-RAN networking, service SLA guarantee and future forward optical network evolution.

### 5.1.1.3 Digitization of antenna feed

As a passive "dumb device", the acquisition of engineering parameters (such as azimuth angle, mechanical inclination angle, longitude and latitude) and the adjustment of antenna feed mainly depend on manual operation. Only a single mechanical adjustment of vertical inclination is supported, and the data real-time performance is poor. The parameters can not be obtained remotely and the error rate is high. The limitation of its perception and adjustment ability cannot adapt to the rapid adjustment needs of service environments such as user distribution migration and dynamic changes of traffic hot spots, which seriously affects the efficiency of network operation and maintenance.

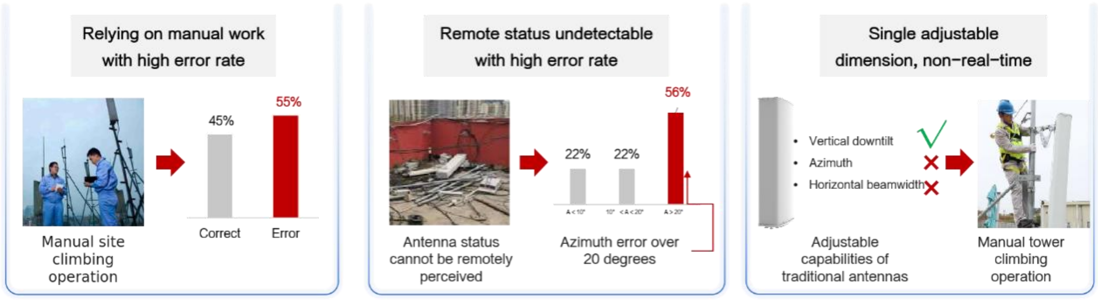


Figure 5.4. Pain Points of Traditional Antenna Feed System

As the only wireless signal transmission bridge between the base station and the end user, the transformation and upgrading of the antenna feed from "passive dumb device" to "intelligent perception and control node" has become an inevitable trend to deal with the challenges of network complexity and service diversification. The following key technologies effectively support the application and development of antenna feed digitization. The specific characteristics are as follows:

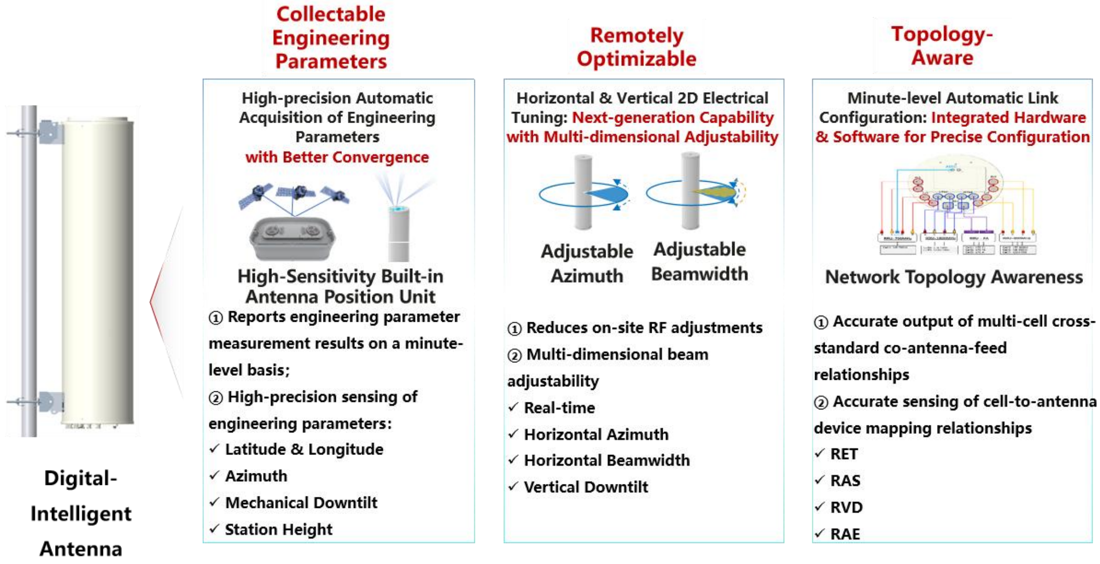


Figure 5.5. Digital-intelligent Antenna Design

- **Network topology intelligent sensing:** Through the remote electric adjustment system, the automatic detection and identification of the topological relationship between the antenna port and the port logic cell are realized. The network management automatically establishes the topological relationship and controls the corresponding antenna port for beam adjustment. Through the built-in module, it supports different channel switching, detects the cell information of the RF channel at the same time, analyzes the channel characteristics of each RF channel, and establishes the correspondence between the RF output port of the base station and the BTU input port.
- **Intelligent collection of industrial parameter information:** Antenna position unit is integrated to accurately acquire engineering parameter information such as azimuth angle, mechanical inclination angle, longitude and latitude in real-time. The antenna position unit module uses dual-star search and high anti-interference antenna design to obtain high-precision and high-reliability engineering parameter information.

- **The network implements real-time multi-dimensional tuning:** Dynamic sensing of user distribution, dynamic real-time adjustment of antenna multi-dimensional beams (including horizontal and vertical planes) based on traffic requirements, to achieve traffic excitation. By sensing the cell distribution and load state of the network, the beam width is dynamically adjusted in real time to reduce the power in the useless direction, improve the beam efficiency, and improve the energy-saving characteristics of the entire network.

#### 5.1.1.4 Clock digitization

With the increasing concentration of BBUs in communication sites, multiple BBUs use shared mushroom head antennas to reduce the number of usage and routing space. However, the entire clock link lacks intelligent monitoring and positioning capabilities. In the event of a clock failure, it can only rely on manual access to the station. The root cause of the fault is located by checking the antenna, power divider and feeder one by one, which has a long troubleshooting cycle and greatly affects the efficiency of network operation and maintenance.

The clock digitization realizes the automatic identification of the site clock topology by adding a micro-control unit and a modem to the GNSS mushroom head antenna and power divider, and using OOK (On-Off Keying) digital modulation. The connection between the mushroom head antenna, the power divider and the BBU is presented on the network management, and the serial number of the antenna, the power divider, and the port number of the power divider are displayed. When a fault occurs, the cause of the fault can be located remotely and accurately, and the station can be quickly eliminated.

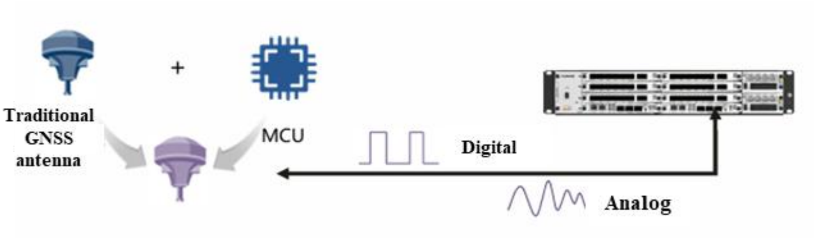


Figure 5.6. Digital GNSS Antenna

#### 5.1.1.5 Environmental digitization

- **Environmental monitoring**

Traditional site environment detection usually covers temperature and humidity, smoke, access control, water immersion, infrared and other detection functions, but these monitoring units are mostly passive devices, wireless network management is difficult to perceive the environmental state in real time, and the operation and maintenance efficiency is low. By integrating digital technology and intelligent management capabilities, the new environmental intelligent control unit realizes comprehensive monitoring of site equipment, environment and energy, intelligent analysis and efficient operation and maintenance, and supports wireless networking of site environmental sensors/equipment to achieve rapid site opening.

The intelligent control unit can monitor all kinds of equipment in real time without dead angle, accurately capture key data such as equipment operation status and environmental parameters, and pass through 4G/5G/IP/GE/POE and other networks at the first time. The data is reported to the network management system, and the operation and maintenance personnel can keep abreast of the site dynamics and find potential problems in time. In terms of data security, the intelligent control unit supports the operation data and logs of the proximal storage device. Even if there is a failure in communication with the system, it can effectively avoid data loss, ensure the integrity and continuity of data, and provide a reliable basis for subsequent data analysis and troubleshooting.

At the same time, the system has excellent intelligent scheduling and analysis capabilities. It can deeply analyze and process the collected equipment operation data and environmental data, realize intelligent scheduling in combination with preset strategies, optimize the equipment operation mode, and improve the overall operation efficiency of the site.

