Indoor 5G Scenario Oriented White Paper

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1. Introduction

Following the finalization of the 3GPP Release 15 standard for 5th Generation (5G) mobile communications and the issuance of 5G licenses in various countries, 5G deployment is now accelerating internationally.

As of July 25, 2019, 5G has been put into commercial use on 27 networks worldwide, with more than 150,000 5G base stations deployed, and this number is continuously growing.

5G offers new experiences and opportunities for E2E industry users. In contrast to 4G, 5G also includes the following innovative technologies: wider radio spectrum, massive MIMO antenna arrays, ultra-dense networking, new multiple access, software-defined networking (SDN), network functions virtualization (NFV), edge computing, and network slicing. 5G can deliver an experienced rate of 1 Gbit/s in average, with peak rates of 10 Gbit/s. In addition, 5G supports more than 1 million connections per square kilometer, as well as a 1ms ultra-low air interface latency. In addition to serving consumers, 5G also supports a wide range of industries, such as 4K live broadcasting, virtual reality (VR), augmented reality (AR), telemedicine, and high-definition (HD) video surveillance. Indoor hot spots such as stadiums, hospitals, transport hubs, and commercial buildings are becoming the scenarios of choice for operators and industry customers to deploy 5G networks and develop 5G services.

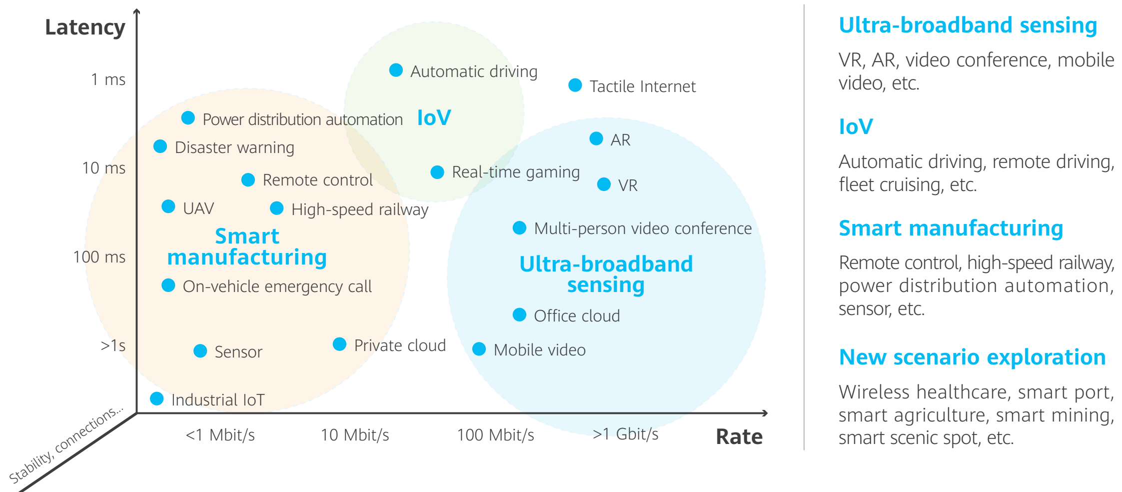
Huawei has teamed up with operators and industry partners to carry out in-depth research on 5G service strategies and network construction strategies in typical indoor scenarios.

Citing the *Indoor 5G Networks White Paper* released by Huawei in 2018, as well as recent practices and reflections, this white paper describes indoor services in the 5G era and the specific requirements of different services for 5G. Based on the characteristics of buildings and services in key scenarios such as stadiums, hospitals, and transport hubs, this white paper provides ideas for indoor network planning and construction. The purpose of this white paper is to inspire managers, technical personnel, and industry partners engaged in 5G construction and operation.

2. Overview

4G has changed people's lives, but 5G is set to change societies. 5G features ultra-broadband, massive connections, and ultra-low latency, providing infinite possibilities for people-to-people, people-to-machine, and machine-to-machine connections and communications.

Building on 4G, 5G provides richer services and further extends industry boundaries. 5G provides basic data services and importantly, more applications for life, business, and industry. 5G will make people's work, lives, and travel more convenient and intelligent, by means of robotic meal delivery, automatic driving, remote holographic conferences, remote VR, and immersive sports events or entertainment programs. 5G can help enterprises improve production efficiency and build smart production systems, such as smart factories, smart mines, and smart hospitals. For industry applications, 5G can help governments achieve efficient social governance.



Source: GSMA & Huawei Wireless X-Labs

Figure 1 5G network scenarios and performance requirements

Statistics show that more than 70% of services in 4G occur indoors, and industry predictions show that this percentage will surpass 80% as 5G spread service diversity and extends business boundaries. Based on this, we can see that 5G indoor mobile networks will become an essential part of operators' core competitiveness.

3. Introduction to 5G Services

3.1 Three 5G Service Types

- Enhanced Mobile Broadband (eMBB)

  eMBB is an enhanced type of mobile broadband (MBB) service to deliver better performance and user experience in scenarios such as live HD videos, VR, and AR.

- Massive Machine-Type Communications (mMTC)

  mMTC is mainly used in Internet of Things (IoT) to improve people-machine or machine-machine connectivity and significantly upgrade the network capacity and connection density.

- Ultra-reliable low-latency communication (URLLC)

  URLLC is mainly used for scenarios requiring ultra-low latency and ultra-high reliability, such as Internet of Vehicles (IoV) and smart factories.

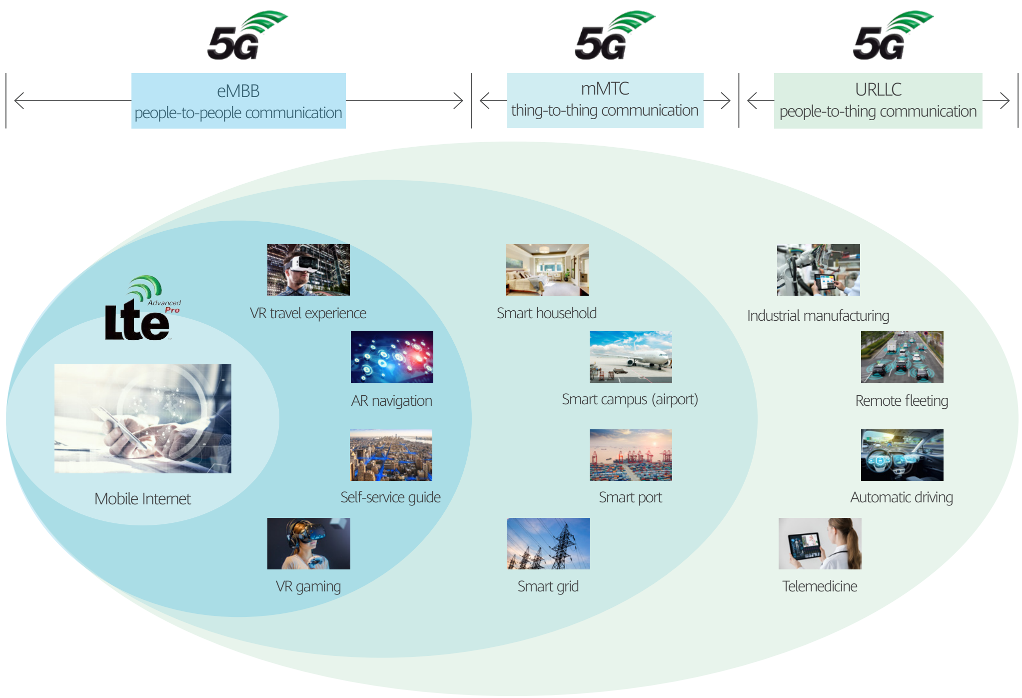


Figure 2 **Three 5G service types**

3.2 Changes Made to Consumer Behavior by 5G

5G delivers a much better user experience than 4G due to its high data rate and low latency. 5G's data rate is 10 times faster than 4G, as such, it takes only a few seconds to download an HD movie on a 5G network. At Shanghai Hongqiao Railway Station, the peak download rate of the 5G digital indoor system deployed by Huawei reached 1.2 Gbit/s. In addition, 5G can achieve a typical end-to-end (E2E) latency of 5–10 ms, far shorter than the approximate typical E2E latency of 50–100 ms in 4G. Consequently, 5G provides a smooth experience for VR gaming compared to possible frame freezing on a 4G network.

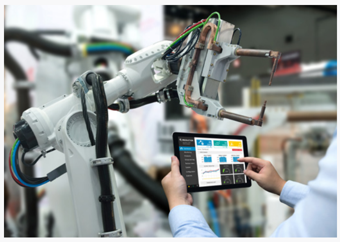
Most people spend indoors more than half of their time every day. 5G will usher in the possibilities of home VR, holographic communication, and HD mobile office services, driving potential user demands. Cloud VR live broadcasting of games, athletic events, and concerts delivers an immersive, near-real-life experience for users.

Figure 3 **5G VR vision**

3.3 Changes Made to Vertical Industries by 5G

5G will be closely related to vertical industries, which were completely independent of each other in the past. For example, as different as the automobile and communications industries may be, in the 5G era they can spawn applications such as remote vehicle diagnosis, remote driving, and automatic driving. Together with operators and partners, Huawei has embarked on explorations of 5G applications in dozens of vertical industries, including but not limited to, smart new media, smart mining, smart port, smart factory, smart healthcare, smart grid, smart education, city security, electric unmanned aerial vehicles (UAVs), smart agriculture, and smart IoV. With the global deployment of 5G and the participation of more partners, 5G is going to create cross-industry applications.

Smart healthcare



Smart industry

Smart agriculture

Smart grid

Smart logistics

Smart media

Smart security

Smart education

Automatic driving

Figure 4 Changes made to industries by 5G

In the healthcare industry, a new application – 5G remote diagnosis – can be introduced to the existing diagnosis system. Supported by high-bandwidth and low-latency 5G technologies, the new application provides real-time data for doctors, providing convenience for patients and achieving expert resource sharing. Hospitals can provide VR teaching and knowledge sharing to reduce costs.

