Indoor 5G Networks White Paper

(Version 2.0)

September 2018

Contents

1. Forewords

The fifth generation of mobile communications technology (5G) represents the main direction of future network development. It promises to enable the transition from broadband interconnection between people to the connectivity of everything, while reshaping the way we live and work.

On December 20th, 2017, 3GPP published the first 5G New Radio (NR) standards at its 78th RAN plenary meeting in Lisbon, Portugal and 3GPP approved the standalone version of the 5G NR standard at the plenary meeting on June 14th, 2018. This release sets out the technical specifications of NR in the first phase of 5G deployment, speeding up 5G's commercial use. More than 20 global operators have begun to set up 5G first office application (FOA) sites or pre-commercial sites. Various services, such as virtual reality (VR) and telemedicine, will flourish in a new, intelligent fully connected world. As the majority of daily activities take place indoors, the industry urgently requires the critical tasks of further research into 5G's services requirements and a deeper exploration into viable network deployment strategies.

2. Overview

5G networks allow for people to people, people to machine, and machine to machine communications, while supporting a myriad of mobile Internet and Internet of Things (IoT) services. Thanks to the brand-new architecture and innovative technologies, 5G networks are able to flexibly suit the needs of diversified scenarios, providing ultra-broadband, ultra-low latency, ultra-high reliability, and massive connectivity. 5G network design aims to provide optimal user experience based on service requirements.

Statistics show that more than 80% services on 4G mobile networks occur indoors. The industry predicts that a greater number of mobile services will take place indoors as 5G spurs service diversity and extends business boundaries. Therefore, indoor mobile networks of the 5G era will become an integral part of operators' core competitiveness.

Compared with 4G services, mainstream 5G services will be carried on higher frequency bands such as C-band and millimeter wave (mmWave) band. Since penetration loss due to air propagation and building blockage increases as frequencies get higher, outdoor base stations will struggle to provide enough coverage for indoor areas during the era of 5G. This is why indoor services need to be carried by dedicated indoor networks.

Indoor 5G networks must feature elastic capacity, visualized operation and maintenance (O&M), and intelligent operation, enabling ultra-broadband, massive connectivity, ultra-low latency, indoor positioning, and many other diverse services. The provision of such indoor networks is to help ensure optimal user experience, efficient O&M, and intelligent operation.

Based on the *5G-Oriented Indoor Digitalization Solution White Paper* (Version 1.0, 2017), this white paper incorporates the latest practices and conducts additional research to further elaborate upon the complex details of indoor 5G network deployment. It discusses indoor services' network requirements, challenges in target networks deployment, and any recommended construction strategies.

3. Requirements of 5G Indoor Services

3.1 Three Major Types of Services

The global mobile communications industry has reached a consensus on 5G application scenarios as the research progresses. International Telecommunication Union — Radio communication Sector (ITU-R) proposed three major types of 5G services, namely Enhanced Mobile Broadband (eMBB), Ultra-Reliable and Low-Latency Communications (URLLC), and Massive Machine Type Communications (mMTC).

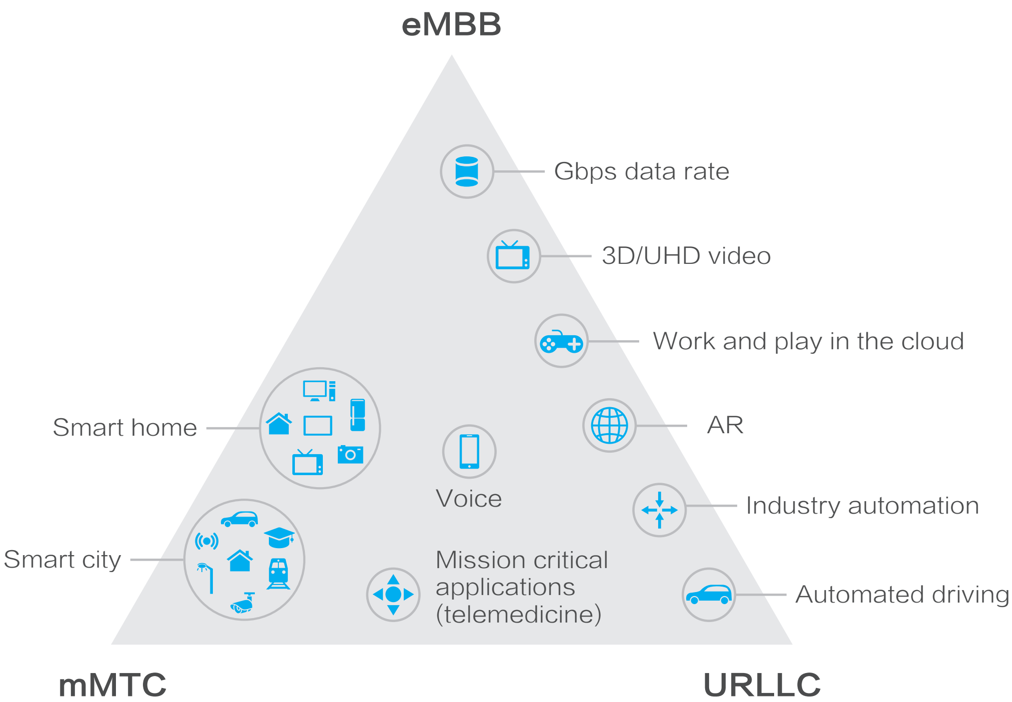


Figure 1 **Three major types of 5G services**

3.2 Indoor Services and Features

Global System for Mobile Communications Association (GSMA) believes that 5G networks will be an important enabler of mobile Internet and IoT. Thanks to 5G, a wider range of more diverse and intelligent services will come to life. 5G will see a wide application in smart home, telemedicine, remote education, industrial manufacturing, and IoT. Typical use cases will include gigabit mobile broadband data access, 3D video, high-definition (HD) video, cloud service, AR, VR, industrial manufacturing automation, emergency rescue, automated driving, and modern logistics. A number of these applications (such as HD video, AR, VR, telemedicine, industrial manufacturing automation, and modern logistics) will predominantly take place indoors.

3.3 Indoor Services' Network Requirements

The following sections describe requirements on 5G networks posed by three different types of services.

3.3.1 Over 100 Mbps Cell Edge Rate

VR and HD video are among the most typical 5G eMBB services. People indoors are usually static or moving slowly. They tend to enjoy VR and HD video services on a frequent basis with each session lasts for a relatively long duration. Wireless networks must have large bandwidth in order to specifically support these types of services.

VR will be widely used in sports events, online gaming, and extreme sports. For example, organizers of the 2018 Winter Olympics in PyeongChang, Korea placed 360-degree panoramic cameras at different locations within the stadium. 5G networks then transmit the collected high-frequency video signals in real time to the VR area of the audience seats. Such VR broadcasting service offers VR users a superior, immersive experience. The following table lists the VR requirements for networks.