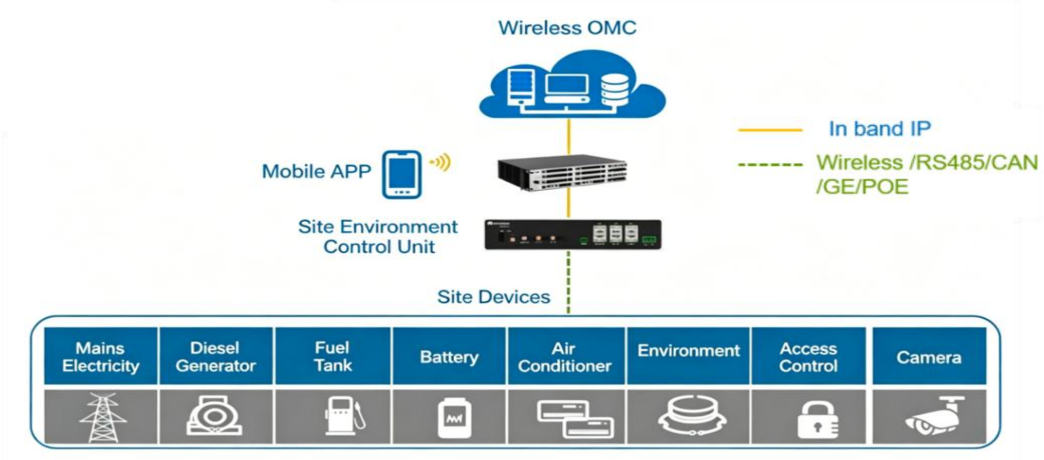


Figure 5.7. Intelligent Control Unit

- **Equipment temperature control**

Traditional communication sites generally use air-cooled heat dissipation schemes (such as room air conditioning, equipment fans), which have problems such as low heat dissipation efficiency, high energy consumption, high noise, and heavy maintenance. At the same time, with the advancement of the minimalist transformation of the communication machine room, the number of BBUs has been increasing. For the development of emerging services such as AR/VR/XR, the demand for computing power to enter the site machine room has increased significantly. With global warming, the number of high-temperature warnings in the machine room has increased. Therefore, it is particularly critical to introduce more effective heat dissipation technology into the site machine room.

BBU air-liquid mixing cabinet is a new green energy-saving room temperature control scheme for centralized deployment of communication equipment (BBU and other transmission equipment) and heat dissipation by natural cold source. The air-liquid heat exchanger is built in the cabinet, and the BBU transfers heat to the liquid working fluid in the air-liquid heat exchanger under the action of wind, and the hot air turns into cold air and reenters the BBU; the liquid working medium absorbs the heat of the equipment and becomes a high-temperature liquid. Driven by the pump, it flows outdoors to transfer heat to the outdoor air and becomes a low-temperature liquid. The air-liquid heat exchanger once again enters the cabinet to absorb the heat of the equipment, so that the cycle completes heat exchange and transfer.

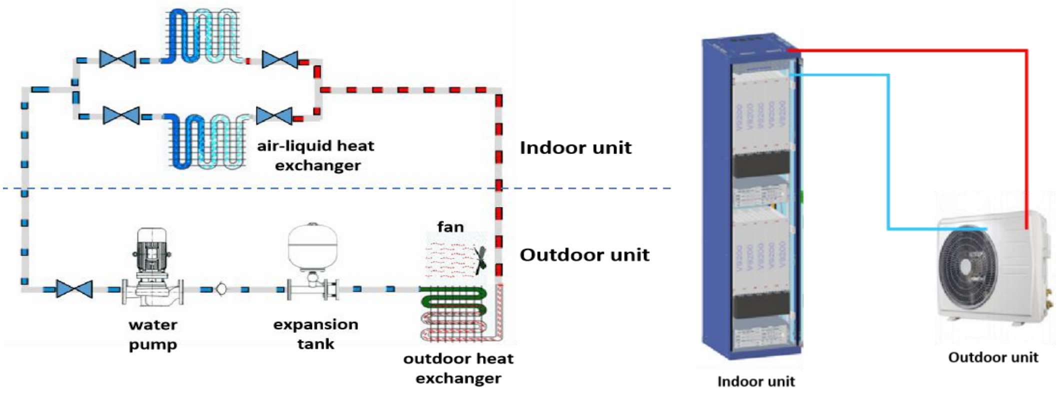


Figure 5.8. Schematic Diagram of Air-liquid Mixing Cabinet

The air-liquid mixing cabinet has the characteristics of high reliability and easy deployment. The coolant is not in direct contact with BBU equipment, which completely avoids the risks of device corrosion and optical module failure caused by liquid leakage. At the same time, it retains the equipment form of traditional air-cooled cabinets (such as 19-inch standard cabinets) and delivery operation and maintenance mode. It does not need to make substantial changes to existing network equipment, and supports the replacement of original cabinets or the rapid deployment of new Intelligent equipment rooms. After adopting this scheme, the PUE (power use efficiency) of the newly built and rebuilt communication room can be as low as 1.3 or less, and the air conditioning energy consumption of the room can be saved by more than 50%.

### 5.1.2 Intelligent Foundation Technology

With the acceleration of 5G-A commercial deployment and the deep integration of AI technology and RAN, network performance continues to increase. At the same time, diversified emerging applications represented by customer differentiation guarantee, low-altitude intelligent connection, embodied intelligence, immersive experience, and intelligent transportation are booming, which puts forward higher requirements for dynamic allocation and efficient supply of wireless network computing resources. At the same time, the digital foundation base realizes the comprehensive perception and aggregation of multi-dimensional data such as power supply, fronthaul, antenna feed, clock and environment. However, in order to complete the key leap from "digitization" to "intelligence", it is necessary to rely on the computing power resources to carry out in-depth processing, analysis and strategy transformation of the original data, and transform the data value into the core competence of network operation and service.

As the core infrastructure for carrying network functions and services, the computing power supply of sites faces many challenges, such as large differences in demand for multi-service resources and uncertain development scale. The traditional "single station fixed resource allocation" mode is difficult to adapt to the changing application scenarios flexibly, which is easy to cause resource redundancy and cost increase. It is urgent to build a new intelligent infrastructure that can be deployed on demand and flexibly expanded to support the long-term stable development of emerging applications.

In order to meet the above requirements, this white paper has innovatively proposed a new architecture for intelligent integration of 5G AI base stations, constructed a three-tier collaborative system of "centralized computing + distributed processing+signal coverage", and created a wireless intelligent base with the characteristics of "sustainable, high flexibility and low cost". The architecture introduces an intelligent centralized processing layer on the basis of the traditional BBU + AAU, and innovatively designs a new intelligent centralized computing unit CCU. At present, the form of Wireless AI Integrated Unit is adopted to realize the pooling of computing resources among multiple base stations and the centralized deployment of AI capabilities. As the "intelligent brain" of the base station, the centralized computing unit supports centralized operation and differentiated reasoning of multiple types of AI models, and provides efficient and flexible computing services for multiple applications.

