5G Indoor White Paper

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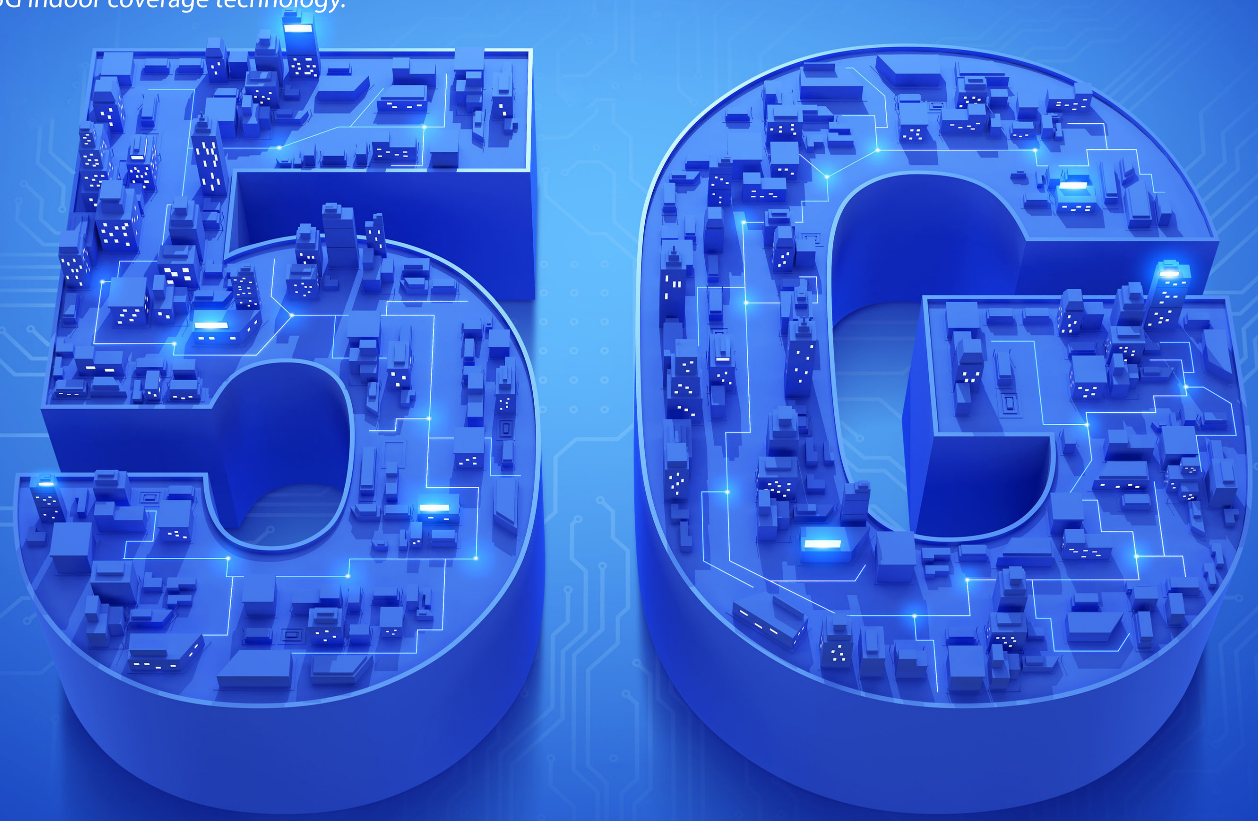
Executive summary

Compared with previous generations of mobile technologies, 5G offers higher bandwidth, more connections, lower latency, and higher reliability. It helps realize the Internet of Everything and the Intelligence of Everything, make revolutionary changes to the people and the industries, and bring the entire society into a new digital era.

In order to materialize all this, network coverage is by no means to be overlooked. Most of 5G traffic, many believe, will take place in indoor. It is therefore crucial for any operators trying not only to offer quality networks but also remain profitable to have good indoor coverage of 5G.