Table 1 Network requirements of VR

Downlink							Uplink
Service	VR				Cloud VR		HD Video
	Pre-VR	Entry-level	Advanced	Ultimate	Entry-level	Ultimate	
Resolution	4K/30 frames	8K/30 frames	12K/60 frames	24K/120 frames	1080P/60 to 90 frames	6600x6600 /120 frames	2K/30 frames
Coding rate	16 Mbps	64 Mbps	279 Mbps	3.29 Gbps	70 Mbps to 130 Mbps	Approx. 5 Gbps	6.7 Mbps
Data rate	25 Mbps	100 Mbps	419 Mbps	4.93 Gbps	100 Mbps to 150 Mbps	Approx. 6.5 Gbps	10 Mbps

HD video is destined to witness broad application in telemedicine, remote tourism, remote education, online shopping, and concerts. The following table lists the HD video requirements for networks.

Table 2 Network requirements of HD videos

Service	Quasi-4K Video	Standard 4K Video	UHD 4K Video	8K Video
Resolution	4K/30 frames/8 bits	4K/60 frames/10 bits	4K/120 frames/12 bits	8K/120 frames/12 bits
Coding rate	25 Mbps to 30 Mbps	25 Mbps to 35 Mbps	25 Mbps to 40 Mbps	50 Mbps to 80 Mbps
Data rate	⩾ 30 Mbps	⩾ 50 Mbps	⩾ 50 Mbps	⩾ 100 Mbps

As listed in Table 1 and Table 2, entry-level VR and 8K videos call for a 100 Mbps service rate. Cloud VR poses more stringent data rate and latency requirements than traditional VR as all images are first rendered in the cloud and then directly transmitted to mobile terminals. While entry-level traditional VR services only demand 100 Mbps data rate and 10 ms latency, ultimate Cloud VR requires 6.5 Gbps data rate and latency of no more than 2 ms. Only 5G networks will be able to accommodate such high requirements.

Future networks must also satisfy VR and HD video services in densely populated areas such as large venues (stadiums and exhibition centers), transportation hubs (airports and high-speed railway stations), university districts (campuses), and commercial centers (shopping malls and trade centers). Assuming that entry-level VR is used, the traffic density in 2022 is expected to reach 2.5 Mbps/m^2 (250 Mbps traffic for every 100 m^2) in the preceding areas. It is also notable that the density will be even higher if users opt for Cloud VR.

3.3.2 99.999% Reliability and Less Than 1 ms Ultra-Low Latency

Telemedicine, smart manufacturing, and emergency rescue are crucial 5G use cases with strict demands in terms of network reliability and latency.

In telemedicine scenarios, patients' medical status and other HD video data collected by surgical robots will be transmitted to remote specialized surgeons via networks for accurate diagnosis. Doctors will remotely observe patients undergoing operations through 360-degree HD videos and accurately control the surgical system. The end-to-end (E2E) latency must be less than 10 ms, and the signal transmission reliability must exceed 99.999%. The American company InTouch Health has been providing telemedicine services for more than 80 hospitals across the country, enabling remote stroke treatment, remote ICU care, and surgical collaboration. The Second People's Hospital of Zhejiang, Beijing Genomics Institute, and China Mobile Zhejiang are jointly working towards further innovation in 5G telemedicine.

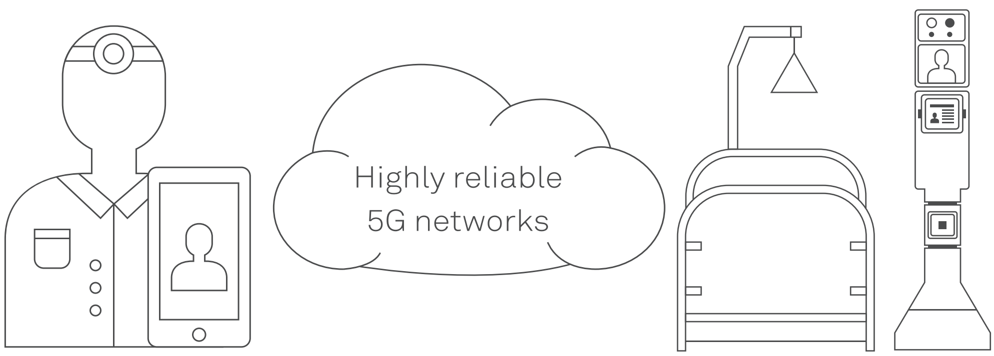


Figure 2 Telediagnosis and tele-treatment

As for smart manufacturing, smart mechanical devices (robots or robot arms) must work in coordination during processing and assembly. These devices usually in fast movements and as such E2E network latency must not exceed 1 ms to ensure the quality and efficiency in precise processing.

In the case of fires or other emergent situations, robots transmit HD videos of the accident scene to the command center in real time. The command personnel then operate intelligent mechanical devices from afar to quickly and accurately complete rescue operations.

All these above mentioned URLLC cases demand 99.999% network reliability, and 1 ms latency.

3.3.3 One Connection per Square Meter

IoT is one of 5G's major services that will see extensive applications in warehouse management (smart logistics) and industrial manufacturing (smart factory).

Wireless networks at logistics hubs must be able to connect the massive amounts of goods with electric labels for efficient management, dispatching, and transshipment. A wide range of shelved goods need to be identified, positioned, sorted, and then automatically transported to dedicated locations with the help of robots. It is estimated that one object needs to be connected for every square meter.

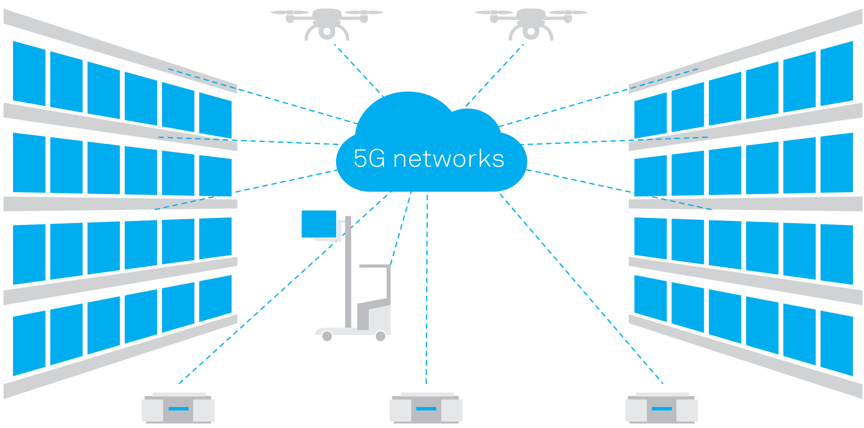


Figure 3 Massive connections at logistics hubs

As for smart factories, wireless networks must support real-time transmission for a huge amount of operating data generated by robots, robot arms, automated guided vehicles (AGVs), and production equipment to the management platform with high reliability. As connections are required for diverse objects, future networks must be able to support 1 connection/m^2.