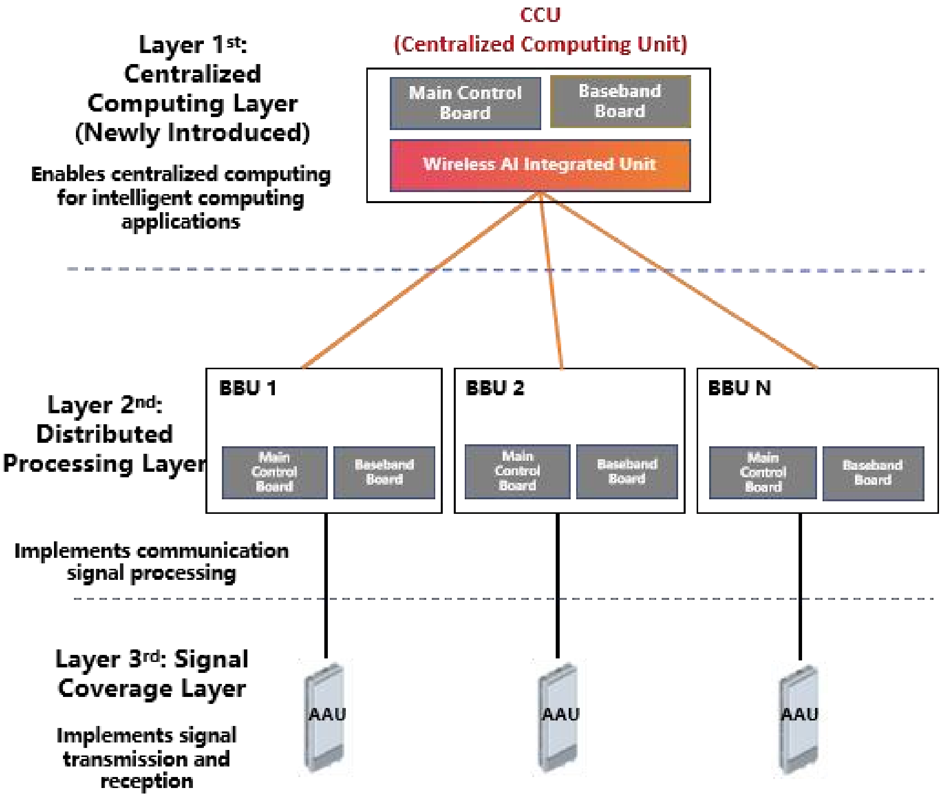


Figure 5.9. New Architecture for Intelligent Integration of 5G AI Base Station

1.Sustainable: compatible evolution, smooth upgrade

The new architecture adopts forward compatible design in wireless air interface, fronthaul interface, backhaul interface, etc., selects a certain proportion of baseband processing units in the current network, and can be smoothly upgraded to a centralized computing unit by inserting a Wireless AI Integrated Unit. Do not replace the existing network equipment, does not affect the existing service operation, to maximize the protection of pre-investment. The architecture has pre-planned multiple evolution paths. According to the development needs of future applications, it can flexibly choose to increase the number of boards, improve the capacity of boards, enrich the type of computing power or upgrade the form of boards to continuously support network evolution.

2.High flexibility: elastic networking, on-demand deployment

Based on elastic networking and resource dynamic scheduling technology, the topology relationship between the centralized computing unit and the baseband processing unit is dynamically adjustable. According to the resource requirements of emerging applications, an appropriate number of baseband processing units are selected to share the centralized computing unit, and the change of application scale is smoothly supported by the way of computing power elastic contraction configuration.

3.Low cost: heterogeneous sharing, dual optimal configuration

Relying on the centralized computing power unit of the Wireless AI Integrated Unit, the computing power resources required for emerging applications can be provided to multiple baseband processing units on demand, avoiding adding new hardware boards for each station and each application. The computing power unit adopts general and special heterogeneous computing power, gives full play to the advantages of general resources such as CPU and special resources such as ASIC, and realizes the optimal allocation of cost and energy consumption.

At present, the architecture has been deployed on a large scale. A single Wireless AI Integrated Unit can currently support 8 base stations, 24 cells, and 4800 users to share computing power. With the empowerment of AI capabilities, the service recognition accuracy rate is more than 95%, the video service experience is improved by 3-6%, and the energy consumption is saved by 4-9%. The efficiency of network optimization and fault handling is shortened from day level to hour level, which fully verifies the significant benefits of the intelligent base in the actual commercial environment.

In the future, with the continuous development and maturity of AI big model, digital twin and agent technology, the intelligent base base based on hierarchical base station architecture will continue to evolve into the core intelligent engine for the capability evolution of 5G-A network, and also lay a solid foundation for the future 6G network architecture.

## 5.2 Scenario-Based Solutions

The sensing capabilities of digital-intelligent base station sites provide the foundation for realizing value across the three domains. By collecting, integrating, and analyzing multidimensional data in real time, they materially strengthen coordination across energy efficiency, operation and maintenance, and services. A comprehensive digital and intelligent foundation breaks down information silos and unifies full situational perception with real-time data acquisition. On this basis, underlying resources can be tightly integrated with upper-layer service scenarios to create precise end-to-end intelligent solutions. This bridges the gap from foundational capability construction to scenario enablement and converts a stable, reliable digital foundation into efficient and sustainable service value.

In the operation and maintenance domain, intelligent management of equipment health, fault warnings, and work-order dispatch shifts operations from reactive repair to proactive prevention, reducing operation and maintenance cost and improving reliability. In the energy-efficiency domain, sensor networks and AI algorithms dynamically monitor and optimize energy consumption, resource utilization, and environmental parameters, supporting green and low-carbon operations. In the service domain, scenario modeling and demand insights use sensing data to align resource supply with service demand, optimize service processes, and enhance customer experience. Together, these capabilities establish a closed loop of data-driven operation, scenario enabling, and value creation, fully unlocking the potential of the digital and intelligent foundation.

## 5.2.1 Cross-Layer Solutions for the Operation and Maintenance Domain

### 5.2.1.1 Automatic Fault Detection

- OTDR-Based Intelligent Fronthaul Fault Detection

Digital intelligent optical transceivers, base-station detection and reporting components, the network management system, a fault management center including the work-order system, and a mobile application together form an end-to-end intelligent transport fault analysis and handling system. Automated interfaces integrate the components, while coordinated operation between field personnel and operation and maintenance systems enables efficient fault resolution.

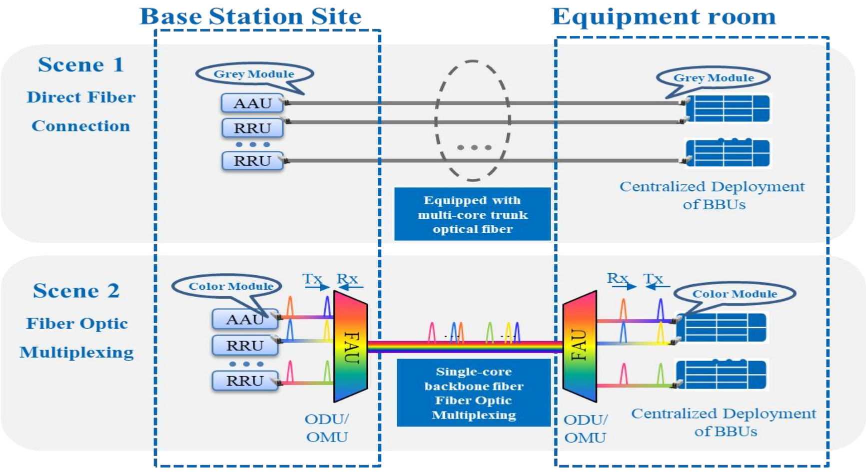


**Figure 5.10. Deployment of Intelligent Fronthaul Fault Detection**

OTDR-integrated intelligent optical transceivers are deployed at both the BBU and AAU sides. When the base station detects alarms such as a fronthaul link failure or cell outage, it automatically initiates an OTDR test at the equipment side. Optical-layer data, including backscatter and reflection traces, event loss, and reflectance, is uploaded in real time, converting the physical fiber condition into analyzable digital signals. The decision layer then combines power-supply status and optical-signal strength, applies intelligent algorithms to analyze the test signals, and compares the scattering trace with a learned healthy baseline. A machine-learning model automatically identifies and classifies event points—such as connectors, bends, and breaks—and accurately calculates the location, loss, and type of each fault. It also assesses severity, generates a diagnosis, and reports recommended actions to the operation and maintenance platform.

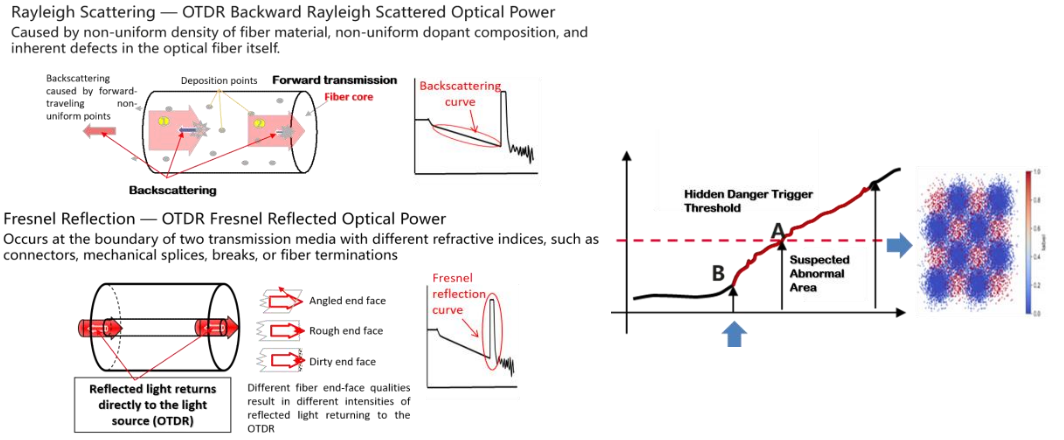


Figure 5.11. Technical Principles of Intelligent Fronthaul Fault Detection

After receiving the information, the operation and maintenance platform automatically pushes the alarm, including fault location, type, and recommended action, to the responsible personnel. It also interfaces with the resource management system to dispatch nearby technicians and spare parts. The fiber at the affected point is then repaired or replaced on site. After repair, the technician can initiate a link retest from the mobile app. The app's intelligent model remotely triggers the test and automatically produces a results report, enabling minute-level fault localization and hour-level restoration for fronthaul links.