For the transport industry, various sensors can be connected to low-latency 5G networks to implement automatic and remote driving, minimizing the likelihood of traffic accidents caused by fatigue or other factors. 5G can provide meter-level indoor positioning to enable customer flow analysis and heat map services in airports and stations to benefit security and operation management. For passengers, indoor navigation and auto-driving scooters can be provided to improve their travel experience.

For the media industry, 5G networks and cameras can work together to implement real-time broadcasting. For example, TV stations can live-broadcast programs flexibly, which saves the costs of leasing satellite bandwidth and constructing transmission networks. In live sports events, 5G can upload videos captured by HD cameras to reduce cable connections and simplify camera layout.

In the real estate industry, 5G can empower existing intelligent building systems. Specifically, the 5G network can carry video surveillance and sensing devices originally connected through the fixed network, thereby making deployment, capacity expansion, and adjustment more flexible. In addition, the 5G network can work with robots to provide three-dimensional intelligent building services based on the 5G location service function. In the future, 5G will become a vital part of smart building property infrastructure, just as important as water, electricity, and gas, and will become the core of smart city evolution.

3.4 Changes Made to Telecom Operators by 5G

The telecom industry adheres to its own Moore's Law: exponential increases towards unlimited data packages, yet a corresponding decrease in subscriber revenue. Increasingly, operators face the dilemma of providing more for less return. The high costs incurred by 5G construction force operators to carefully prepare business plans and exercise caution when investing. Today's operators face the challenge of balancing 5G dominance with a quick return on investment (ROI). 5G construction has to provide improved user experience while adopting new business models. By building networks on demand, a new ecosystem can be nurtured to benefit both industry partners and operators.

5G construction will impose two major changes to operators' services:

Business model reconstruction: Operators will have to shift from traffic monetization (relying mainly on connections) to traffic value monetization (inclusive of rate, latency, and slicing). In other words, operator business models must provide both intelligent platforms and services instead of merely traffic pipes.

Vertical networking architecture: The new business model will inevitably drive network architecture toward integration with vertical industries. In addition to providing wireless connections, networks must also work with intelligent units in the industry to form a cloud-pipe-device architecture.

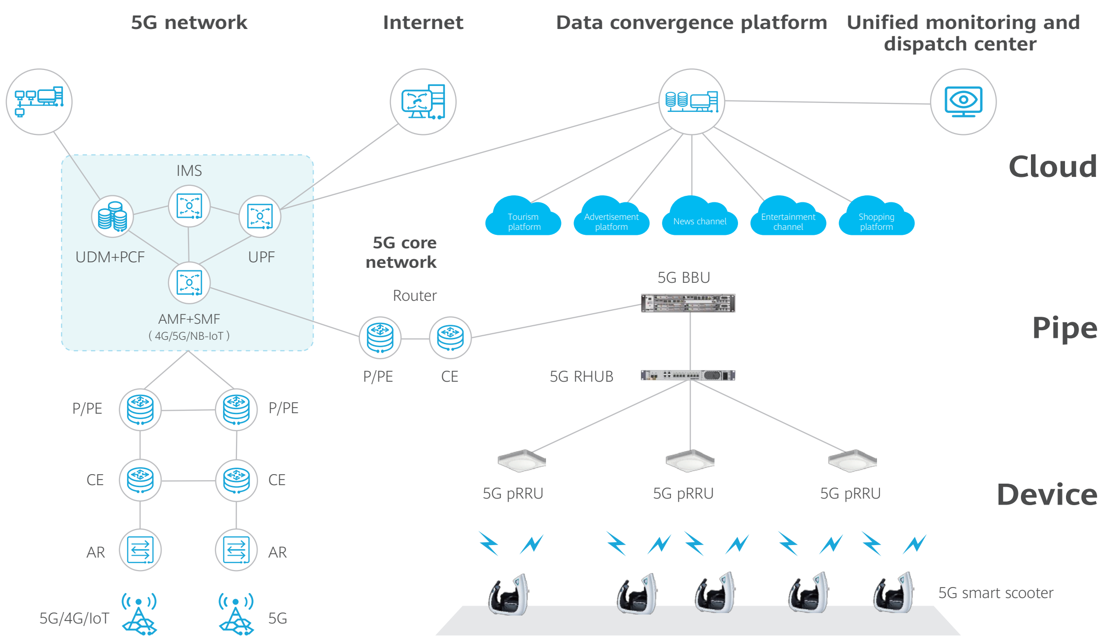


Figure 5 Use case of 5G for indoor automatic driving

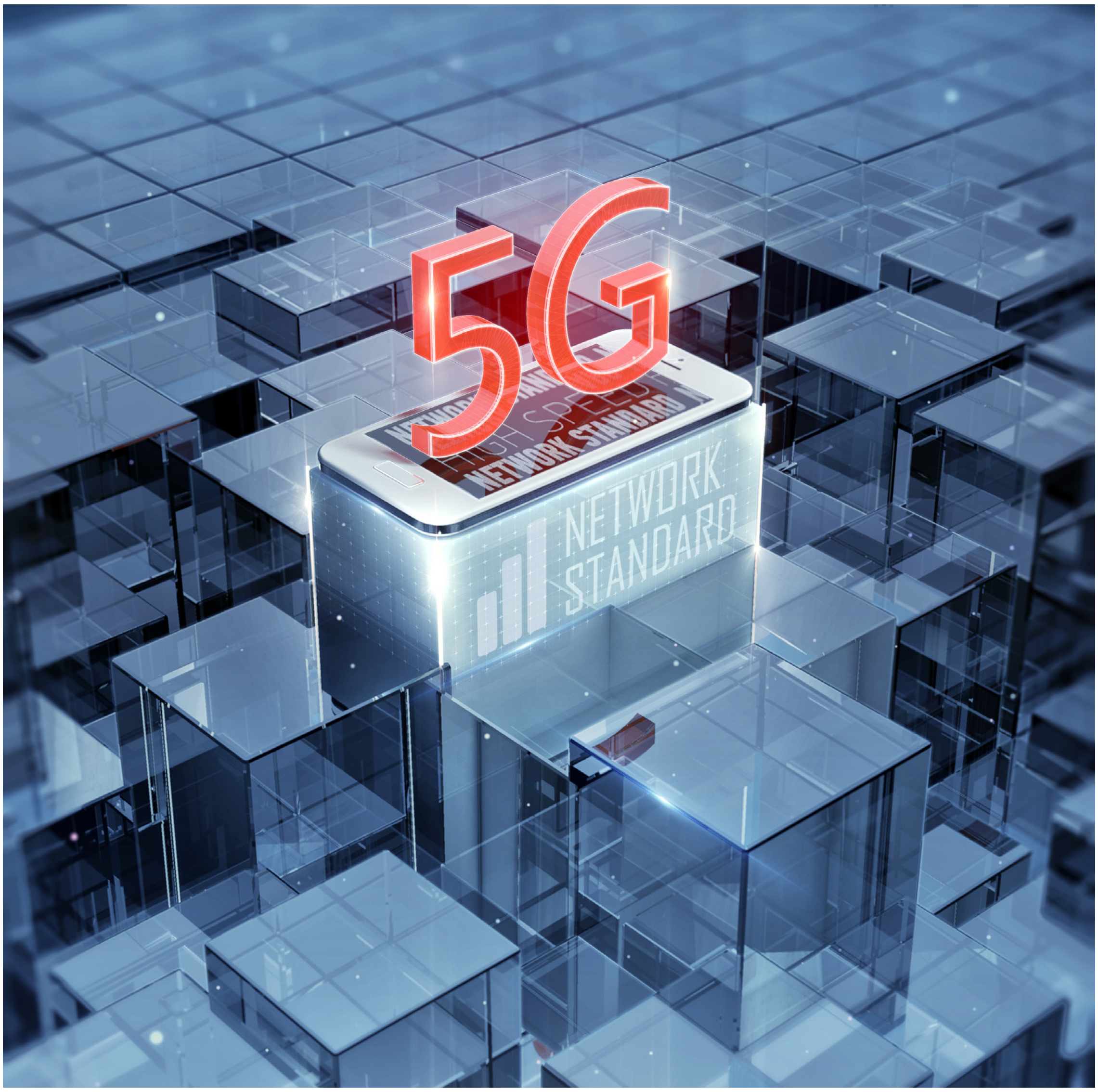
These two changes will eventually create new value:

- Interconnection: In 4G, growing IoT services have already become a new source of revenue for operators. 5G construction will establish even more connections, which are vital for operators to create new business value. For example, operators can set up connections to more elements, and charge by the connection length or quantity. This interconnection could also lead to the transformation of all aspects of daily life, from food and clothing to housing and transport, creating a truly smart life. For example, watches, bicycles, trash cans, and billboards will be transformed by technological developments and become smart.
- Traffic: 5G delivers a better user experience than 4G when faced with a large volume of traffic. For example, digital 4K TV broadcasting on a 5G network realizes real-time news on mobile platforms, with operators providing the network and charging TV stations and commercial advertisement companies for services. Operators can also provide customized service design to achieve multi-win. In addition, other services such as 5G live TV and VR can also create traffic value.
- High speeds: 5G rate design can provide different levels of service experience to suit the needs of different users. For example, 4K conferences and holographic conferences offer a different experience and therefore can be charged by usage and the service level based on network quality.
- Low latency: 5G's low latency enables real-time communication between automobile service centers and automobile repair shops, allowing the automobile service center to perform remote diagnosis for cars. Such services do not consume much data but require a low latency, and so operators can charge services according to their latency levels.
- Slicing: 5G slicing will be widely used in business to business (B2B), business to consumer (B2C), and business to home (B2H) scenarios to meet the diverse requirements of enterprises and individuals. For example, operators can provide dedicated network slicing for VR and temporary live broadcasting, and deliver purposed traffic packages to subscribers by time segment and area.