In conclusion, future indoor applications will require 5G networks to enable 1 connection/m^2 (or 1 million connections/km^2).

3.3.4 Others

Location based services (LBSs) are expected to become increasingly popular as 5G arrives. Indoor navigation, indoor passenger flow analysis, user profile, precise marketing, and various other LBSs require capable networks to support indoor positioning with a precision of 1 m to 3 m or higher.

3.3.5 Conclusion

The discussion in this chapter suggests that indoor services in the 5G era demand future networks to support 100 Mbps downlink cell edge rate, 1 ms latency, 2.5 Mbps/m^2 traffic density (required by 2022), and 99.999% reliability. Next-generation networks must also be able to support 1 connection/m^2 and 1 m to 3 m precise indoor positioning.

Table 3 Requirements for indoor 5G target networks

Requirements	
Cell edge rate	Downlink : ⩾ 100 Mbps Uplink: ⩾ 10 Mbps
Traffic density	2.5 Mbps/m^2 (densely-populated indoor scenarios) 0.5 Mbps/m^2 (general indoor scenarios)
Connection density	1 connection/m^2 (1 million connections/km^2)
Latency	1 ms
Positioning accuracy	1 m to 3 m
Reliability	99.999%

As network requirements vary from one 5G service to another, operators must flexibly set up the most appropriate indoor 5G network deployment targets to suit each distinct application scenario.

4. Challenges Facing Indoor 5G Target Network Construction

Different types of indoor 5G services are going to be carried on the same physical network via network slicing. This involves multiple factors specifically during network construction. High frequency bands (such as C-band and mmWave band) are the only candidate bands for 5G networking. This is largely due to the abundance of spectrum resources to guarantee a cell edge rate of 100 Mbps. Network architecture and coverage will require redundancies to ensure 1 ms latency and 99.999% reliability. Flexible capacity expansion is also an indispensable feature for future 5G networks to fit the needs of areas with 1 connection/m^2. In addition, as service volume is soaring and new services for indoor scenarios have been partially deployed, networks must include additional support for flexible capacity and intelligent operation. It is thus clear that qualified indoor 5G networks must tackle challenges in networking on high frequency bands, flexible capacity expansion, reliability, O&M, and operation.

4.1 Networking on High Frequency Bands Making Indoor In-depth Coverage Difficult

4.1.1 High Propagation and Penetration Loss

ITU-R recommends to deploy 5G networks using Sub-6 GHz and microwave bands since high frequency spectrum resources can provide sufficient bandwidth. Sub-6 GHz (such as 3.5 GHz and 4.9 GHz) and mmWave bands vary widely in terms of coverage capabilities. According to the propagation law of radio waves, the higher the frequency, the greater the propagation loss in the air and penetration loss caused by physical obstructions. As a result, it is growing extremely difficult to provide sound outdoor-to-indoor coverage. The following table lists the results of 5G network field tests in China and Korea.

Table 4 Differences of outdoor-to-indoor signal loss on different frequency bands

Frequency Band (GHz)	Free Space Loss Difference (dB)	Penetration Loss Difference (dB)	Overall Loss Difference (dB)
	Distance fading coefficient: 20	Results of field tests in Hangzhou	
1.8	Baseline	Baseline	Baseline
3.5	5.8	4.8	10.6

The above table indicates that radio waves experience more propagation and penetration loss on 3.5 GHz frequency band than on 1.8 GHz, with overall loss difference reaching approximately 10.6 dB. The difference between overall loss on 4.9 GHz and 1.8 GHz frequency band is even greater. Therefore, it is more challenging for outdoor signals on 3.5 GHz or 4.9 GHz band to cover indoor areas than those on 1.8 GHz. Given the walls and structures acting as blockades inside these architectures, the deep interior sections of buildings will experience much worse outdoor-to-indoor coverage using high frequency bands.

Accordingly, an increasing number of buildings are in urgent need of independent 5G networks, which will be better deployed on 3.5 GHz or 4.9 GHz band than on Sub-3 GHz band.

4.1.2 Passive Distributed Antenna System: Difficult Evolution, High Signal Loss, and Strong Intermodulation Interference

Passive distributed antenna systems consist of power splitters, couplers, feeders, ceiling antennas, and other components. The existing passive distributed antenna systems do not support 5G frequency bands, which means the 5G-oriented evolution is infeasible due to technical issues and high cost.

To begin with, the current systems' components (power splitters, couplers, and ceiling antennas) support only Sub-3 GHz (698 to 2700 MHz) frequency band. Multiple sampling tests reveal that the key performance indicators (such as insertion loss, coupling degree, and standing wave ratio) of the Sub-3 GHz components are not up to acceptable standards when operating on 3.5 GHz band. In such a case, the passive distributed antenna system on live networks fail to support 3.5 GHz, let alone 4.9 GHz, or mmWave band. Although the current feeders can transmit 3.5 GHz signals, the resulting loss is higher than when Sub-3 GHz signals are transmitted.

Second, 5G networks predominantly occupy high frequencies. Signals transmitted at 3.5 GHz band tend to undergo more overall loss (including the transmission loss of the passive distributed antenna system, free space loss, and wall penetration loss) than at Sub-3 GHz band. The following table lists the test result.

Table 5 Difference of overall indoor coverage loss on 1.8 GHz and 3.5 GHz bands

Frequency Band (GHz)	Overall Loss Difference (dB)
1.8	-9.9
3.5	Baseline

As listed in the preceding table, the overall loss of 3.5 GHz signals is 9.9 dB higher than that of 1.8 GHz signals. On the one hand, building 5G on 4G networks is prone to result in significantly deteriorated network coverage. On the other hand, high propagation loss and construction cost also halt the addition of new 5G passive distributed antenna systems.

What's more is that as a potential side-effect, the coexistence of 5G and GUL networks can further complicate intermodulation interference for passive distributed antenna systems. Providing that 5G has larger signal-source power and wider frequency bandwith, the intermodulation interference on the system will inevitably be more severe.

To conclude, neither the deployment of new passive distributed antenna systems nor the reconstruction of existing ones can support 3.5 GHz/4.9 GHz 5G networks.