- Topology-Aware Power Fault Detection

Conventional power fault management relies on manual inspection and alarms and cannot quickly identify root causes such as short circuits or under voltage. The new intelligent power distribution unit provides digital sensing at the perception layer. High-precision circuit-sensing modules and multiple sensors for voltage, current, and temperature collect, in real time, the direction and magnitude of utility input current, the output characteristics and connection paths of backup-power equipment such as battery banks, and the electrical characteristics of base-station equipment ports. The system accurately identifies connectivity and operating parameters across the utility–backup–equipment chain and builds an end-to-end power-system topology map. At the decision layer, real-time data is compared with predefined normal ranges and fault signatures, such as abrupt current waveforms for short circuits and sustained voltage thresholds for under voltage. Pattern recognition extracts and matches data features, while adaptive algorithms dynamically adjust fault-detection thresholds, enabling accurate fault type and location identification and efficient conversion of data into decisions.

Operation and maintenance personnel can view the topology and root-cause information from the decision layer in real time through a mobile app, and repair or replace hardware and software at the fault point. After restoration, a retest command can be issued through the app for automatic verification, avoiding repeated manual troubleshooting and significantly reducing resolution time. This completes a closed management loop across perception, decision, and application.

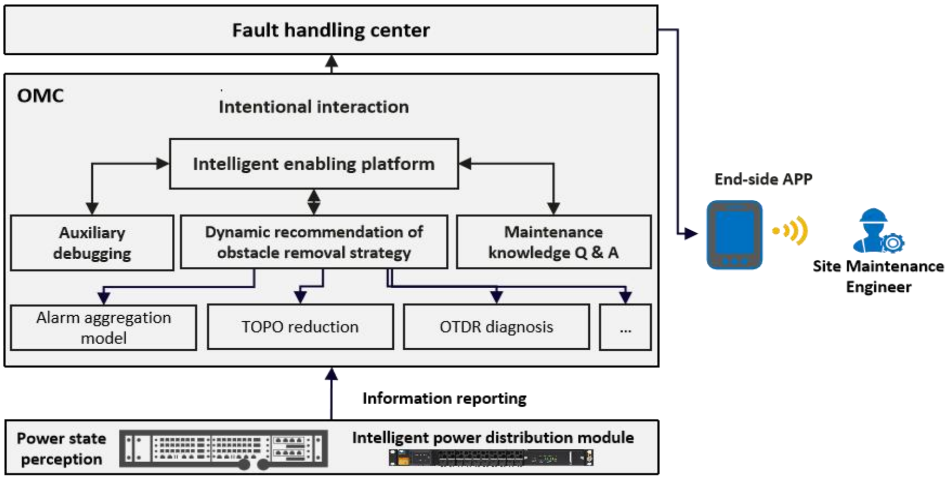


Figure 5.12. Power Fault Detection Solution

### 5.2.1.2 Proactive Risk Prediction

As 5G networks become increasingly complex and a single network carries a wider range of services, both fault volumes and handling complexity continue to grow. Proactive risk prediction is essential to maintain service stability in such an environment.

To address the difficulty of identifying latent risks in field equipment and engineering implementation, the proactive risk prediction solution evaluates network operation from multiple perspectives through key network-level modules, including outage and service-loss risk, disaster-recovery protection, transport availability, resource availability, and service KPIs. At the network-element level, it builds multidimensional profiles covering timing, hardware, power, fronthaul, environment, resources, backhaul, and configuration. Each profile focuses on a specific area, such as timing synchronization, hardware health, power stability, fronthaul-link quality, or environmental adaptability. Correlation analysis and intelligent assessment across operating status, configuration validity, and environmental fit identify potential fault points and performance degradation risks in advance. Based on the assessment, the solution analyzes each issue and provides targeted site recommendations, enabling proactive prevention and rapid remediation.

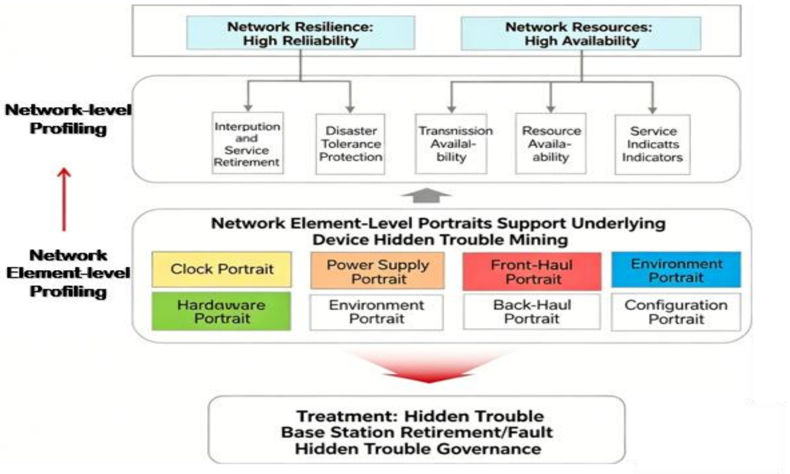


Figure 5.13. Proactive Risk Prediction Solution

For example, an excessively long power cable or an undersized conductor can cause excessive voltage drop, reducing the equipment input below its minimum operating threshold and creating a latent site risk. A cable-detection technique can build a power-supply profile. The RRU sends a time-stamped link-monitoring signal to the intelligent power module, which immediately returns a feedback signal. Cable length is calculated from propagation delay, and conductor size is derived from impedance and resistivity. This completes the power-supply profile and enables proactive risk prediction.

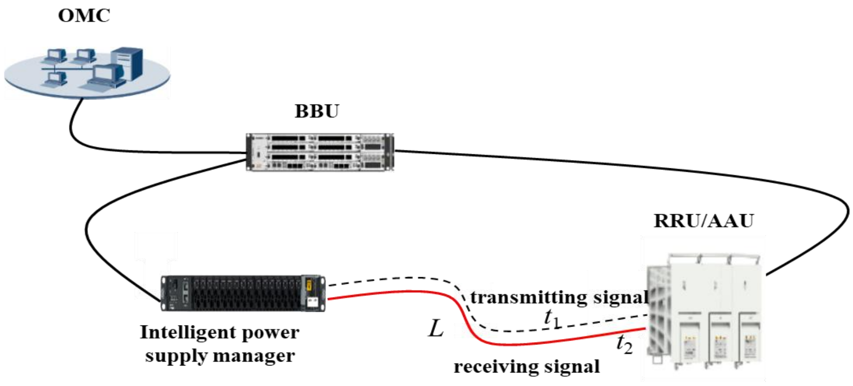


Figure 5.14. Power Cable Detection

### 5.2.1.3 Automated Site Inspection

As communications networks expand and architectures become more complex, dependencies among devices increase and a single issue can trigger cascading failures. Traditional manual inspection is inefficient, slow, and late in detecting problems, and cannot support frequent, fine-grained management of massive base-station estates. More accurate risk prediction is required. Intelligent site inspection follows the principles of high reliability, high availability, maintainability, and protection, and establishes a health-evaluation framework based on multi-agent collaboration and score-based models. A high-precision 3D model provides a digital representation of site infrastructure, main equipment, and power and environmental systems, integrating real-time monitoring with historical-data analysis. Health scores, multidimensional indicators, and AI-based predictive alarms visualize both overall site condition and detailed status, enabling minute-level health calculation, hour-level remaining-life prediction, and automatic generation of comprehensive site inspection reports.

- **Multi-agent collaboration**: Distributed agents intelligently evaluate the performance of site infrastructure and base-station equipment, automatically identify anomalies, perform initial diagnosis, and uncover patterns and potential issues in the data.
- **Multidimensional scoring model:** Four scoring dimensions—reliability, availability, maintainability, and protection—are combined with an AI-driven tiered assessment method to analyze service KPIs. Cross-dimensional analytics and algorithmic modeling convert distributed digital capabilities into intuitive quantitative scores and targeted optimization recommendations.
- **Multi-view visualization:** Dashboards and 3D models present equipment health, network performance, and environmental parameters. Pie charts, bar charts, and line charts display analytical results clearly, while detailed data can be viewed and exported to support rapid investigation of anomalies.