In the 5G era, even greater explosion of data traffic will occur. Unlimited traffic packages will become a basic requirement, and the business value system will be reshaped. Operators need to increase the value of their operations by developing positive business cycles through differentiated value monetization methods based on rate, latency, and slicing.

3.5 Summary

5G preludes a new network era. Mining the value of 5G requires deep reflection from both consumer markets and vertical industries on the changes, convenience, and value that 5G will bring about. The necessary dependence between 5G construction and service development requires that the network construction by operators and the industry ecosystem construction take place at the same time. Indoor 5G has generated many applications, and it is critical to design indoor services, as well as plan and construct networks, based on service requirements. To deliver an optimal user experience, efficient O&M, and intelligent operation, the indoor networks in the 5G era must be digital.



4. Scenario-Oriented Indoor 5G Service Requirements and Network Construction Suggestions

In the 5G era, service requirements vary with indoor scenarios. Different service requirements lead to diverse network construction requirements. In order to keep up with the booming and diversified 5G services, a network with flexible capacity ought to be adequately prepared. Such networks not only need to meet the changing volume requirements of services as time and areas vary, but also must cope with rapid surges in traffic.

Table1 Relationships between various services and bandwidth/latency

Typical 5G Service	Bandwidth (Edge Rate) (Mbit/s)	Latency (ms)	Service Scenario	Indoor Scenario
Cloud VR 720p	20	50	Entertainment, education, marketing, healthcare, tourism, real estate, engineering, social networking, and shopping	Stadiums, airports, stations, shopping malls, office buildings, residential areas, subways, and campuses
Cloud VR 1K	50	20		
Cloud VR 2K	150	10		
AR	150	5	Family, healthcare, industry, social networking, sports, and games	Stadiums, shopping malls, offices, residential areas, campuses, and hospitals
4K 2D	25	20	Education, entertainment, social networking, security, and healthcare	Stadiums, airports, stations, shopping malls, office buildings, residential areas, subways, campuses, and hospitals
4K 3D	50	20		
8K 2D	100	20		
8K 3D	200	20		
MBB access	300	20	Remote live broadcasts, such as games, parties, and press conferences	Stadiums, airports, stations, shopping malls, offices, residential areas, subways, campuses, and exhibition halls
IoV	N x 10	5	Remote vehicle diagnosis and control	Airports, stations, shopping malls, and hospitals
Industrial control	10	1	Production line control and power system control	Factories, industrial parks, etc.

The above table lists the bandwidth and latency requirements of typical 5G services. The following sections describe typical use cases and network construction suggestions for different indoor scenarios.

4.1 Use Cases and Construction Suggestions for 5G Networks for Stadiums

As major events and gatherings occur in stadiums, they are the core scenario for operators to build their brands and guarantee user experience. In 4G, the main services are intensive voice, instant messaging, as well as picture and short video sharing. In the 5G era, however, more applications will be derived from the large bandwidth and low latency of networks, such as cloud surveillance, cloud live broadcasting, and cloud VR which will benefit the operators and stadium proprietors.

4.1.1 Use Cases

4.1.1.1 5G Cloud VR

The appeal of watching games lies in the immersive experience for the spectators. However, not every spectator can get the best seat on the stands, and the audience with poor visibility may miss exciting moments. 5G will bring revolutionary changes to the on-site viewing experience, including high uplink bandwidth-enabled 8K and VR video transmission, live video analysis, person recognition, scenario identification, the real-time display of athlete and sports data, and VR live interaction. The event is broadcast in real time using HD video, delivering a thrilling spectator experience.

For operators and stadium owners, VR experience services are likely to become a new revenue growth point. For example, spectators can rent VR glasses from the stadium, and operators can also provide customized VR service packages to users for extra profit.

Figure 6 Watching football games using VR glasses

4.1.1.2 5G Cloud Live Broadcasting

Traditional live sports broadcasting are high-cost due to the requirements of a satellite lease, private line operation, and long construction period of private lines. As cameras are installed at fixed positions, images in other areas cannot be flexibly captured. In addition, the original video files are large in size and must first be edited and processed onsite by a large number of personnel and then sent back to the TV station over a fixed network dedicated line or a satellite link for further processing and forwarding. The entire process of cabling and system construction requires substantial labor, which translates into high costs.

With 5G, outdoor ultra-HD media can be live-broadcast, turning bandwidth and rate into commercial values for the broadcasting industry. By configuring a 5G customer-premises equipment (CPE) for each camera, the camera operator can move around to capture the best perspective. In addition, the images captured by cameras can be transmitted to the TV station production center in real time over the high-rate, large-bandwidth, and low-latency 5G network. This simplifies the onsite production process and greatly reduces the investment for site management.

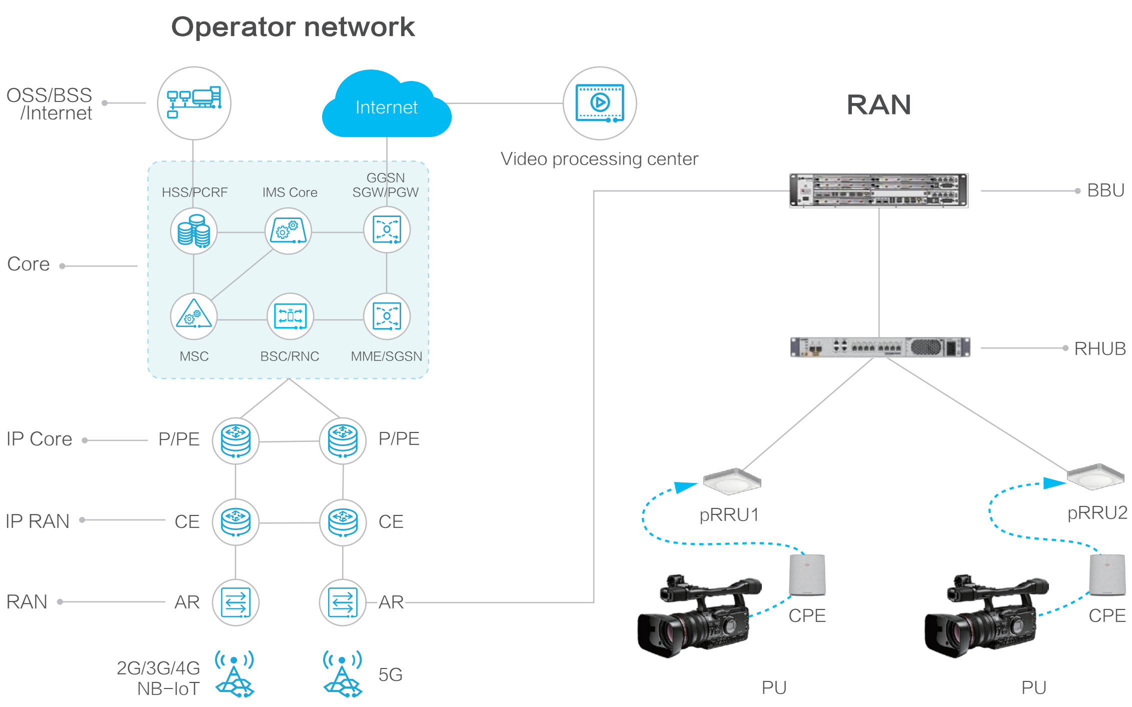


Figure 7 Use case of 5G for real-time broadcasting

Operators can provide dedicated 5G live TV assurance services, namely monetizing 5G bandwidth from TV stations, while TV stations can save costs on the system deployment and site lease.

Other 5G applications can also be tapped into by stadium owners, for example, remote cleaning, automatic driving, and UAV filming.

4.1.2 Network Construction Suggestions

The two preceding 5G applications show that service requirements vary with stadium scenarios. Therefore, service differences according to functions must be considered during indoor network design. Function-specific network design based on service requirements is at the core of 5G network construction for stadiums.

Empirically, a stadium is divided into the following functional areas based on service requirements:

- Media zone: This zone is for onsite commentators and journalists and features a large number of uplink service requirements, such as HD live broadcast and news data uploading, cloud live broadcasting, and cloud monitoring. Compared with cloud monitoring, cloud live broadcasting has higher requirements concerning uplink bandwidth, latency, and jitter.
- Stand zone: This zone has a high user density, high volume of burst traffic, a vast open space, with interference being difficult to control. Key services here include high-speed data services, VR, AR, and HD videos.
- VIP zone: This zone is located at the top or, in some stadiums, in the center of the stands. The service requirements in this zone are similar to those of the stand, but key coverage and service assurance are required.
- Central venue: In addition to the HD video, AR, and VR service requirements during concerts, this zone also requires live video upload from cameras at different angles.
- Office area/parking lot: This zone can be further divided into the office area, news release area, restaurant, and parking area. The requirements for service rate are lower than those for other functional areas.

Based on research and 5G commercial projects, the following table analyzes services in different parts of the stadium.

Table 2 Likelihood of X service being used

Scenario	Rate ≥ 100 Mbit/s		Rate 50–100 Mbit/s		Rate < 50 Mbit/s		Capacity and Sector Planning Suggestions
Functional Area	AR	Live Broadcasting	VR	4K HD Video	Video Surveillance	Real-time Communication	
Media zone	10%	100%	30%	20%	50%	80%	Large uplink capacity, low latency, and independent sector planning are required.
Stand zone	10%	10%	30%	10%	50%	80%	High-density sector planning based on an analysis of traffic trends and cell combination in low-traffic hours are required.
VIP zone	20%	20%	40%	10%	50%	80%	Independent sector planning is required.
Central venue	20%	50%	20%	5%	50%	40%	Scalable capacity design and cell splitting during traffic bursts are required.
Office area	5%	0%	5%	10%	50%	80%	Capacity design based on office traffic models and independent sectors planning are required.
Parking lot	0%	0%	0%	0%	50%	80%	Coverage assurance is the primary concern. The network must meet requirements for services such as parking navigation and payment.