4.2 Diverse Services Requiring Larger Scalable Network Capacity

Traffic usage tends to peak when crowds aggregate in large venues, entertainment centers, theaters, and other densely populated areas. Traffic hubs, shopping malls and other hotspots can see fluctuation in traffic demands. When it comes to scenarios where companies cluster together (industrial parks, office buildings, and entrepreneurship innovation parks), explosive capacity requirements frequently occur during office hours or commercial events. Therefore, 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.

On top of flexible capacity, future 5G networks must also support slicing to provide SLA assured services for any enterprises.

In general, no matter whether it is for capacity scheduling or network slicing, network capacity must feature redundancy and scalability. Only then can the nework respond to real-time capacity demand in hotspot areas and carry versatile services. Yet, passive distributed antenna systems at the current stage of development can allow neither demand-based resource scheduling, nor flexible network capacity expansion.

4.3 Industry Applications Requiring High Network Reliability

Industry applications such as smart manufacturing and telemedicine depend on precise control, which calls for ultra high reliability of transmission networks. According to the 3GPP TS 22.261, the network reliability must be higher than 99.999%.

Normally, network reliability is evaluated from three aspects: average mean time interval between failures (MTBF), average mean time to repair (MTTR), and system availability.

Average MTBF: Passive distributed antenna systems mainly consist of a large number of passive components and a small number of active devices. It is less likely for a single passive component to malfunction when the connection is reliable. However, an indoor passive system is made up of multiple connected passive nodes (modules). A faulty passive node in serial connection may result in a shutdown of the entire system. Since the status of these passive nodes is invisible and cannot be monitored, the average MTBF is difficult to calculate.

Average MTTR: When a fault occurs on a traditional indoor network, it only counts on engineers to locate and rectify each fault by running through every component in the indoor passive system. It is no surprise that fault locating and rectification is a time-consuming process.

System availability: Given the uncertain MTBF and MTTR, the availability of the system is relatively low.

In light of the foregoing, the reliability of the passive distributed antenna system is in question. In order to improve the robustness of the system and meet the 5G requirements for ultra-reliable communications, it is essential to ensure that networks are both controllable and manageable.

4.4 Four RATs Coexisting and New Services Development Requiring Efficient O&M and Intelligent Operation

A passive distributed antenna system has a large number of passive nodes, and 100% of them cannot be monitored or managed. Therefore, routine inspection costs huge manpower and material investment. Due to the limited annual maintenance budget, the network maintenance departments of the operators can only select a few sites for routine test, inspection, and rectification. The process, rather difficult and time-consuming, have long bothered relevant departments. Now when the 5G era rolls out, operators find the maintenance task even harder, because they have to take care of 2/3/4/5G coexisting networks.

Taking advantage of network slicing and quickly developing new services or enterprise services in particular areas would be the major lucrative business for operators. Before provisioning a service, operators need to evaluate the network resource usage, capacity requirements of new services, and to what extent the services meet SLA standards. Currently, the digitalization of indoor networks is still not mature enough to support refined evaluation, network resource prediction, and fast capacity expansion in certain areas. Given this, it is necessary to offer enterprise services a set of indoor network system, which however involves a long construction period and enormous investment. If operators plan to develop wireless office for hospitals, they have to add new radio access networks indoors, as the established passive distributed antenna systems cannot be deployed. This largely slows down service provisioning and investment payback.

At the moment, a passive distributed antenna system cannot have headend working status visible and capacity easily expanded. Therefore, how to construct digital networks that can enable immediate new service provisioning, efficient O&M, and intelligent operation are key priorities.

4.5 Conclusion

In summary, the indoor 5G network construction will face a series of challenges such as networking on high frequency bands, flexible capacity expansion, reliability, efficient O&M, and intelligent operation.

In order to overcome these considerable challenges, the construction strategies for indoor 5G target networks must be defined from the following perspectives: networking strategy, Multiple-Input Multiple-Output (MIMO) selection, solution selection, capacity planning, network reliability, network O&M, and operation.

5. Construction Strategies for Indoor 5G Target Networks

5.1 Networking Strategy: Hierarchical Networking of High, Medium, and Low Frequency Bands for Larger Capacity

As mentioned above, 5G networks will use multiple groups of high frequency bands. The main spectrums are C-band (3.5-4.9 GHz bands) and 26-28 GHz mmWave.

The propagation loss, spectrum bandwidth, and networking cost of each frequency band greatly differs. The most significant challenge of networking design is to fully consider network coverage, capacity, and cost of construction.

Indoor 5G target networks require at least one frequency band to achieve continuous coverage. The radio propagation loss and penetration loss of C-band are much lower than those of mmWave. C-band can achieve continuous indoor 5G network coverage at a relatively low network construction cost. mmWave features wide spectrum but weak coverage capability. Headends with high density are required to achieve continuous coverage and network construction cost is often very high. In indoor areas where the C-band spectrum resources cannot meet service requirements, mmWave must be superimposed onto these networks to meet the requirements of ultra-large capacity.

Considering spectrum resources, radio propagation characteristics, and network construction costs, C-band is used indoors to provide continuous coverage for 5G basic coverage and capacity layer. However, in hotspot areas mmWave spectrum is used for traffic absorption, as shown in the following figure.

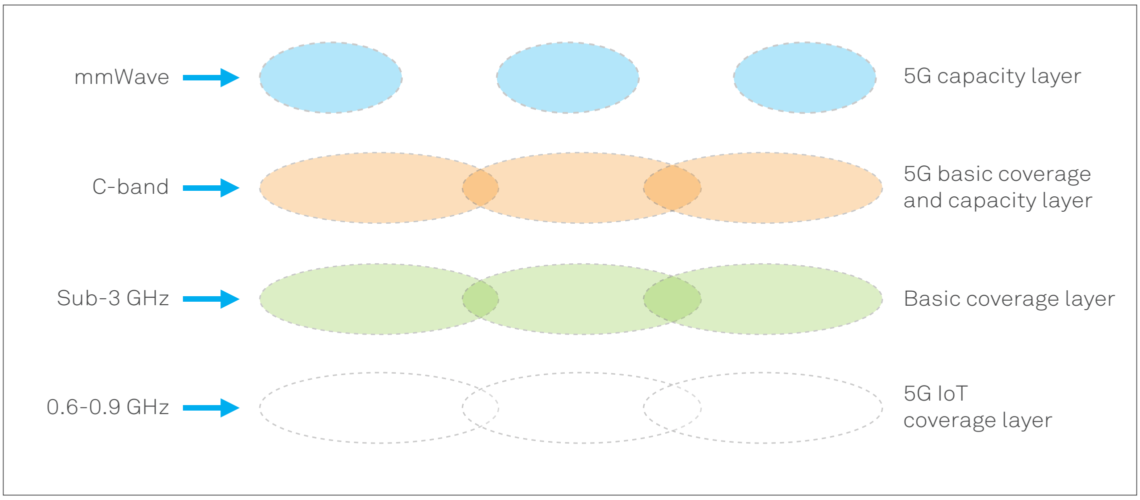


Figure 4 5G networking strategy

5.2 MIMO Strategy: 4T4R Standard Configuration to Provide Better User Experience

MIMO supports multi-layer transmission over the air interface, which greatly increases cell capacity. MIMO also provides uplink and downlink diversity gains to improve network edge rates and user experience.