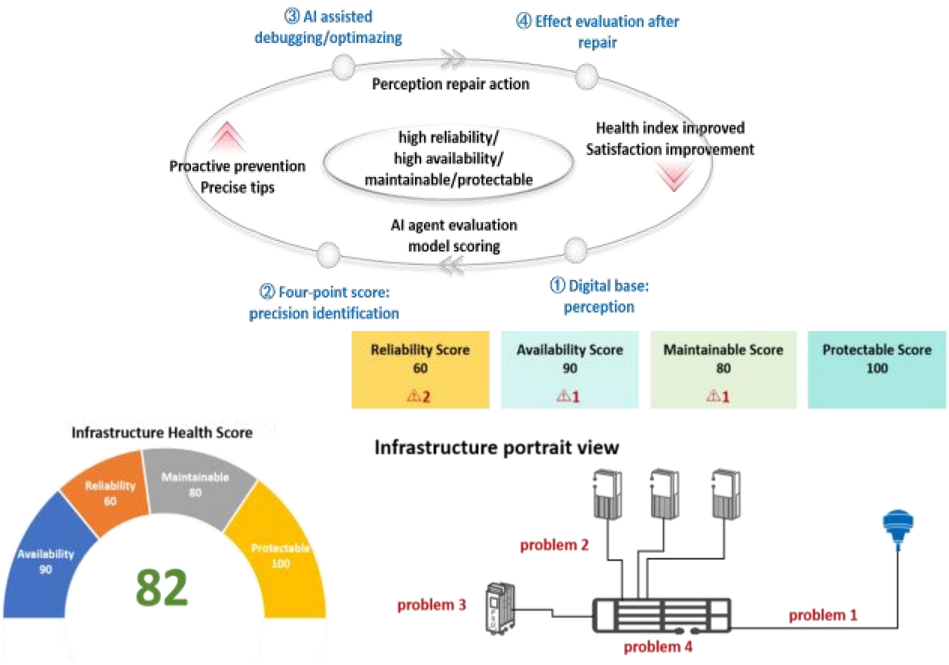


Figure 5.15. Automated Site Inspection Solution

## 5.2.2 Cross-Layer Solutions for the Energy-Efficiency Domain

### 5.2.2.1 Real-Time Monitoring and Wake-on-Demand Ultra-Deep Energy Saving

To meet peak traffic demand, 5G networks deploy large numbers of base stations across multiple frequency bands and radio access technologies. At night or in low-traffic areas, however, the network may remain lightly loaded or idle for extended periods. Keeping every cell's radio module active throughout these periods creates substantial idle energy consumption, which can account for 10–15% of daily site energy use. By deploying an intelligent power distribution unit, the network can implement wake-on-demand ultra-deep sleep at the granularity of individual radio modules. Idle resources are powered down on demand without compromising coverage or basic services, materially reducing equipment energy consumption.

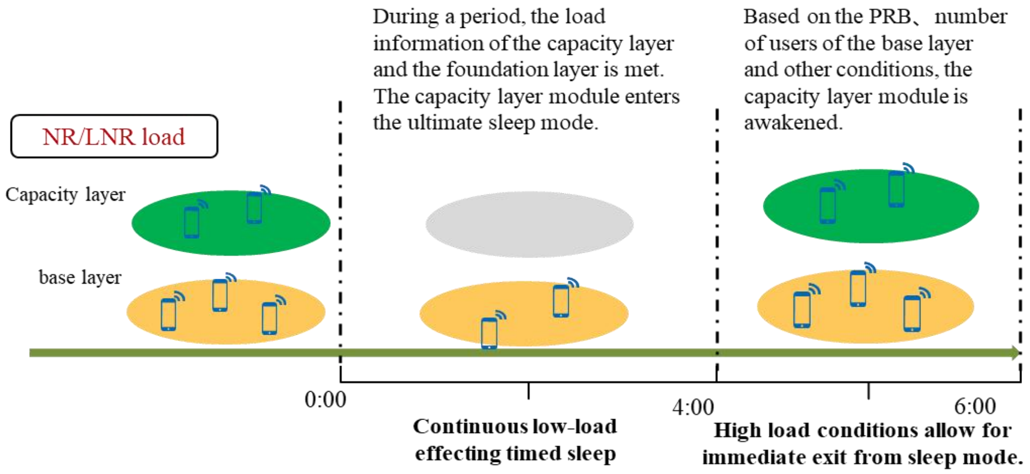


Figure 5.16. Wake-on-Demand Ultra-Deep Energy-Saving Solution

The solution is jointly implemented by the baseband unit and the intelligent power distribution unit. The power distribution unit collects hardware data in real time, including power status, current, and power consumption of the target radio module. Through the base-station interface, it also obtains service-load information for the coverage and capacity layers—such as PRB utilization, user count, and service rate-as well as time parameters such as configured off-peak periods, forming a multidimensional state-awareness matrix. Based on this data, the decision layer applies a dual-condition logic. When the configured sleep window is active and coverage-layer load is below the threshold, it triggers a sleep decision for capacity-layer radio modules, while verifying spare load in neighboring cells to ensure traffic can be migrated. When coverage-layer load reaches the wake-up threshold, it generates a wake-up command. The application layer executes the decision: the power distribution unit cuts power to the target radio module to enter sleep, with a power-off response time below five seconds, and uses cell reselection and handover signaling to move traffic to surrounding coverage cells. When wake-up is triggered, power is rapidly restored, the radio module restarts, and service resumes. User service recovery is completed within five minutes, balancing energy savings with communications quality.

### 5.2.2.2 Fine-Grained and Tiered Backup-Power Optimization

Utility-power failures account for a high share of service outages and often have long durations. Backup batteries mitigate the impact, but conventional backup solutions lack real-time coordination between power systems and service demand. They cannot apply fine-grained strategies to extend base-station online time, and sites with limited battery capacity may experience short outages. The optimized backup-power solution uses intelligent power policies to combine real-time battery state, predicted service power consumption, and service priority, automatically planning and issuing energy-saving strategies. This can extend service continuity by more than 50%.

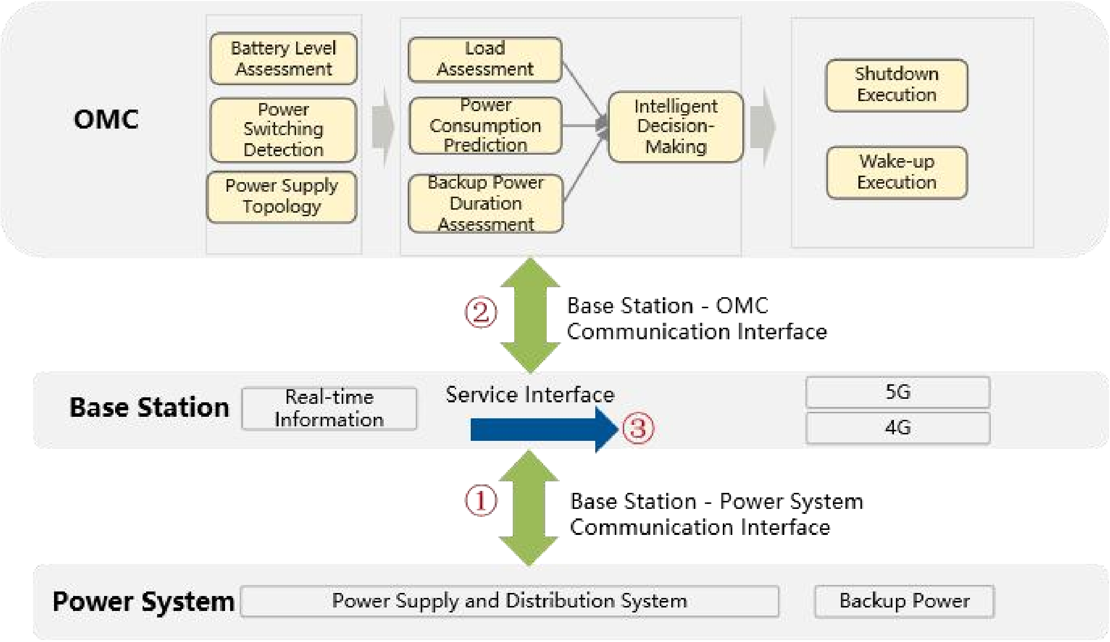


Figure 5.17. Optimized Backup-Power Solution

After a utility-power failure, the power system detects the event through voltage monitoring or dry contacts and activates the optimized backup-power function. The network management system then collects battery capacity and service energy consumption from the base station at short intervals to support strategy generation and delivery. Historical baseline traffic and energy data are used to predict future site power consumption. In parallel, the system dynamically identifies the priority of bands that may be shut down and the baseline bands that must remain active. Combining these priorities with the power forecast and real-time battery state, it calculates the additional backup duration obtained by shutting down each band. The strategy optimizer then weighs duration gain against traffic loss and selects either a traffic-loss-minimization or endurance-priority policy. After the first policy is applied, the system periodically evaluates the actual savings, automatically adjusts the strategy, and feeds the results back into the decision loop. This extends battery backup time while maintaining essential user services.