Based on above service analysis of functional areas, targeted network construction standards must be formulated to ensure good service experience. Scenario-oriented solutions need to be designed in three steps: solution selection, capacity planning, and coverage planning:

Solution Selection

The digital indoor system is recommended in the stand zone to provide sufficient capacity and meet the requirements for easy installation, maintenance, and capacity expansion. To minimize inter-sector interference, it is recommended that high-specification beamforming (BF) antennas are used to control the overlapping coverage area between sectors and mitigate the interference between neighboring cells. In a stadium with insufficient space and installation positions, active antenna units (AAUs) with massive MIMO antenna arrays can be used to suppress interference between users and improve the multi-stream transmission capability.

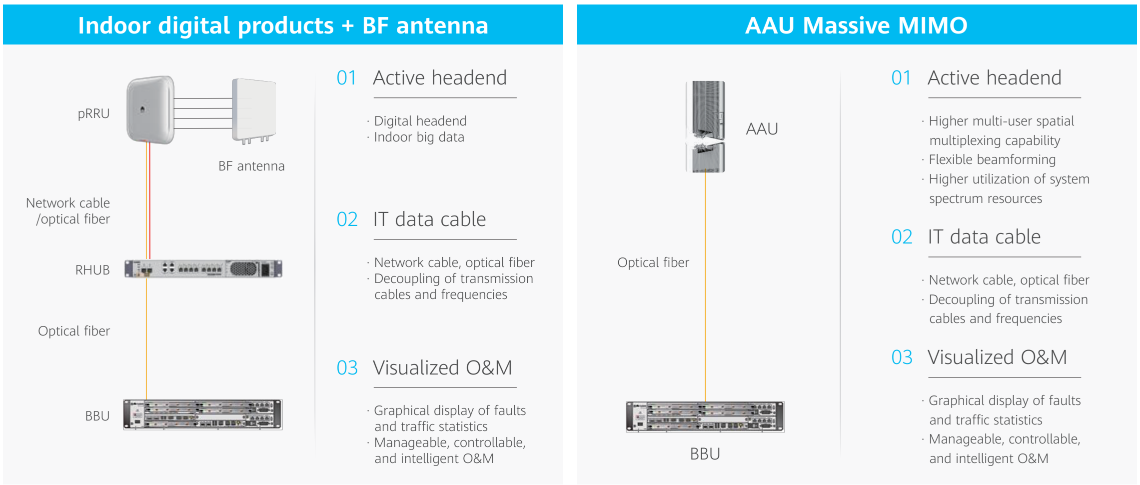
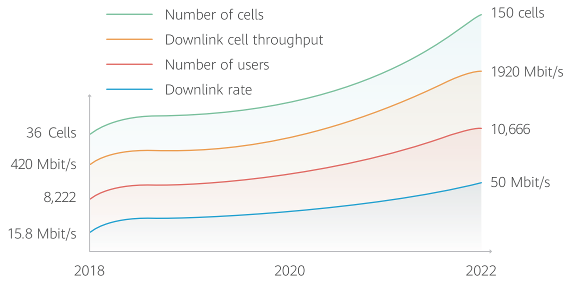


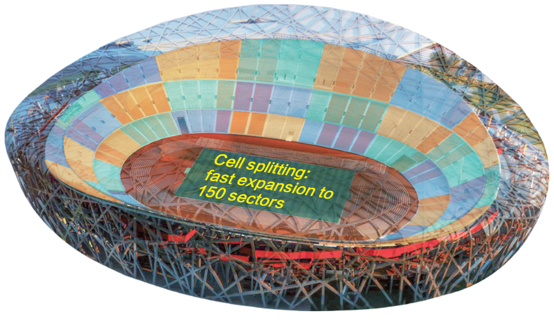
Figure 8 Indoor digital system

Capacity Planning

Different functional areas need to be analyzed according to their user distribution, traffic model, service experience requirements, future service changes, and user growth in order to accurately estimate capacity. One-time hardware deployment, repeated cell splitting, and smooth capacity expansion should be implemented to meet evolution requirements for the next three to five years. For example, if a stadium has a small number of users during the initial 5G rollout, only four cells are planned. In five years' time, with the development of the 5G service, the cells are split into 150 on demand using background software, without changing the hardware, in order to meet the demands of user requirements and service growth.



Large-capacity prediction and planning design in the next 3–5 years

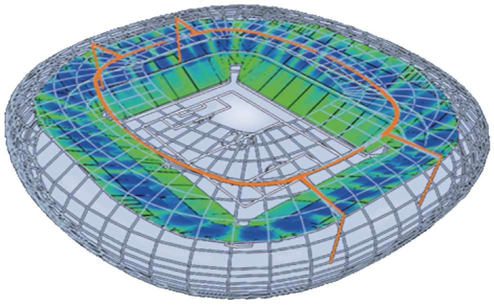


High-density sector design and interference control scheme

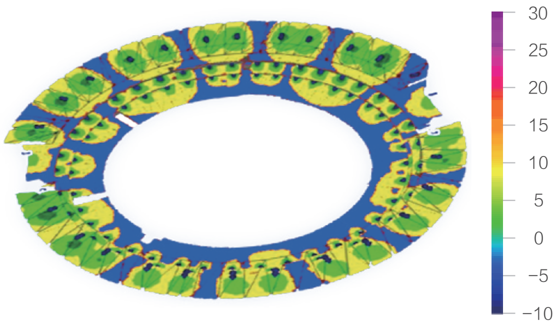
Figure 9 Stadium planning and design

Coverage Planning

A stadium is served by a large number of cells. Open line-of-sight (LOS) propagation causes severe coverage overlap between cells, making interference control a major concern in high-density sector deployment. The antenna type, installation position, and installation angle all have great impact on inter-cell interference. Therefore, the antenna coverage design must meet both the demand for large capacity and interference suppression requirements. In the stand zone, BF antennas are recommended to effectively control the coverage boundary. The antenna installation height and azimuth are determined through iterative simulation to achieve the optimal coverage effect.



3D intelligent modeling



High-density sector design simulation

Figure 10 Stadium design simulation

4.2 Use Cases and Construction Suggestions for 5G Networks for Hospitals

In the healthcare industry, the unequal distribution of medical resources, shortage of doctors, and difficulties in providing access to medical treatment are common issues. Through a digital and intelligent transformation, 5G can revolutionize the traditional healthcare industry.

4.2.1 Use Cases

4.2.1.1 5G Remote Consultation

5G features can be leveraged to build a remote consultation solution that supports multi-terminal access for future healthcare scenarios. Doctors in different hospitals can perform remote consultation through 5G terminals at any time and place, thereby sharing high-quality medical resources. Patients can receive high-quality medical treatment services locally without the need to travel. Simultaneously, the service level of grassroots medical and health institutions can also be improved greatly.

Compared with 4G, high-bandwidth 5G enables sharing of 3D 4K pathological images of patients. In addition, with mobile edge computing (MEC) deployed in hospitals, the low latency can realize real-time multi-screen interaction where doctors can discuss and annotate in real time and output medical solutions in a timely manner.

Figure 11 5G remote diagnosis data display

4.2.1.2 5G Remote Surgery

More advanced than 5G remote consultation, 5G remote surgery integrates surgery robotics with 5G to transmit 4K HD medical images and stable robot control signals in real time. This realizes the remote application of robotic medical surgery that has been in development for over ten years.

4.2.1.3 5G Remote Ward Round

In addition to remote consultation and surgery, hospitals can use 5G networks to implement cloud VR-based remote ward rounds. With VR panoramic cameras and sensors deployed in wards, doctors can use these devices to view patient images and recovery status and communicate with patients in real time.

4.2.1.4 5G Smart Navigation and Consultation

Currently, many hospitals already provide intelligent navigation and consultation for patients through 4G or Wi-Fi to shorten patient waiting time and make efficient use of medical resources. In 5G, with the maturity of intelligent robotics, more applications will emerge for patient service scenarios. An example of this is the smart mobile wheelchair. By configuring a smart camera, a 5G communications module, and a positioning module on the wheelchair, it can be remotely scheduled and operated to take the patient to the desired destination, eliminating the need for nurse attendance.

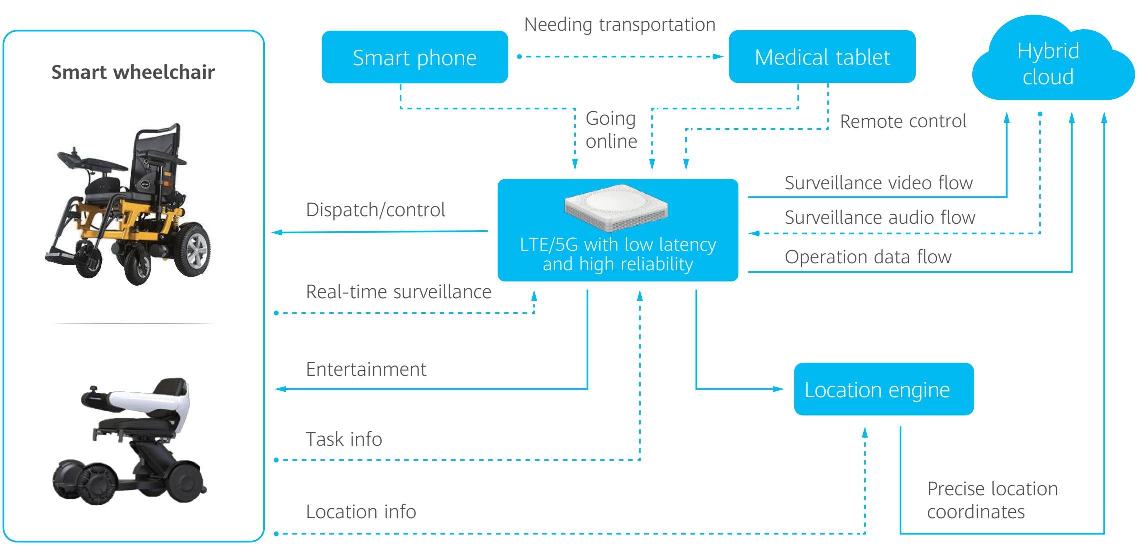


Figure 12 Indoor auto-driving wheelchair

4.2.2 Networking Suggestions

The 5G digital system design for hospitals needs to be customized according to service requirements. Specifically, the outpatient and inpatient departments of a hospital experience fluctuating requirements on service traffic, known as the "tidal effect". Therefore, the network planning and design must coordinate capacity planning for different functional areas, as well as dynamic network adjustment and optimization, thereby improving resource utilization:

- Outpatient waiting area: The average waiting time for a patient is one hour, during which time large amounts of traffic are generated. Data services include Internet browsing, video streaming, information query, and instant messaging.
- Inpatient department: As 5G services develop, data traffic in wards will increase significantly, and the number of IoT applications will continue to grow in the future.
- Operating room: Remote surgery requires a highly reliable 5G backhaul solution to ensure that key operations, such as surgeries, are not interrupted.
- Canteen and rest area: Traffic in the restaurant shows the tidal effect. The main services here are video calls and instant messaging. Network resource sharing must be considered during solution design.
- Conference room and office: Traffic in conference rooms also shows obvious tidal effects. It is critical that there is enough available bandwidth during remote 4K conferences. Network resource sharing also needs to be considered in this solution.
- Parking lot: Robots and smart parking will be key services in parking lots. Such services require low latency, but have less stringent requirements on bandwidth.

Based on exploration and practices in 5G commercial projects, the following table analyzes services in different functional areas in hospitals.

Table 3 Probability of various services occurring in hospitals

Scenario	Downlink Rate > 100 Mbit/s		50 Mbit/s ≤ Downlink Rate ≤ 100 Mbit/s		Downlink Rate < 50 Mbit/s		Capacity and Sector Planning Suggestions
Hospital Functional Area	AR	Remote Surgery	VR	4K HD Video	Wireless Surveillance	Real-time Communication	
Outpatient waiting area	5%	0%	5%	50%	30%	80%	Cells need to be planned to accommodate the network tidal effect.
Inpatient department	30%	0%	30%	50%	20%	80%	Independent sector assurance is required.
Operating room	10%	30%	0%	30%	30%	80%	Independent sector assurance is required. Robustness requirements such as redundancy must be considered during design.
Canteen and resting area	10%	0%	10%	60%	20%	80%	Cells need to be planned to accommodate the network tidal effect.
Conference room	10%	0%	30%	30%	10%	80%	Independent sector assurance is required.
Office	5%	0%	5%	30%	20%	80%	Capacity design based on traffic models; independent sectors are required.
Parking lot	0%	0%	0%	0%	50%	60%	Coverage assurance is the primary concern. The network must meet requirements for services such as parking navigation and payment.

Based on above service analysis according to functional area, network construction standards are formulated to ensure excellent service experience. Scenario-oriented solutions need to be designed in three steps: solution selection, capacity planning, and coverage planning:

Solution Selection

The Digital Indoor System (DIS) is recommended for outpatient departments and operating rooms for the following reasons:

- DIS implements flexible sector splitting to adapt to fluctuating traffic volumes. This is achieved by remotely increasing the network capacity when traffic suddenly increases.
- For key scenarios such as operating rooms, the robustness of the system is critical. DIS improves system reliability by enabling mutual backup between antenna terminals.
- DIS implements remote management over headends, including traffic and working status management. This allows faulty headends to be located immediately.

In multi-partition scenarios such as wards and dormitories, innovative DIS, such as Huawei LampSite Grid, can be used for economical coverage.

Capacity Planning

Capacity planning must vary between different functional areas. For example, in large-capacity areas such as outpatient departments, cells need to be designed in accordance with traffic models and the number of users. In peak hours, cell splitting can be used to quickly expand capacity. To prevent other services from affecting remote surgeries, it is recommended to plan independent sectors and ensure system robustness in operating rooms. In wards, if only corridors are covered, one sector can be designed per floor, with more sectors planned if diversified services are required. In scenarios with tidal traffic, such as offices and canteens, a logical sector can be flexibly combined based on the time and location to better allocate baseband resources and investment. As 5G services continue to develop in the future, smooth capacity expansion can be implemented through cell splitting.

Coverage Planning

Coverage in key areas such as operating rooms must be highly reliable. This can be ensured through increasing pRRU deployment density. In areas with multiple partitions, such as wards, pRRUs with external antennas should be properly deployed to ensure network coverage. For other areas, select coverage solutions based on the floor characteristics. For example, in parking lots, use directional antennas or log periodic antennas to provide cost-efficient basic coverage.

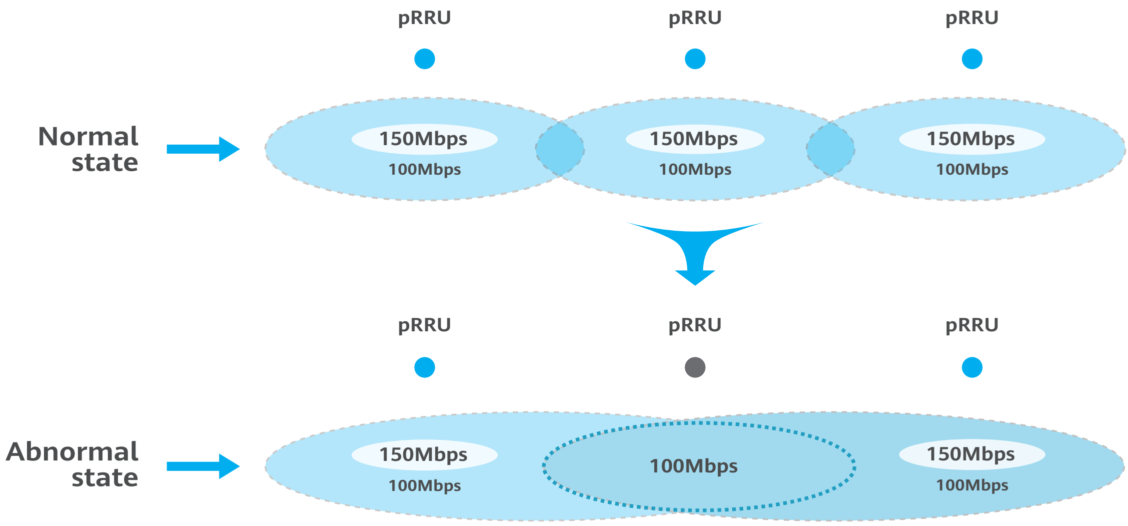


Figure 13 **Robustness design of pRRUs**

4.3 Use Cases and Construction Suggestions for 5G Networks at Transport Hubs

Transport hubs include airports, railway stations, and bus stations. As ways of travelling become more diversified, so do the services required in corresponding scenarios. In response, major transport hubs have been exploring and launching smart systems to provide better experience to passengers, improve the level of intelligence, and reduce the operating expense (OPEX).

4.3.1 Use Cases

4.3.1.1 5G Smart Travel

In addition to high-speed data services such as HD video streaming, fast downloads, and VR, 5G networks will also provide passengers with a more comfortable and convenient travel experience, such as: facial recognition check-in, consignment, classified security check, smart navigation display, and boarding. Furthermore, indoor automated driving services will be made increasingly available as both 5G and manned robot (smart scooter) technologies mature.

In major traffic hubs, passengers often have to spend long time moving from place to place, which can be extremely inconvenient when they have a lot of luggage. In such scenarios, 5G indoor digital networks can provide indoor positioning, navigation, remote control, and other services for smart scooters. All what passengers need to do is to send a request with an app, and the smart scooters will automatically locate and reach the passengers, who in turn can communicate with the scooters, through AI voice recognition, providing information about where they need to go and by which route. Passengers can then take a ride on the scooters, during which time they can obtain more information about the airport or stations (such as travel schedule, destination info, and store discounts) through interactive screens. Once they arrive at their destination, the scooters will automatically return to the charging station.

The 5G network enables communication between the control room and scooters and between the scooters themselves. In emergencies, the 5G network provides high bandwidth with low latency to ensure scooters can be driven remotely, as well as be able to brake suddenly, ensuring passenger safety.

In this scenario, operators not only provide the basic communication network, but also share the service revenue with the airport by providing the 5G value-added services (VASs), thus increasing the operation revenue.

Figure 14 Indoor auto-driving service ecology

4.3.1.2 5G Cloud Eye Service (CES) and Pan-tilt-zoom (PTZ) Control

- Wireless surveillance: Surveillance is a necessary part of all airports and stations. Video surveillance systems can work with the 5G network to enable mobile video transmission. By installing 5G CPEs and cameras on the shuttle buses and maintenance vehicles, and combining this with cloud-based AI facial recognition and path recognition, the remote surveillance center can schedule resources at any time to implement full-coverage surveillance in real time and ensure the security of airports.
- Remote maintenance: Supported by the 5G network, 4K cameras can be deployed at airports and stations to allow maintenance personnel to remotely inspect devices, clear faults, and share their expertise with less experienced technicians. This reduces the skill requirements for onsite maintenance personnel and improves maintenance quality and efficiency.

4.3.1.3 5G Digital Train

When traveling by train, passengers need to access the Internet to fill in some time or even to make necessary arrangements for when they arrive at their destination. However, especially for high-speed trains, base stations often fail to provide adequate coverage in carriages due to the blocking of radio signals by carriages as well as the Doppler Effect. If passengers want to watch videos on their tablets or smart phones, they need to download the content in advance. When 5G terminals are installed on trains, vehicle-mounted video servers will be able to continuously communicate with 5G base stations through these terminals, enabling real-time transmission of TV broadcast signals. Even in the case of signal loss, videos can still be played offline. When a train arrives at a station, the 5G network at the station can instantly update the program to the train's server, enabling live-streaming of online videos, and ultimately improving the passenger experience.