Currently, 4G smartphones support 1T1R or 1T2R. 5G smartphones will use higher-order MIMO technologies, such as 2T4R for building a 5G network that adapts to terminal capabilities and service requirements. MIMO technology selection is also considered to be a very important step.

Limited by installation space, massive MIMO (64T64R) antennas cannot be installed for indoor 5G network coverage. Only small-size MIMO antennas can be used. Considering the penetration loss of a wall of indoor buildings and the headend transmit power identical with 4G networks, Huawei uses the indoor non-line-of-sight (NLOS) propagation model defined in the 3GPP TS 38.900 to simulate a 5G network. The following figure shows the simulation results of cell edge rates in 4T4R, 2T2R, and 1T1R cells on the 3.5 GHz band and cell edge rates in 2T2R cells in LTE networks.

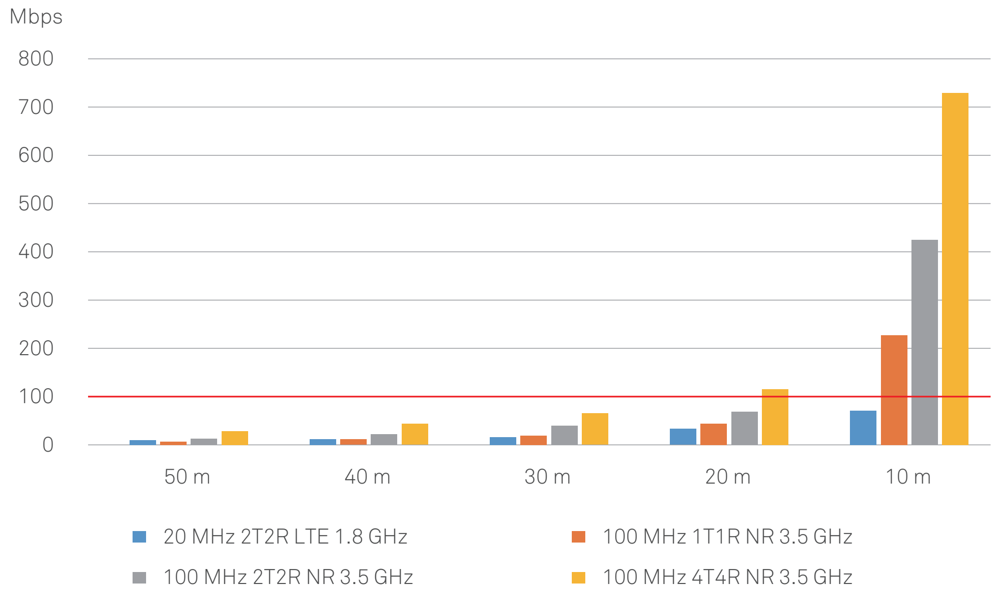


Figure 5 Relationship between rates and indoor inter-headend distances

As shown in the preceding figure, LTE networks cannot meet the bandwidth requirement of 100 Mbps anytime anywhere. 4T4R can better meet the requirements of the cell edge rate of 100 Mbps. In addition to coverage gains, 4T4R provides higher system throughput, which meets the requirements of ultra-high bandwidth, especially ultra-high traffic density. Adjacent 4T4R headends can form virtual 8T8R using a network configuration algorithm, so as to provide higher system throughput and cell edge rates.

Considering factors such as the cell edge rates and system throughput, high-order MIMO technologies must be selected for indoor 5G networks. Moreover, considering the antenna volume, technical complexity, and terminal specifications, 4T4R is a more appropriate choice.

5.3 Solution Selection: Large-Capacity Digital Solution Is an Inevitable Choice

Available indoor 5G network solutions can be divided into three types: indoor digital distributed base station, passive distributed antenna system, and distributed optical fiber repeater.

The following compares and analyzes three types of indoor 5G network solutions from the aspects of coverage, capacity, cost, O&M, and operation.

· Indoor digital distributed base station

An indoor digital distributed base station consists of a BBU, extended unit, and active headend. Its architecture has 3 main characteristics, including digital headend, IT cable and visualized O&M. The components are connected using network cables or fiber optic cables. Capacity can be flexibly configured as required thanks to the headend-level cell splitting capability. Based on the full active digital system and headend-level measurement report (MR) capability, network devices can be visualized, network performance can be geographically displayed, and network fault recovery and preventive management can be implemented. In addition, indoor digital distributed base stations provide indoor location-based services to support 5G network capability exposure and continuous operation.

· Passive distributed antenna system

A passive distributed antenna system consists of passive components such as combiners, power splitters, couplers, coaxial cables, and antennas. The system is a radio frequency (RF) signal transmission channel. It cannot be used on high frequency bands due to the following characteristics: full passive mode, unmanageable, multiple nodes, difficult fault locating, no support for independent capacity, and large loss on C-band and mmWave.

· Distributed optical fiber repeater

A distributed optical fiber repeater consists of a local unit, optical signal extension unit, and remote unit. The local unit is connected to the signal source device to convert analog RF signals into optical signals. The remote unit converts optical signals into analog RF signals and amplifies the signals. Compared with a passive distributed antenna system, a distributed optical fiber repeater has the capability to conduct visual management, but it is difficult to integrate with the operations support system (OSS) of the signal source device. In addition, the distributed optical fiber repeater is essentially a transparent transmission channel of RF signals. It cannot provide independent or elastic capacity, and cannot support digital operation.

The following figure compares optional indoor 5G network solutions.