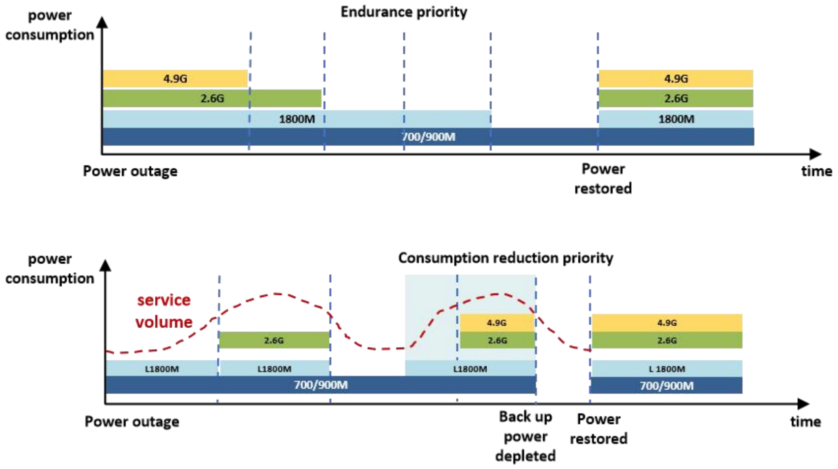


Figure 5.18. Backup-Power Strategy Selection

### 5.2.2.3 Smart Flexible Off-Peak Charging and Discharging

Electricity tariffs commonly divide each day into critical peak, peak, standard, and off-peak periods according to grid load, with different prices used to encourage time-shifted consumption. For communications sites, peak shaving and valley filling with battery storage must first protect backup reliability and battery safety. Outcomes are affected by utility outages, load fluctuations, battery capacity, and battery age. A uniform fixed configuration can therefore cause unexpected site outages or insufficient economic benefit. The required approach is to use site power forecasts and backup-duration SLA requirements to learn a site-specific depth of discharge, maximizing usable battery discharge while maintaining backup reliability. The expected energy saving is more than 3% per site.

The precise charging and discharging solution is built around the intelligent power distribution unit and battery management system (BMS). It continuously collects key parameters, including utility status, base-station load power, battery voltage, current, temperature, state of charge (SOC), and state of health (SOH), providing accurate inputs for intelligent decision-making. At an on-site control node or the network management platform, optimization models use real-time and historical data to jointly consider electricity cost, load forecasts, SOC, SOH, and other constraints. The models dynamically generate an optimal charge-low/discharge-high strategy and issue specific commands for timing, power, and SOC thresholds. The site-side intelligent scheduler, centered on a bidirectional power conversion system (PCS), then controls bidirectional energy flow between the grid and the battery, charging efficiently during off-peak periods, discharging during peak periods, and switching to battery supply during emergencies. Power to the base station load remains seamless and stable. Execution is fully automated, with status fed back in real time to the power distribution unit and BMS to form a closed control loop.

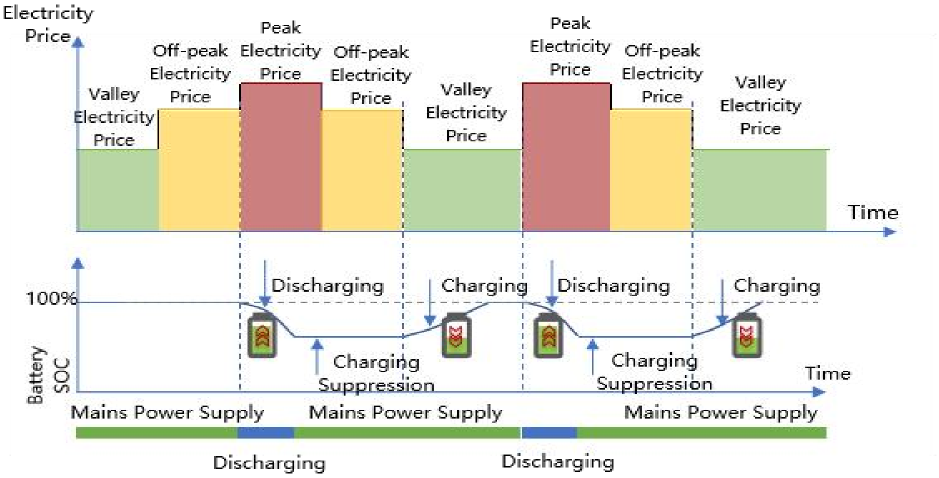


**Figure 5.19. Flexible Charging and Discharging Solution**

## 5.2.3 Cross-Layer Solutions for the Service Domain

### 5.2.3.1 Intelligent Hardware Resource Reconfiguration

As drone technology matures and industry applications expand, network terminals are becoming more vertically distributed and spatially uneven, challenging the static resource allocation of existing base stations. In areas with sparse low-altitude users, fixed resource configurations can leave resources underutilized and make it difficult to jointly optimize aerial and terrestrial coverage.

To increase terrestrial coverage gain and maximize resource utilization, the network establishes a dynamic allocation mechanism for aerial and terrestrial users. After precisely meeting the service requirements of low-altitude users, radio-channel configurations are adjusted flexibly and dynamically so that more resources can be focused on terrestrial users. This materially improves ground coverage, user experience in high-value scenarios, and overall resource utilization.

In FDD deployments, the total number of base-station channels remains unchanged, while additional RF transceiver channels and corresponding antenna elements allow fine-grained, time-domain reconfiguration at symbol or subframe granularity according to low-altitude user activity. When no low-altitude user is present, the base station enters listening mode. The air-facing RF channels are assigned to aerial coverage only during common-channel transmission and reception; at all other times, they serve terrestrial users. When low-altitude users are present, the base station enters dynamic sharing mode, allocating air-coverage time according to their traffic requirements and assigning the remaining time to terrestrial users. AI forecasting and online sensing support rapid response and optimal resource-allocation decisions throughout the process.