It is however often more difficult to achieve good indoor coverage than outdoor coverage, let alone the even more diverse types of services and their consequently diverse requirements on the networks' capability and capacity in the 5G era. The existing indoor coverage solutions have their benefits and limitations and new solutions are sometimes in strong needs. This white paper looks into the main considerations of 5G indoor coverage, deployment principles of 5G indoor coverage, how to optimize the existing indoor coverage solution to evolve towards 5G, how to coordinate with indoor and outdoor coverage to improve user experience, and outlooks the development trend of 5G indoor coverage technology.



Characteristics of 5G indoor coverage and an overview of the established solutions

The characteristics of 5G indoor coverage

A wide variety of service types

According to different application scenarios, ITU-R proposed three major 5G service types, including Enhanced Mobile Broadband (eMBB), Massive Machine Type Communications (mMTC) and Ultra-Reliable and Low Latency Communications (URLLC), which sets the foundation for Internet of Everything. Indoor applications and services, of course, will account for a large portion.

According to service objects, 5G indoor services can be divided into two categories: mobile internet services and mobile IoT services. Different service characteristics and performance requirements further classify these two categories.

Mobile internet	Messaging	5G messaging
	Interactive	AR, VR, cloud desktops, online games
	Conversational	HD video conferencing, VR, panoramic live broadcast
	Transmission	Cloud storage
	Streaming	4K, 8K (2D & 3D)
Mobile IoT	Control	Smart manufacturing, telemedicine, and smart storage
	Data collection	Video surveillance, smart home, and remote meter

Table 1 Typical indoor 5G services

Diversified deployment scenarios

5G will be gradually integrated into people's life and work, along with which comes the diversity of 5G indoor deployment scenarios. For the consumer market, the 5G indoor coverage scenarios are basically the same as those of 4G. There are scenarios with open space and high traffic, such as transport hubs, stadiums, shopping malls, and other scenarios with more separated space, such as hotels, office buildings, and school dormitories. There are not only the common scenarios such as residential buildings but also the special scenarios such as subways and tunnels. In addition, regarding the vertical industries, there are a lot of application scenarios and requirements, such as smart factories, remote education, telemedicine, and warehousing and logistics, all requiring better indoor networks.

Diverse requirements on network capabilities

Unlike the traditional mobile network focusing on voice and data services, diversified 5G indoor services require differentiated and extensive network capabilities in more dimensions. eMBB services such as UHD video, AR and VR require high speed. URLLC services such as intelligent manufacturing and telemedicine require high network reliability and low delay. mMTC services such as remote meter reading, indoor monitoring and smart home require high network capacity and deep indoor coverage.