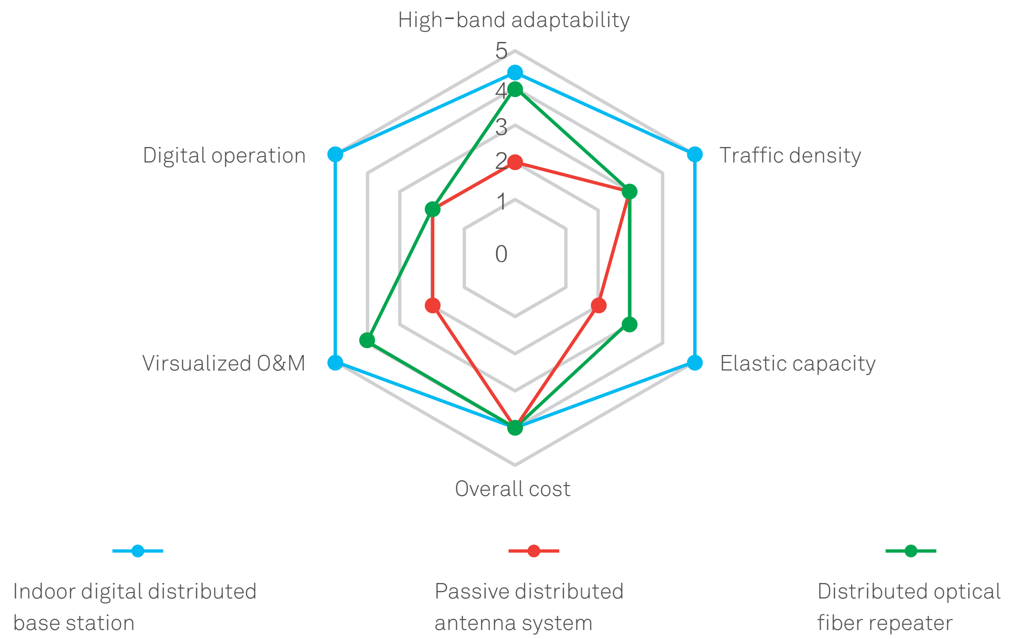


Figure 6 Comparison among the three indoor 5G network solutions

As shown in the preceding figure, the passive distributed antenna system and distributed optical fiber repeater cannot meet 5G service requirements in terms of elastic capacity, digital operation, visualized O&M, and high-band adaptability. Only digital distributed base stations can meet requirements such as ultra-high traffic density, ultra-high bandwidth, ultra-high reliability, ultra-low latency, massive connections, location-based services, visualized O&M, and intelligent operation.

5.4 Capacity Strategy: Elastic Capacity to Flexibly Meet Service Requirements

Indoor 5G network capacity planning concentrates on the traffic model, crowd density, and target coverage area. 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.

Huawei can draw several conclusions for 5G traffic models based on the 4G traffic trend, as shown in the following figure.

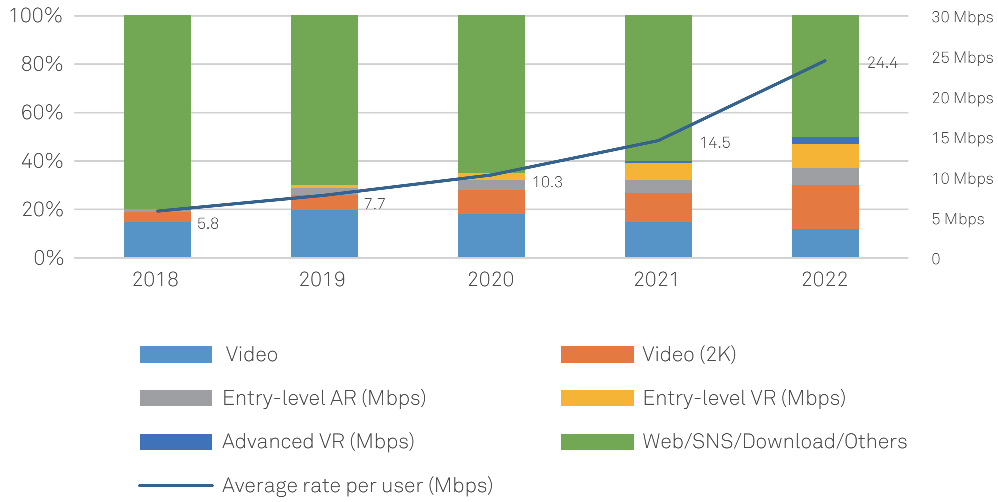


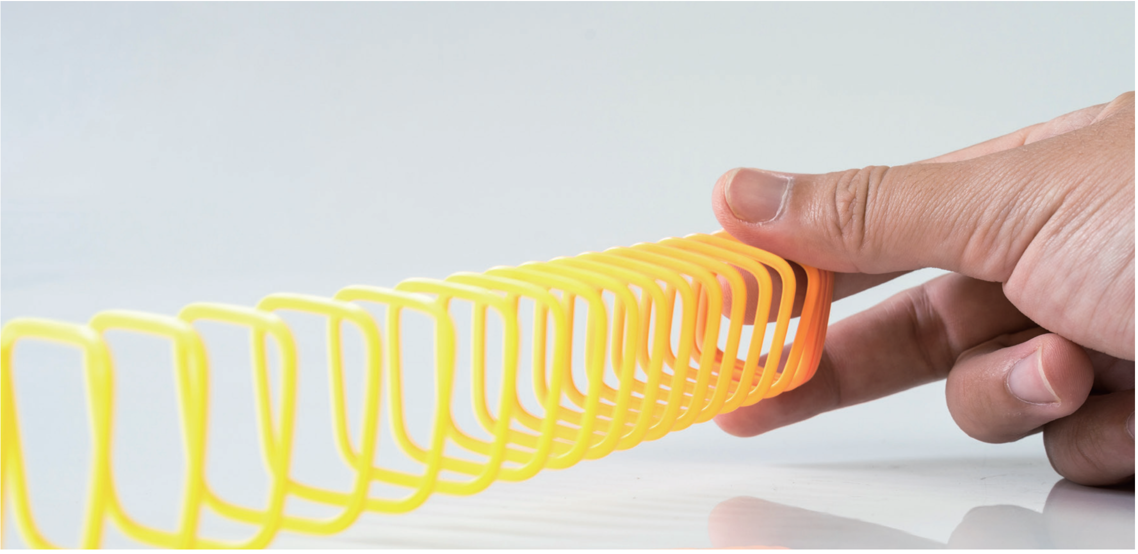
Figure 7 5G traffic model forecast

As shown in the preceding figure, high bandwidth services such as VR services and HD videos are rapidly increasing. The location and behavior mode of high bandwidth requirements are difficult to predict. Especially when traffic is not limited, it is difficult to predict which users and indoor areas require burst traffic. Therefore, elastic capacity design is a serious issue that must be considered during indoor 5G network capacity planning.

- Elastic capacity design predicts 5G capacity requirements by scenario based on scenario characteristics, 5G service characteristics, historical network development data, and 5G user development plan.
- Network architecture design must comply with the flexible capacity expansion principle. 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, 5G traffic burst areas, such as news centers and assembly sites, 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.



5.5 Reliability Strategy: Reliability Design for 5G Services

In addition to network visualization, network manageability, and system self-healing, network reliability for key areas must be designed from the aspect of coverage overlap, capacity redundancy, and network backup structure. The following describes how to ensure 99.999% network reliability in terms of design.