4.3.2 Networking Suggestions

Transport hubs involve a wide range of scenarios, such as departure, arrival, and waiting halls, all with different service requirements:

- Departure area: Departure areas of a traffic hub include the airport check-in area, security check area, waiting hall, and ticket booths. In an airport's waiting hall, for example, passengers will usually remain for a long period of time, during which they will require data for video streaming and gaming. In addition, the airport also manages devices such as billboards and robots through wireless networks. In contrast, in the waiting hall of an intercity bus station, the waiting time is relatively short, and passengers usually use instant messaging services.
- Arrival area: The main services are 5G shuttle buses and electronic billboards. Passengers stay here for a long time and the service requirements are high.
- VIP area: High-end experience services, such as 4K video, 360-degree VR, and VIP service robots, are widely used in VIP rooms and lounges.
- Dining area: Passengers spend a long time in the dining area, where various services, such as HD video and food delivery robots, can be used.
- Baggage reclaim: A large amount of data services, mainly instant messaging services, occur at the baggage reclaim area. In addition, the automatic baggage vehicles can be supported by the 5G network.
- Stores: Services here are mainly electronic billboards and IoT. Passengers use services such as instant messaging, mobile payment, and photo or video uploading on social media apps.
- Airport equipment operation area: The main services here include robots, remote diagnosis, and IoT.
- Parking lot: The main services include the robots and cameras to monitor the flow of taxi passengers.

Based on exploration and practices in 5G commercial projects, the following table analyzes services in different functional areas in transport hubs.

Table 4 Probability of various services occurring in transport hub scenarios

Scenario	Downlink Rate > 100 Mbit/s		50 Mbit/s ≤ Downlink Rate ≤ 100 Mbit/s		Downlink Rate < 50 Mbit/s		Capacity and Sector Planning Suggestions
Transport Hub Functional Area	AR	Big Data Transmission	VR	4K HD Video	Data Application	Real-time Communication	
Departure area	30%	50%	30%	50%	50%	80%	Scalable capacity design and cell splitting during traffic bursts are required.
Arrival area	10%	50%	30%	50%	50%	80%	
VIP area	30%	30%	30%	60%	30%	80%	Capacity design based on VIP area traffic models; independent sectors are required.
Dining area	20%	30%	20%	30%	60%	80%	Independent sectors are required to ensure services.
Baggage reclaim	5%	20%	5%	10%	60%	80%	
Store	10%	20%	10%	20%	60%	80%	Island-type structures require co-cell design for the upper and lower floor.
Airport equipment operation area	20%	20%	5%	0%	60%	80%	Independent sector assurance is required. Robustness requirements such as redundancy must be considered during design.
Parking lot	0%	0%	0%	0%	50%	80%	Coverage assurance is the primary concern. The network must meet requirements for services such as parking navigation and payment.

Based on the service requirements of transport hub functional areas, the solution design is completed in three steps: solution selection, capacity planning, and coverage planning.

Solution Selection

The solution can be a network consisting of the DIS and AAUs. For example, in an airport, AAUs can be deployed in outdoor runways and aprons to provide full coverage, allowing passengers to access the network as soon as they arrive, and helping operators compete for high-value international roaming users. Multi-sector planning is recommended in scenarios with high requirements on data services, such as waiting halls and VIP lounges. If traffic bursts occur, the DIS can implement remote capacity expansion. This also allows the capacity to be expanded on demand to meet current and future evolution requirements. Because security check areas have low traffic volume, they are designed as handover bands to effectively control interference. During network design, multiple deployment and camouflage modes can be adopted to fully utilize the existing airport facilities, seamlessly integrating the devices with the airport environment:

Capacity Planning

The capacity is planned based on the passenger traffic, operator market share, user activation ratio, service duty ratio, and service rate requirements. In addition, the service requirements for the following 3 to 5 years need to be considered so that one deployment mode can sustain long-term evolution.

Coverage Planning

The building structures vary greatly in different areas. Therefore, a detailed site survey must be carried out on the airport, with the network design depending largely on local conditions. For example, for island buildings in shopping and catering areas, the interference between the upper and lower floors must be fully considered during design, with the coverage radius and height of antennas being customized accordingly. Also, the co-cell policy can be used to avoid frequent handovers and mitigate interference between cells. In contrast, in the parking apron area, outdoor AAUs are deployed for coverage, while the corridors and bridges are covered by the DIS to form macro-micro coordinated coverage and reduce the overall construction cost.

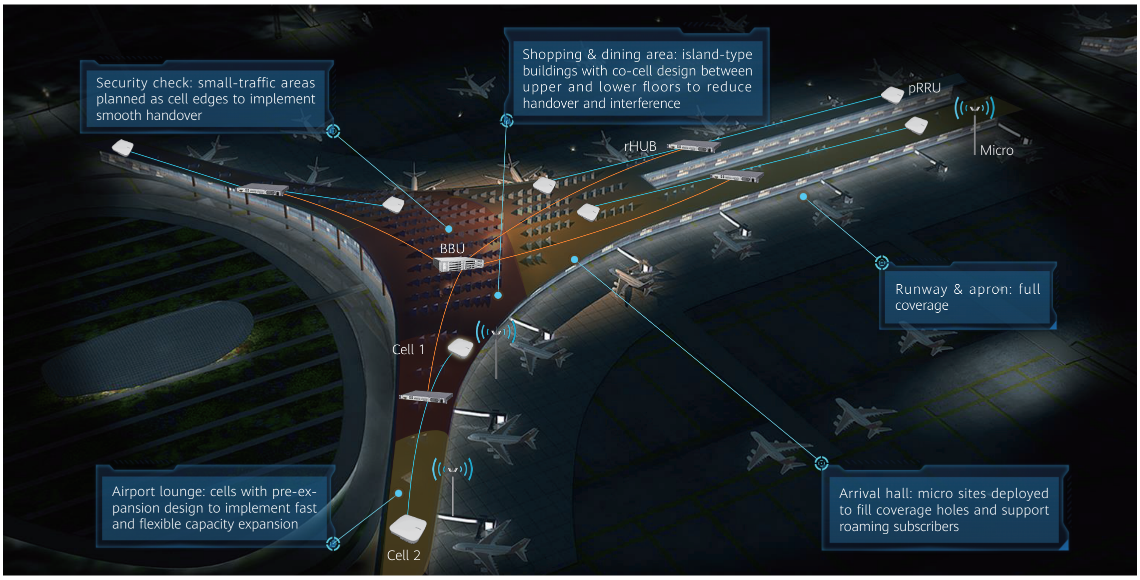


Figure 15 **5G deployment suggestions for airports**

4.4 Use Cases and Construction Suggestions for 5G Networks in Commercial Buildings

Commercial buildings include shopping malls, hotels, and office buildings, which require various applications that can be fully supported in the 5G era. From the perspective of industry development, commercial buildings in the future mainly require three types of services: HD video, edge computing, and service association on basic networks.

The HD video requirement of the basic network refers to HD (4K and 8K) video streaming and real-time HD communication. For example, 4K or higher HD video services are required in conference rooms and exhibition halls, same as are live HD programs in catering areas. In terms of edge computing, the 5G network can be used to implement local data computing and processing within the building. For example, data of the facial recognition system can be processed locally, reducing security risks and reducing the latency. In terms of service association, many sensors will be deployed in buildings. In the future, 5G networks can support the deployment of more sensors in places where cables cannot be deployed. Such a huge number of wireless sensors can be integrated with the control subsystem of the building over the 5G network to implement information sharing and mutual invoking, upgrading the management of smart buildings.

4.4.1 Use Cases

4.4.1.1 Service Robots in 5G-enabled Buildings

In commercial buildings, there may be a large number of deliveries every day. With so many people accessing and leaving the building, security risks will undoubtedly arise. What's more, delivery personnel spend much time delivering the food, with poor efficiency. With advanced indoor positioning and low latency, 5G networks enable delivery robots to finish the last-100 m delivery. Human delivery personnel need only to deliver to the robots, greatly improving their work efficiency. In hotels, customers often require room service. Similarly, 5G-enabled hotel service robots can greatly reduce the dependency on human porters, improving customer service experience and reducing operation costs.

In addition, operators can provide dedicated service experience assurance for robot services and share service revenues with building management companies.

Figure 16 Service robots in 5G-enabled buildings

4.4.1.2 5G-enabled Multimedia Conference Rooms

The high-bandwidth offered by 5G networks will greatly improve the office experience. For example, today's "flat" telepresence conferences will evolve to 4K/8K HD telepresence conferences and holographic projection conferences. Operators can also provide dedicated 5G conference room solutions for enterprises, with special assurance services for important conferences. Such services will bring operators more network revenue through charging based on time, service level, and traffic.

Figure 17 5G multi-media enabled conference

4.4.2 Networking Suggestions

Commercial buildings have many functional areas, such as lobbies, offices, and suites, which have different service requirements:

- Lobby: As customers and building personnel remain in lobbies only for a short period of time, the basic coverage solution will suffice. IoT services and building service robots can be considered in capacity design.
- Elevator: Generally, only basic coverage is ensured. Design considerations include handovers between elevators and floors, as well as service requirements of electronic billboards and cameras inside elevators.
- Dining area: Customers stay in the dining area for a long time, and various services, such as HD video and food delivery robots, will be used here.
- Hotel suites: In the future, hotel suites will provide robot service applications, as well as cloud games, 4K movies, and cloud computers.
- Parking lot: In addition to basic coverage, the parking lot may provide robot applications.
- Conference center: VR, holographic, or 4K conference services can be provided and charged by the number of times used. Dedicated capacity and bandwidth assurance is required.
- Logistics area: Coverage of IoT applications must be ensured.