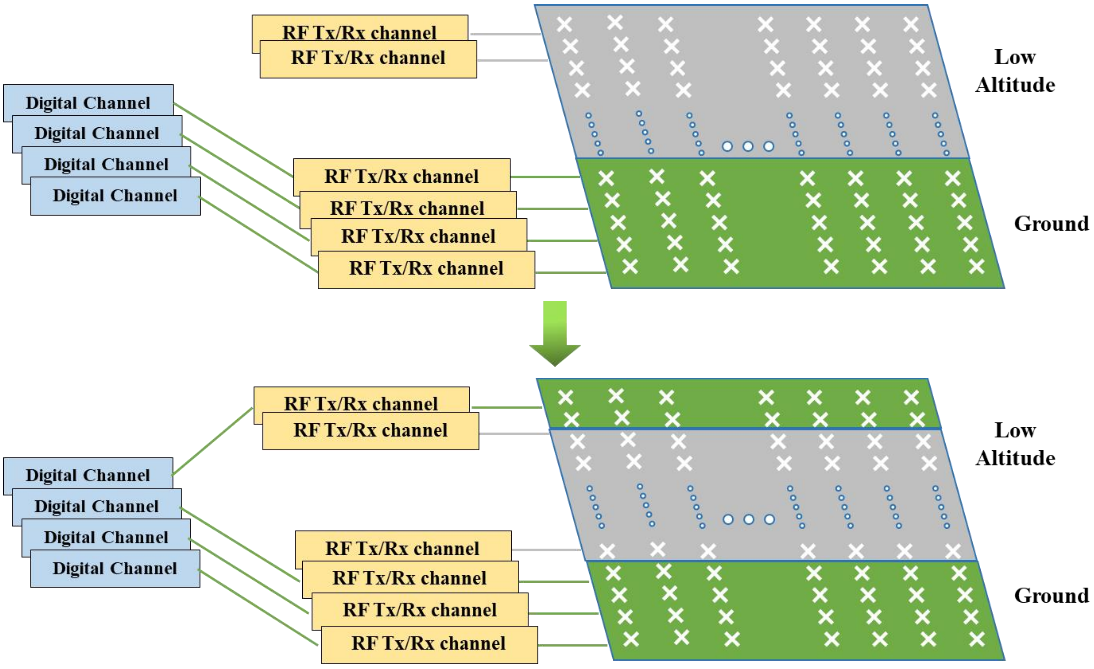


Figure 5.20. Dynamic RF-Channel Allocation in FDD deployments

In TDD deployments, AI enables cross-cell coordination and dynamic allocation of RF-channel resources. Based on historical data and online traffic forecasts, the AI model estimates the minimum number of RF channels required by the low-altitude coverage cell for current and future services. Information on shareable surplus RF channels is then delivered through inter-cell signaling to neighboring terrestrial-coverage cells. After resource negotiation and policy coordination, the cells synchronously reconfigure their RF channels at the start of the next predefined cycle, strengthening terrestrial coverage. Closed-loop control and intelligent decision-making significantly improve multidimensional resource utilization and network adaptability.

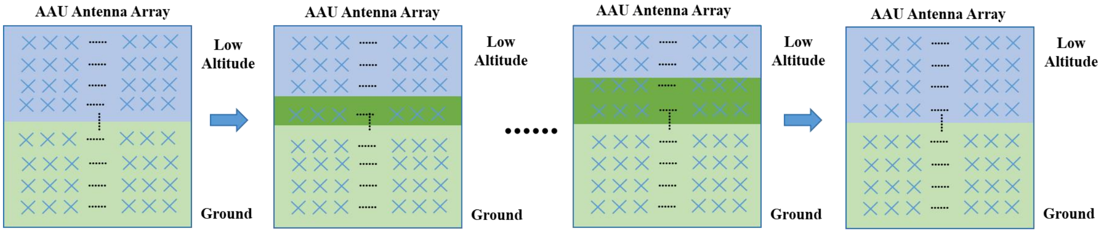


Figure 5.21. Dynamic RF-Channel Allocation in TDD deployments

### 5.2.3.2 High-Throughput AI-MU

In high-capacity, ultra-high-throughput 5G-Advanced scenarios, conventional MU-MIMO pairing typically relies on channel-correlation calculations and must traverse all UEs. This causes significant delay in spatial-information updates. The system cannot track dynamic channel changes in time, which limits multi-user spatial multiplexing and fails to meet the efficiency requirements of high-capacity deployments.

AI-MU introduces AI models into two key stages—UE pairing and adaptive modulation and coding (AMC) convergence—to enable rapid inference and optimization. It combines spatial characteristics, such as direction of arrival (DoA), with channel-quality features, such as channel quality indicator (CQI) and rank indicator (RI), and incorporates historical scheduling information to build a comprehensive and accurate UE profile. This provides a rich data foundation for precise pairing and dynamic adjustment. Advanced algorithms, including clustering and elite ant-colony optimization, rapidly identify compatible users in large populations and form efficient MU groups, avoiding the high complexity and low efficiency of exhaustive UE traversal. The system uses a spatial-multiplexing policy model and MCS mapping and tracking models for online training and inference updates. The spatial policy model partitions the cell by angular domain rather than conventional geographic grids and is trained with measurement report (MR) data to derive the optimal pairing inference model. The MCS model dynamically adjusts and tracks MCS based on precise UE identification across spatial features, channel state, historical transmission patterns, and other dimensions, ensuring that modulation and coding remain aligned with channel conditions.

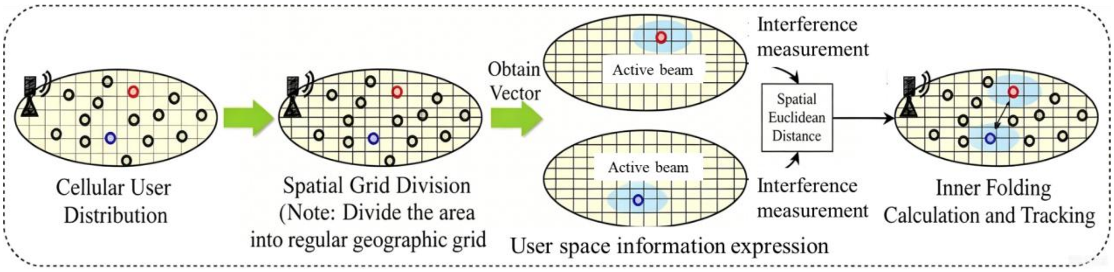


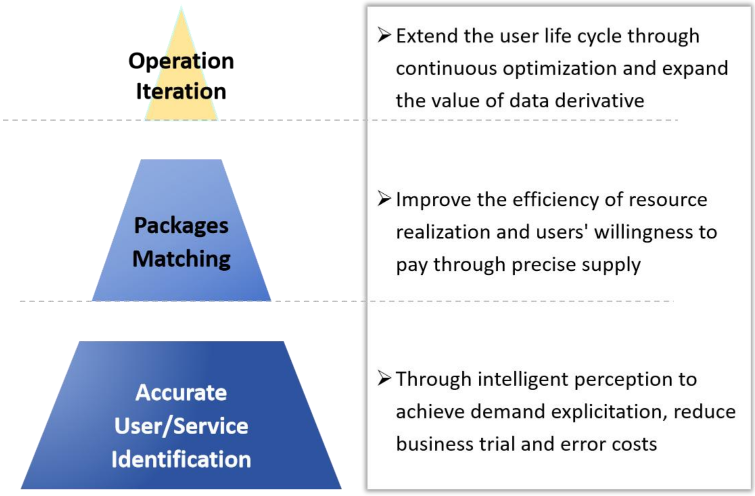
**Figure 5.22. AI-MU Solution**

AI-MU can be flexibly deployed on the Wireless AI Integrated Unit and supports online training of inner-loop tracking models across multiple cells. The models adapt continuously to changes in the network environment and maintain high accuracy. After training, they are deployed to the baseband module for online inference and directly output the MCS values required for UE scheduling. This enables fast, precise scheduling, improves spatial-multiplexing efficiency and overall system throughput, raises resource utilization in high-capacity scenarios, and provides users with more stable, higher-speed services.

### 5.2.3.3 Precise User Demand Identification

In refined 5G-Advanced site operations, conventional sites often understand user demand only at a superficial level. User requirements are diverse and dynamic, and traditional methods cannot accurately identify latent service needs or experience bottlenecks. As a result, site value operations lack precision and cannot deliver services that truly match user requirements, affecting both experience and market competitiveness.

To develop deeper insight and convert ambiguous demand signals into measurable, actionable value guidance, the site collects multidimensional user-behavior data in real time and applies AI-driven, high-precision user identification. Models combine network-side service-flow characteristics with user-side behavior labels. Real-time user identification and network-state analysis establish a closed operating model of precise user/service identification, plan matching, and iterative operations. This enables scenario-based marketing and personalized service-plan matching at individual-user granularity. Data-driven plan operation and continuous iteration form a closed loop that improves high-value user retention. Accumulated operational data can also refine the user-insight model and, after anonymized analysis, support monetizable outputs such as industry reports and API services, extending the site's value chain.



- Extend the user life cycle through continuous optimization and expand the value of data derivative
- Improve the efficiency of resource realization and users' willingness to pay through precise supply
- Through intelligent perception to achieve demand explicitation, reduce business trial and error costs

**Figure 5.23. Precise User Identification Solution**

Precise user identification can be flexibly deployed on the Wireless AI Integrated Unit and supports online training of inner-loop tracking models across multiple cells. Machine learning extracts multidimensional features from encrypted traffic and builds a feature library covering more than 16,000 service types, achieving identification accuracy above 95%. Based on service type and real-time network conditions, the system applies differentiated generalized-QoS scheduling and assigns optimal resources to video, gaming, payment, and other services.