First, indoor 5G network coverage redundancy must be considered and multiple headends must be deployed in areas requiring high reliability. If one of the headends is faulty, the adjacent headend can provide signal coverage.

Second, indoor 5G network capacity redundancy must be considered. If a single headend cannot provide sufficient capacity, the adjacent headend provides capacity for users and can be scheduled on demand.

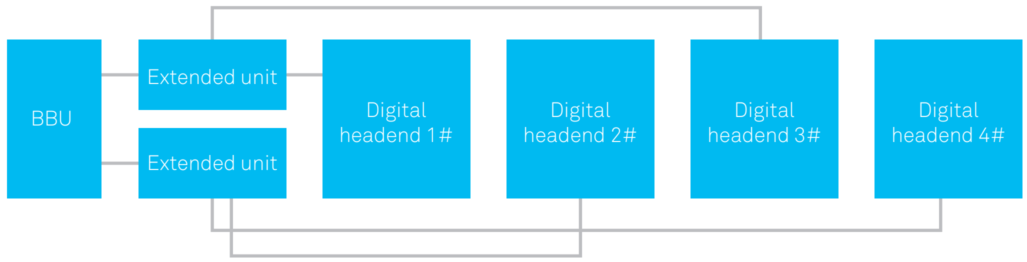


Figure 8 Network reliability design

Finally, network reliability must be considered from the aspect of network topology during network design. Redundancy backup is used on key connections and nodes. Different headends use different transmission lines. When a temporary fault occurs on a transmission line, the adjacent headend can still provide services. The preceding figure shows reliable networking.

5.6 Deployment Strategy: E2E Digital Deployment to Lay a Foundation for Network O&M and Operation

During the indoor 5G network deployment phase, both the deployment cost and the impact of the deployment quality on subsequent routine O&M must be considered. If digital deployment is not used, the mapping between headends and OSS display cannot be ensured, and the specific positions of headends cannot be accurately identified. As a result, visualized O&M and intelligent operation are unavailable. Therefore, digital deployment is required for indoor 5G site selection, survey design, integration, and completion acceptance.

The site selection based on big data technologies has been widely used for 4G network deployment. As 5G traffic is concentrated in indoor areas, the traffic volume varies with time and space more frequently. Therefore, 3D distribution of services, users, and traffic needs to be generated based on 4G network data and serves as the basis for indoor 5G site selection.

After selecting a proper site, it is critical to use intelligent survey devices to collect data onsite and generate a refined indoor 3D digital map as the input for indoor 5G capacity planning and coverage design. After iterative simulation verification, the design solution outputs the headend location, cable routing, and connection relationship that meet coverage, capacity, and reliability requirements. All survey, design, and simulation data will be recorded in a delivery platform to help streamline data.

In the implementation of the subsequent integration process, confirm the installation position, cable routing, and connection relationship according to the digital 3D design diagram. Install

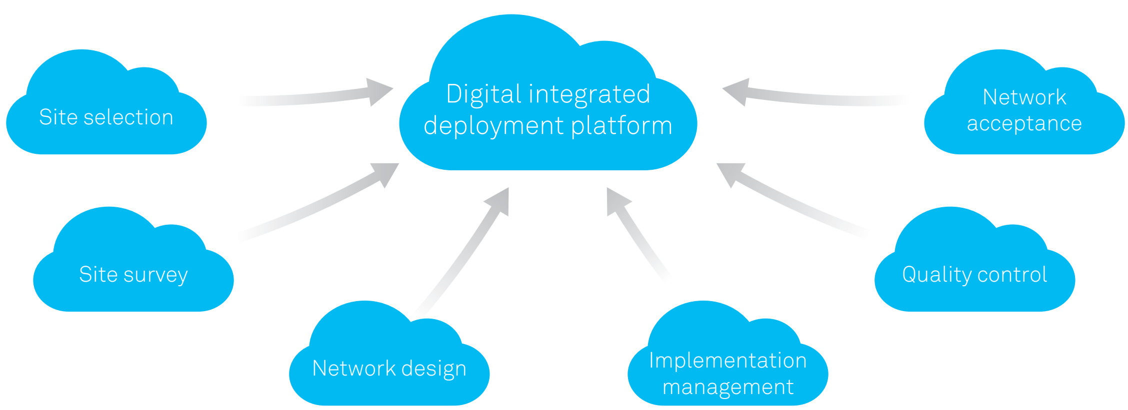


Figure 9 **Digital integrated deployment platform**

the corresponding network elements or headends in the specified positions according to the specifications. Record the actual deployment results in the database of the delivery platform. In this way, the consistency between construction and design is ensured, the integration deployment process is visible, the quality is controllable, and repeated rectification is avoided.

After the system is powered on, design parameters are configured on each headend, and the indoor 3D digital map and actual deployment database information is imported over to the system. The system dynamically monitors the working status, service volume, and changes in user number of the headends in real time. After operation for a period of time, the system generates network running indicators and performance reports based on the template to assist in network completion acceptance.

The site selection, survey, design, construction, and acceptance processes can only be streamlined when the unified digital integrated deployment platform is used to implement E2E digital network deployment. This ensures data consistency, completes indoor 5G network deployment in an accurate, efficient, and high-quality manner, and lays a solid foundation for efficient O&M and intelligent O&M.

5.7 Network O&M Strategy: Visualized O&M for Manageable and Controllable Indoor 5G Networks

Various problems or faults may occur during long-term network operation. Refined network maintenance is required to ensure good user experience and efficient network operation. The simple and efficient O&M of indoor 5G networks is based on the visualized work status of all network elements and headends. Dynamic network monitoring, fault identification, and quick location require a visualized operating status. The following figure shows visualized network O&M based on an indoor 3D digital map.