Based on exploration and practices in 5G commercial projects, the following table analyzes services in different functional areas in commercial buildings.

Table 5 Occurrence probability of various services in commercial buildings

Scenario	Downlink Rate > 100 Mbit/s		50 Mbit/s ≤ Downlink Rate ≤ 100 Mbit/s		Downlink Rate < 50 Mbit/s		Capacity and Sector Planning Suggestions
Business Building Functional Area	AR	Big Data Transmission	VR Service	4K HD Video	Data Application	Real-time Communication	
Lobby	5%	20%	5%	20%	50%	80%	Capacities are planned based on user service models. Independent sectors are configured to ensure smooth handovers between indoor and outdoor cells.
Elevator	0%	0%	0%	0%	30%	40%	Service requirements of electronic billboards and cameras in the elevators and basic coverage are required.
Office	20%	50%	10%	10%	30%	80%	Capacity design based on office traffic models; independent sectors are required.
Dining area	10%	0%	10%	40%	60%	80%	Independent sectors are required to ensure services.
Hotel suites	30%	60%	20%	10%	20%	60%	Capacity design based on user traffic models; independent sectors are required.
Parking lot	0%	0%	0%	0%	30%	50%	Coverage assurance is the primary concern. The network must meet requirements for services such as parking navigation and payment.
Conference center	30%	70%	20%	50%	60%	80%	Capacity design based on traffic models for 4K/8K video conferences; independent sectors are required.
Banquet hall	20%	40%	10%	30%	40%	80%	Capacity design based on user traffic models; independent sectors are required.
Logistics area	5%	50%	5%	20%	50%	80%	Independent sectors are required. The system requirements of IoT services must be considered during design.

Based on the service requirements of commercial building functional areas, the solution design is completed in three steps: solution selection, capacity planning, and coverage planning:

Solution Selection

The business building solution can be deployed in macro-micro coordination mode. For the shallow indoor coverage area close to the macro base station, the outdoor macro base station is preferred. For the deep and rear indoor coverage areas, ensure good coverage by the window and avoid handovers between indoor and outdoor cells. For areas far away from macro base stations, the DIS is preferred, as it provides coverage for core areas of business buildings, such as open workshops, conference rooms, and offices. As service requirements vary, the functional areas with special capacity requirements, such as conference rooms and banquet halls, are planned as independent cells.

Capacity Planning

The capacity planning of commercial buildings concentrates on the traffic model, crowd density, and target coverage areas. The traffic model is considered the most important factor. During initial network construction, the forecast for 5G traffic models and capacity requirements in different scenarios must be based on 4G networks and the development trend of 5G services. Therefore, elastic capacity design is a key issue that must be considered during indoor 5G network capacity planning.

- Elastic capacity design predicts scenario-specific 5G capacity requirements based on scenario characteristics, 5G service characteristics, historical network development data, and 5G user development plan.
- Network architecture design must comply with the principle of flexible capacity expansion. Equipment space and transmission lines must be reserved for several times of elastic capacity expansion.
- Network layout must ensure that no obvious interference exists between cells after capacity expansion.
- When designing an elastic capacity network, areas with 5G traffic burst, such as conference center and dining area, must be considered.

However, for a passive distributed antenna system with multiple headends sharing one signal source, the headend capacity cannot be independently scheduled, and the capacity is not flexible, making it difficult to meet 5G service development requirements. To provide large capacity redundancy, a passive distributed antenna system requires a large number of signal sources, resulting in high costs and poor flexibility in capacity expansion and adjustment.

Coverage Planning

Handovers must be considered during coverage design. For example, it is better if an elevator is covered by a single cell; In the parking lot, the handover between indoor cells and outdoor macro cells must be considered. Specifically, the antenna power and density must be planned in accordance with the site environment to achieve coordinated indoor and outdoor planning; To avoid signal leakage in the lobby, directional antennas can be deployed with lower-power antenna ports. This ensures smooth handover between indoor and outdoor coverage; In offices or hotels with many partitions, it is recommended that pRRUs with external antennas be deployed to ensure coverage; For basic coverage scenarios such as parking lots, directional antennas are recommended to reduce the number of devices.

4.5 Summary

Services on 5G networks differ from those on 4G networks. That is, in addition to traditional voice and data services, 5G networks provide various B2B and B2H industry applications. Service requirements vary by rate, latency, and occurrence probability in different scenarios. During indoor network construction, the impact of these services must be considered during coverage and capacity planning, ensuring the service and user development can be supported for the next three to five years. This means the network must have high scalability, evolution, and reliability.

5. 5G E2E Indoor Digital Integration Service

As wireless networks evolved from 2G to 4G, a large number of indoor coverage systems were deployed. As we usher in the 5G era, the requirements for indoor network bandwidth and latency are much higher than those of 4G. How can existing 4G indoor networks be smoothly evolved to 5G while protecting existing investment? How do operators make precise investment in 5G indoor sites? How can be achieved controllable progress, visible quality, and efficient deployment of high-quality indoor networks during indoor site integration? How can be opened the "black box" of an indoor site to visualize and improve O&M efficiency? This chapter describes how to utilize E2E 5G indoor digital integration services when constructing an indoor 5G network with flexible capacity scheduling and visualized O&M, thereby supporting more services, higher experience rates, network scalability, efficient E2E operations, and smoother 5G evolution, ultimately helping operators effectively cope with increasingly diverse services and growing requirements in the 5G era.

5.1 5G Indoor Network Planning and Evolution

5G indoor network planning must be based on service requirements and the principle of "on-demand network construction". First, plan the current and future indoor services; then, determine the network construction standard based on service requirements; finally, select the most suitable indoor coverage solution based on the scenario characteristics.

5.1.1 New 5G Indoor Network Accurate Planning

5G indoor network consulting and accurate planning need to be carried out in accordance with operators' service policies (such as promoting high-quality videos), to help operators identify indoor value hotspots based on the indoor distribution scenario, services, and user experience on the live network. This is achieved through methods such as indoor and outdoor traffic differentiation, multi-dimensional evaluation and sorting, solution matching, and traffic suppression restoration. The final product is indoor network investment suggestions based on ROI analysis, achieving precise indoor network construction.

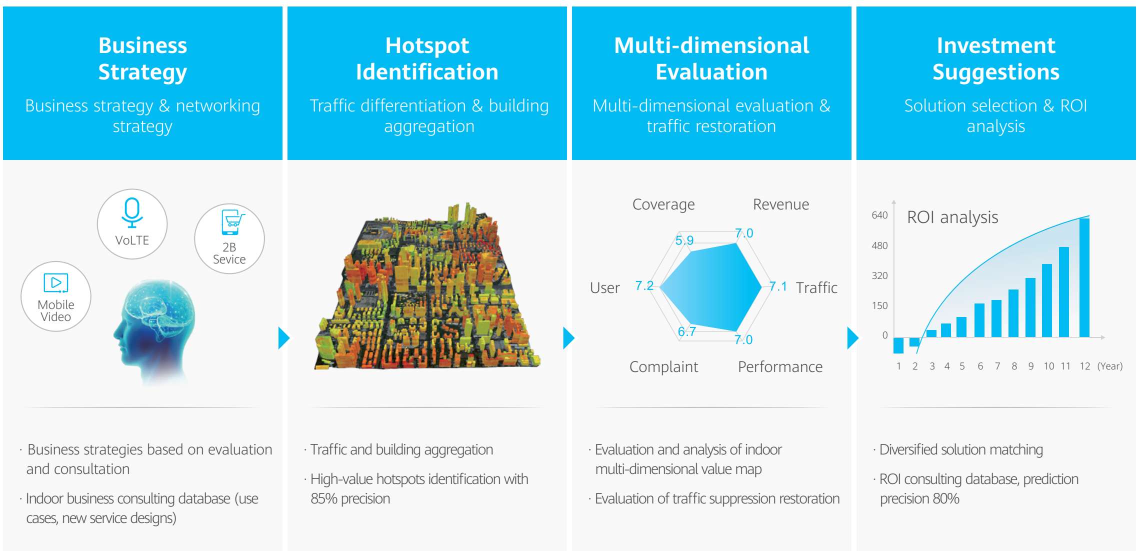


Figure 18 5G indoor accurate planning

5.1.2 5G Evolution of Existing Indoor Networks

Existing indoor sites are evaluated in terms of scenario, coverage, dual-channel balance, frequency band of passive components, and link loss. Then, 5G evolution solutions are provided, such as direct combination, reconstruction before combination, and indoor digital overlay solutions. For sites in high-value scenarios — for example, existing indoor sites at transport hubs, large stadiums, hospitals, and shopping malls — direct deployment of 5G indoor digital solutions, such as LampSite Pro, is recommended. For multi-partition scenarios, such as hotels and offices, cost-effective indoor digitalization solutions with external antennas, such as LampSite Grid, are preferred. In coverage-driven scenarios where there is no competition requirement, if the existing passive indoor distribution system supports the 5G frequency band, perform coverage prediction after 5G combination and analyze the feasibility of direct combination. If direct combination cannot be performed, it is recommended that the indoor digital solution is added.