# 6 Application Cases

## 6.1 Intelligent Fronthaul for Operation and Maintenance Efficiency Improvement

In mid-2025, the intelligent optical-path detection demonstration zones was first established in Hefei, Anhui, and Jiaxing, Zhejiang, and completed pilots of intelligent optical transceivers with integrated optical-path diagnostics. The objective was to address the difficulty of locating faults in conventional fronthaul optical paths and the resulting low operation and maintenance efficiency. To overcome the lack of fiber-link visibility and reliance on manual field investigation, the project introduced intelligent optical-transceiver technology for real-time sensing and precise localization of fronthaul connectivity, breakpoints, and degradation. This moved fronthaul operation and maintenance from a black-box model to real-time visibility. In the Hefei demonstration zone, monthly average fault-localization time was reduced from four hours to minutes, and average site repair time fell by more than 30%. The Jiaxing pilot accurately identified and localized fiber breaks, loose connections, contamination, bends, and other anomalies.

The results demonstrate that intelligent optical-path monitoring is ready for scaled commercial deployment. They also establish a new benchmark for 5G-Advanced and future-network operation and maintenance, accelerating the transition of optical-network operations from reactive response to precise prediction and proactive autonomy. This provides a practical foundation for highly reliable, low-latency intelligent network infrastructure.

Figure 6.1. Application Case of Intelligent Fronthaul Fault Detection Pilot

## 6.2 Wireless AI Integrated Unit Enhances User Experience

In July 2025, a pilot of hierarchical for differentiated assurance using Wireless AI Integrated Unit has been successfully completed in Guangzhou, Guangdong. The project addressed the challenge of protecting the experience of high-value users in dense traffic scenarios. At concerts and similar high-concurrency events, network congestion and experience degradation are common. The Wireless AI Integrated Unit solution accurately identifies service flows and schedules resources intelligently, upgrading conventional 5G base stations into intelligent base stations with differentiated assurance. The base station senses congestion in real time and dynamically adjusts allocation policies to absorb sudden traffic surges and protect high-value-user experience. Field results showed a 72% reduction in the share of poor-quality instant-messaging sessions for users of the concert service plan, and a 67% reduction in high-latency events, materially improving perceived experience.

The pilot validates the effectiveness of intelligent hardware in complex scenarios and provides practical evidence for service-model innovation based on differentiated experience assurance, supporting the evolution of 5G from connectivity services to intelligent services.

Ping时延 29ms
下行速率 261.19Mbps
上行速率 88.11Mbps

Figure 6.2. Application Case of User-Experience Improvement with Wireless AI Integrated Unit

## 6.3 Intelligent Power Supply Enable Green and Low-Carbon Initiatives

In the first half of 2025, the field deployments and pilot tests of intelligent power distribution units has been successfully carried out in Chengdu, Sichuan, and Shishi, Quanzhou, Fujian. This pilot project utilized key technologies such as wake-on-ultra-deep-sleep and breakthrough power-saving features, significantly reducing energy consumption at the sites and greatly improving operational efficiency. In terms of practical applications, the three-layer awaken able extreme sleep technology based on 5G service loads offers the following advantages: 1) an average daily sleep time of 4.42 hours per base station, 2) annual power savings of over 1,600 yuan for three-sector pole stations, 3) a 200% improvement in remote operation and maintenance efficiency, and 4) a reduction of two on-site inspections per month on average. In addition, through breakthrough power-off power-saving technology, it truly achieves "0-watt power consumption" of the equipment in idle state, significantly improving energy utilization efficiency.

This pilot project not only validated the significant benefits of intelligent power distribution units in energy conservation, and reduced consumption, as well as improved operational efficiency, but also driven the transformation of base station operation and maintenance models towards unmanned operation and intelligent decision-making. It has provided an important practical pathway and industry benchmark for building a green, low-carbon, and highly efficient autonomous new-generation communication network.

**Figure 6.3. Application Case of Intelligent Power Distribution Unit with Extreme Energy Saving**

## 6.4 Intelligent Antenna System Ensures Network Operations

As of July 2025, intelligent antennas have completed large-scale deployment verification and application in multiple provinces, including Liaoning, Yunnan and Guangzhou, effectively addressing the technical bottlenecks of unknown engineering parameters and non-adjustable orientation in traditional antennas. This solution enables a transformation from manual tower operations to remote intelligent optimization, providing a next-generation approach for regional network coverage enhancement and improved user experience. Field test data from multiple provinces indicates that the intelligent antenna has delivered significant results, as follows: 1) the accuracy of latitude and longitude measurements has improved to 0.5 metres, representing a reduction in measurement error of two orders of magnitude compared to traditional data. 2) topological recognition accuracy has reached 100%, with operational efficiency increasing 30-fold and labour costs reduced by 40%. 3) overall network traffic has increased by 20%, while the proportion of low-speed downlink traffic has improved by approximately 5%. In terms of service experience, video buffering on WeChat has been reduced by 76% and latency during Douyin live streams has been reduced by 80%. More than 20 4G/5G KPIs have remained stable under peak-load conditions, while total user traffic in the region has increased by more than 18% month-on-month. By intelligently adjusting the beam and network, this pilot project enables refined network operations, effectively unlocking the network's latent traffic potential.

This large-scale validation not only demonstrates the maturity and reliability of intelligent antennas, but also marks the official entry of wireless network operations into a new era of self-optimisation and self-intelligence, laying a core foundation for the evolution of 5G-Advanced and future networks towards comprehensive intelligence.

**Figure 6.4. Application Case of Intelligent Focus-Tracking Antenna**

## 6.5 Intelligent Equipment Room Helps to Save Energy and Reduce Consumption

The first commercial deployment of a hybrid air-liquid cooling system for BBUs has completed in Fuyang, Anhui. This initiative aims to address operational bottlenecks such as high energy consumption and persistently high PUE in C-RAN Equipment rooms, while meeting the requirements for green, low-carbon infrastructure set out in the national "Dual Carbon" strategy. The project innovatively employs a combined air-liquid cooling architecture, consolidating the BBUs and transmission equipment from multiple conventional cabinets into a customised combined air-liquid cabinet. It incorporates a synergistic cooling mechanism that combines contactless liquid cooling with natural cooling sources, and utilises an intelligent speed control system to dynamically adjust the coolant flow rate in response to service load, thereby achieving efficient heat dissipation and precise energy consumption control. The test results show that the overall PUE of the data centre has been reduced by over 30%, with significant energy savings achieved per cabinet, while also demonstrating outstanding performance in reliability, operational convenience, and space efficiency.

**Figure 6.5. Application Case of Air-Liquid Mixing Cabinet for Energy Saving**

# 7 Conclusions and Prospects

Centered on business-driven core demands and underpinned by technological innovation as the implementation path, the digital-intelligent base station site has established a complete closed-loop system spanning from application requirements to technical implementation. This has resulted in a "One Infrastructure, Three Layers, Three Domains" technical framework for digital-intelligent base station sites, delivering a comprehensive solution that covers multiple scenarios and adapts to diverse requirements. It provides end-to-end, highly reliable and strongly collaborative digital and intelligent support for the industry’s digital transformation and intelligent upgrading.

In the future, GTI will continue to drive the evolution of the digital-intelligent base station site technology system. By deeply integrating technologies such as artificial intelligence and digital twins, GTI aims to build a "Digital Twin" that synchronizes in real time and dynamically interacts with physical sites, thereby enabling functions such as full-lifecycle visualisation of network status, automated policy validation and continuous self-optimisation. The site will not only feature closed-loop management with self-configuration, self-healing and self-optimisation capabilities, but also be able to precisely allocate and dynamically adjust resources such as computing, storage, spectrum and energy on an on-demand basis in line with service requirements. At the same time, the site's multi-dimensional sensing capabilities, computing resources, and high-quality connectivity services will be made available to third parties as orchestrable "Atomic Capabilities", empowering innovative application scenarios such as smart cities, industrial

Internet and the low-altitude economy. This will continuously expand the scope and value of our services, thereby building an efficient, green and open intelligent ecosystem.

# 8 References

1. White Paper on 5G-Advanced Scenario Requirements and Key Technologies. IMT-2020 (5G) Promotion Group, 2022.
2. White Paper on Technical Solutions for Typical AI Application Scenarios in 5G Networks. China Mobile Communications Group Co., Ltd., 2024
3. White Paper on Integrated Architecture of New 5G-A Technologies. China Mobile Communications Group Co., Ltd., 2024.
4. White Paper on Design of Next-Generation Integrated Wireless Architecture for Communication, Sensing, Computing and Intelligence. China Mobile Communications Group Co., Ltd., 2025.