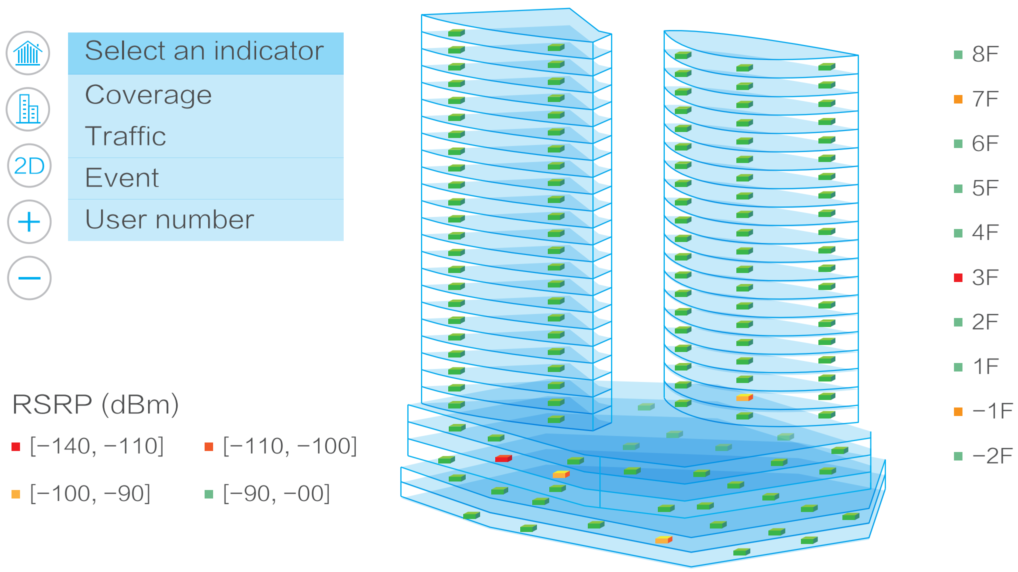


Figure 10 Visualized O&M of indoor 5G networks

Improving the O&M efficiency of indoor 5G networks requires a prediction of service changes based on a large amount of historical data. Capacity allocation and energy consumption management policies must be adopted in time, and operations must be remotely performed such as parameter optimization and mode changes on network elements or headends. Further, network faults need to be counted and analyzed, and the severity of faults must be sorted in a prioritized hierarchy of importance. In addition, intelligent judgment is performed, and emergent and important troubleshooting work orders are automatically generated, which greatly reduces the number of work orders and the workload of troubleshooting. This improves network O&M efficiency and greatly reduces O&M costs.

5.8 Network Operation Strategy: Intelligent Operation of Indoor 5G Networks Based on Network Operation Platform

First, operators will use powerful 5G network slicing capabilities to provide high-quality network services for industry customers. In the future, enterprises do not need to set up or maintain independent indoor private networks. Enterprises can instead use operators' online service system to apply for network services and potential new services. For example, a hospital can apply to an operator for the network services of local medical offices and telemedicine. A commercial center temporarily applies to an operator for network bandwidth to support VR-based commodity promotion activities. In addition to elastic capacity expansion, an indoor network operation platform must be established to efficiently identify high-value services, spot potential customers, and implement precise marketing based on big data analysis, thereby supporting flexible service provisioning.

Second, future society will encounter data-driven development. The indoor 5G networks with ultra-large traffic provide an invaluable source of data. Big data based on the 5G network indoor location has been widely used in indoor navigation, shopping guides, indoor customer traffic, security monitoring, and precision marketing. Higher data precision produces larger value. In order to better develop big data services on indoor 5G networks, indoor digital distributed base stations must be deployed and an indoor network operation platform must be established to build basic capabilities. These include indoor location, user profile, and data security, and enable many industry applications with the help of increased capability exposure.

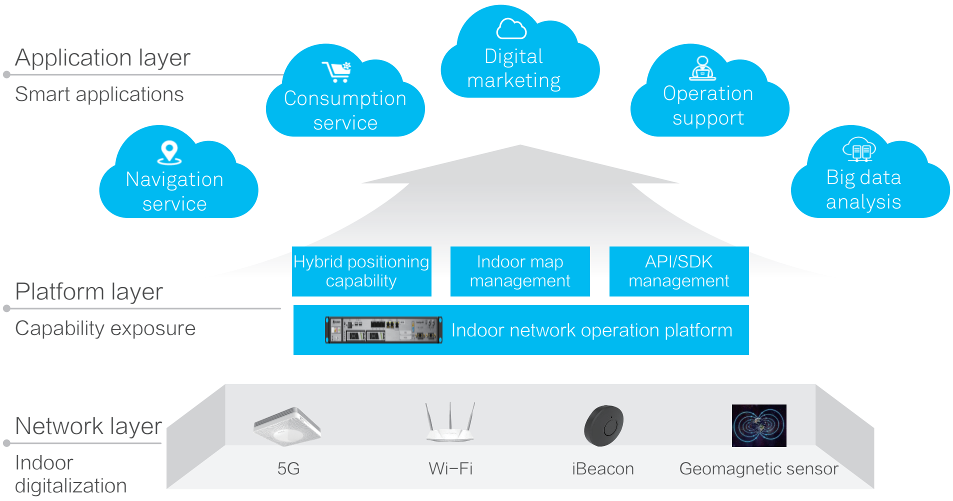


Figure 11 Indoor network operation platform

5.9 Conclusion

In order to address various challenges of indoor 5G networks, we need to:

- Adopt the hierarchical networking strategy of high, medium, and low frequency bands.
- Select digital distributed base stations of 4T4R or above.
- Plan and construct indoor digital 5G networks with elastic capacity, 99.999% reliability (high reliability service areas), and 3D visualization based on an indoor digital integrated deployment platform.
- Implement intelligent network operation based on an indoor 5G network operation platform.

6. Summary

5G networks are strategic requirements for the development of cloud computing, big data, artificial intelligence, and IoT. Its cutting-edge architecture and technologies will help all of the society to collectively combine their efforts and build a comprehensive ecosystem to ensure the connectivity of everything. 5G networks will also prove instrumental in helping to create innovative technologies, products, ecosystems, and new business models. Such networks are destined to deeply influence and change the production structure, production mode, lifestyle, and thought patterns of how we as human beings perceive the world around us. All of these aspects will bring greater convenience through higher levels of technological advancement and help to achieve a substantial increase in social productivity.

Indoor 5G services such as ultra HD video, VR, and massive intelligent sensor interconnection require capabilities such as high bandwidth, low latency, high reliability, and high-precision indoor location. Therefore, indoor 5G network construction will face challenges in high-band networking, elastic network capacity, network redundancy, network visualization, efficient operation, and other aspects.

The following are highly recommended:

- Indoor digital distributed base stations of 4T4R or above
- The E2E digital integration deployment mode for the planning and construction of indoor 5G networks (with large capacity concentration, flexible capacity adjustment, and visualized O&M)
- Intelligent operation of indoor 5G networks based on the indoor network operation platform

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HKT is Hong Kong's premier telecommunications service provider and leading operator in fixed-line, broadband and mobile communication services. It meets the needs of the Hong Kong public and local and international businesses with a wide range of services including local telephony, local data and broadband, international telecommunications, mobile, and other telecommunications businesses such as customer premises equipment sales, outsourcing, consulting, and contact centers.

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GSA (the Global mobile Suppliers Association) is a not-for-profit industry organization representing companies across the worldwide mobile ecosystem engaged in the supply of infrastructure, semiconductors, test equipment, devices, applications and mobile support services. GSA actively promotes the 3GPP technology road-map — 3G; 4G; 5G — and is a single source of information for industry reports and market intelligence. GSA Members drive the GSA agenda and define the communications and development strategy for the Association.

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