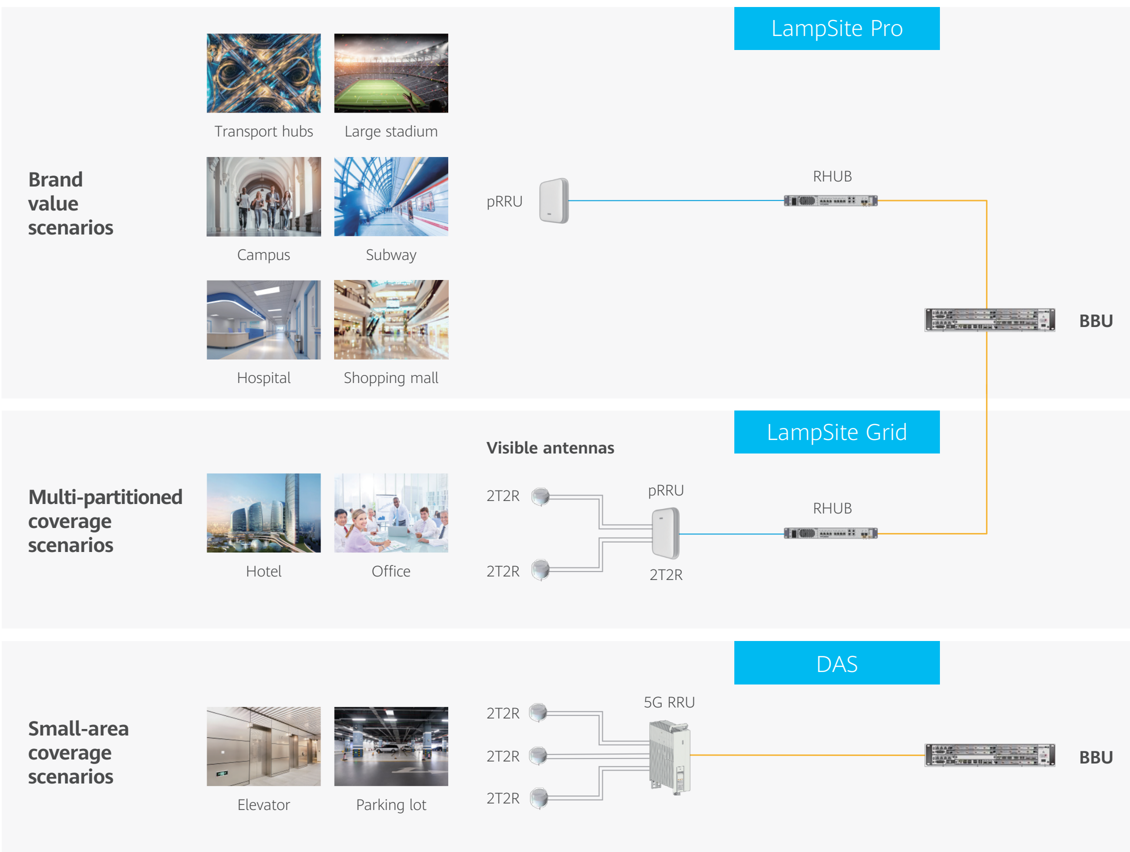


Figure 19 5G evolution for existing indoor sites

5.2 Indoor Digital Integration

During indoor 5G site deployment, both the deployment cost and the impact of the deployment quality on subsequent O&M must be considered. If no digital solution is used, device installation positions cannot be accurately displayed on the NMS. As a result, visualized O&M and intelligent operations cannot be implemented. Therefore, digital deployment is required for indoor 5G site selection, survey design, integration implementation, and completion acceptance. Huawei's indoor digital integration system adopts a cloud-terminal coordinated architecture. Onsite personnel perform digital surveys, implementation, testing, and optimization using terminals (cell phones), and upload data to the cloud for processing. The cloud platform leverages the support of various tools and experts to analyze the test data, and outputs optimization solutions based on global network construction experience. The cloud platform implements an operation-driven process with data streamlining, IT-based operations, and visualized progress and quality management, which improves E2E deployment efficiency and quality.

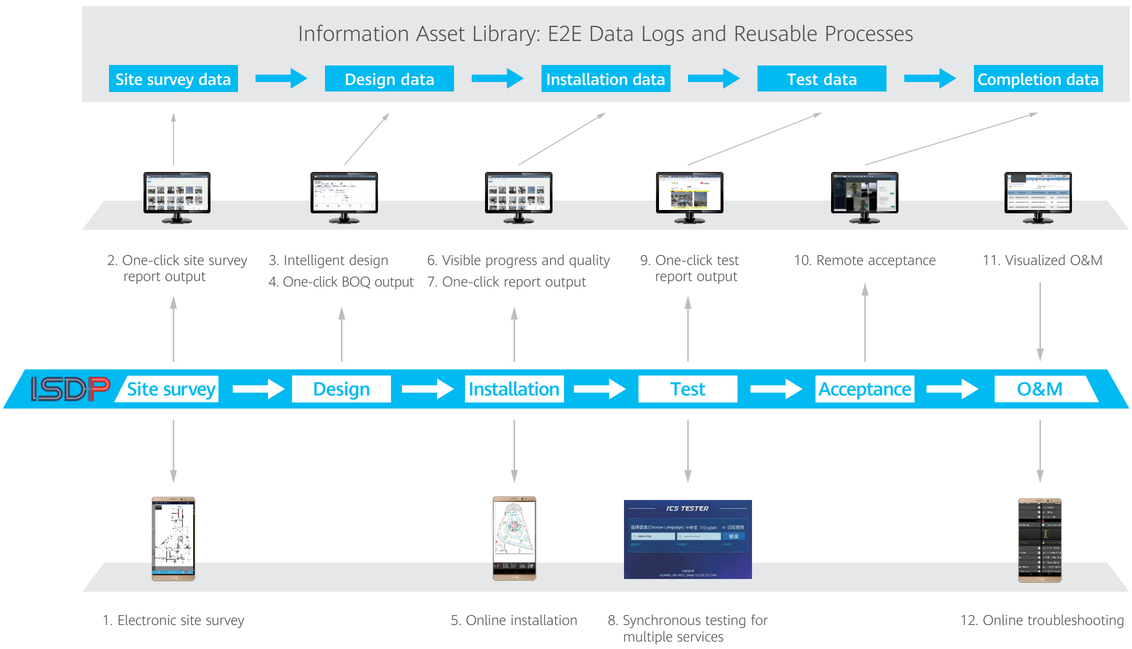


Figure 20 E2E indoor digitalization integrated deployment platform

- Site survey: completed by the intelligent survey tool. A smartphone is used to take photos and collect data onsite, and these are used later for indoor 5G design. One mobile phone suffices to complete onsite operations and generate a survey report in one-click mode.
- Design and simulation: The design simulation tool implements 3D intelligent modeling, automatic system design, and 5G-oriented repetitive simulation to output the optimal indoor design solution.
- Implementation and quality control: Using the visualized integrated implementation tool, the engineer confirms the installation positions, cabling routes, and connection relationships based on the drawing output by the design tool. The engineer then completes onsite implementation, and records the actual deployment result in the system to ensure the consistency between the construction and design. The system performs an AI-based quality review on the installation photos collected onsite. In this way, the integrated deployment process is visible and the quality controllable, preventing the need for rectification due to construction errors.
- Testing and acceptance: After the site is powered on, the indoor walk-test tool is used to collect wireless network performance data and upload the collected data to the cloud. Next, the system automatically generates an indoor walk test report based on the customized report template. In addition, design parameters are configured on each headend in the visualized indoor O&M system, and device installation information collected during actual deployment is imported to the system. The system can dynamically monitor the working status, service volume, and user changes of the headends in real time. After running for a period of time, the system generates network running indicators and performance reports based on the template to assist in network completion.

5.3 Indoor Digital O&M

The indoor digital O&M platform provides the following functions: geographic display of device alarms, grid-based indoor coverage display (including coverage, capacity, rate, and anomalies), and indoor intelligent energy saving. The following functions help operators quickly and accurately locate and rectify indoor network faults as well as effectively reduce indoor OPEX:

Figure 21 Indoor visualized O&M platform

- Alarm visibility: This feature sheds light on indoor coverage network maintenance. Alarm locations are easy to see, greatly improving problem locating efficiency. Faults can be detected proactively instead of being passively revealed through user complaints, improving user experience and satisfaction.
- Performance visibility: Using KPI drilldown from the global perspective and the indoor grid-based traffic map, the performance and coverage of different floors in a building can be accurately evaluated. Compared with the traditional indoor walk test, problem locating efficiency is greatly improved.
- Capacity visibility: The traffic distribution in different areas of each floor is evaluated to identify high-traffic areas and perform capacity expansion accordingly. If the traffic volume at

the cell edge is high, cell division is adjusted to mitigate interference to UEs at the cell edge and improve user experience.

- Energy saving visibility: Indoor traffic tends to move in waves. For example, the traffic in offices is extremely low at night. The energy saving visibility feature helps operators save energy and reduce emissions by configuring energy-saving features based on an analysis of indoor traffic trends and user behavior, formulating energy-saving policies, and evaluating the effect of such policies.

6. Summary and Expectations

5G will bring two important changes to operators: a restructuring of business value and a vertical extension of network architecture. In the future, indoor 5G will become an element of property infrastructure as vital as water, electricity, and gas, becoming one of the driving forces for operators to monetize their 5G networks.

During the planning of indoor 5G networks, the features of different functional areas in a building must be taken into consideration. In addition, network planning design must be refined based on the B2C, B2B, and B2H service requirements of the functional areas to meet business and network requirements.

Concerning indoor 5G construction, it is recommended to use all-scenario full-series indoor digital products to meet the demands of large capacity, low latency, and high performance. The unified digital integrated deployment platform can achieve the following: process-based implementation, data streamlining, IT-enabled operation, and visualized progress and quality management, thereby improving E2E deployment efficiency and quality.

For enhanced O&M, the indoor 5G network is now illuminated through a geographic display of device faults and a grid-based indoor coverage display, improving O&M efficiency. Furthermore, indoor intelligent energy saving minimizes the power consumption of indoor sites.

In conclusion, indoor digital networks will become the valuable core of mobile networks in the 5G era, and so digital indoor coverage is an undeniable industry trend. To deliver an optimal user experience, efficient O&M, and intelligent operation, digital products, integration, and O&M can be used to build an indoor digital network.

In the future, Huawei will continue to work with the industry to increase investment in digital indoor coverage solutions, deepen cooperation with operators and industry partners and explore new business models. Huawei aims to construct a brand new industry ecosystem, and jointly build indoor 5G networks that are more intelligent, efficient, and profitable.

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