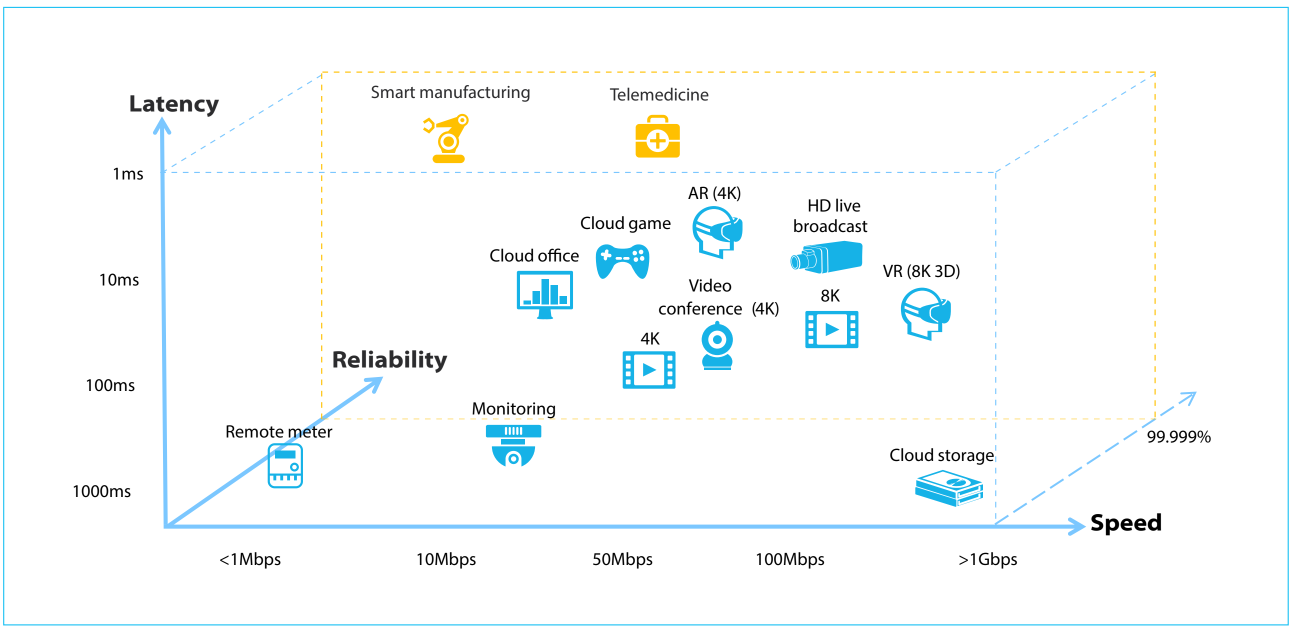


Figure1 Differentiated network capability requirements for typical indoor 5G service

Features of the established indoor solutions and the challenges towards 5G evolution

As one of the operators' core competitiveness, how to build efficient, economic, and high-quality 5G indoor networks has become one of the key concerns of the operators. The typical indoor solutions can be divided into three types: outdoor-to-indoor, traditional passive DAS, and digital indoor distribution system. They vary in advantages and challenges toward 5G evolution.

Outdoor-to-indoor

Outdoor-to-indoor solution has the advantages of fastest deployment and lowest CapEx, which makes it a popular indoor coverage solution in early stages of network deployment. It is however more suitable for smaller buildings than for larger and more complex ones, with many other factors limiting its applicable scenarios including the building materials, building structure, frequency of the radio signal, and capacity requirements.

The new challenges of outdoor-to-indoor solution towards 5G evolution

1 As most of the popular 5G frequency bands are higher than those of 4G, it is often more difficult to provide deep indoor coverage using 5G than using 4G.

5G utilizes higher frequency bands mainly for higher system capacity. However, the higher the frequency, the higher the space propagation loss, and the higher the penetration loss through building materials. Based on the standard propagation model, the path loss of 2.6 GHz is about 4.5 dB higher than that of 1.8 GHz at the same distance, and is about 2.5 dB higher than that of 2.6 GHz. The following table shows the test data of building materials in different frequency bands regarding penetration loss.

Item	1800Mhz & 2100MHz	2600MHz	3500MHz
Penetration loss of brick wall (dB)	10-15	11-18	12-20
Penetration loss of concrete wall (dB)	20-30	22-32	25-35
Penetration loss of drywall (dB)	8-12	9-14	10-15
Penetration loss of ordinary glass wall (dB)	2-5	4-6	5-8
Penetration loss of thin wooden door (dB)	3-5	5-7	5-8

Table 2 Test data of penetration loss of different building materials in different frequency bands

2 It is challenging for 5G macro-base stations to offer both horizontal coverage and vertical coverage for high-rise and dense buildings.

The basic coverage of the 5G is first determined by how SSB beams of 5G gNB are configured and scheduled. It is currently a popular choice for most mobile operators to deploy 5G in sub-6 GHz using 7 or 8 beams (depending on their respective frame structures), for good reasons: it can deliver very good horizontal coverage because of the multiple energy-concentrated narrow beams on the horizontal plane; it can deliver almost the same coverage of the broadcast channel as of downlink service channel, which is hard to achieve using 4G Massive MIMO. However, this solution does have its limitation: all beams are used for horizontal coverage, which makes it hard to optimize vertical coverage when needed.

The traditional passive DAS

The traditional passive DAS transmits the radio signals from the base stations through passive components such as couplers, splitters, and combiners. The signals are evenly distributed to each antenna in each area of the building through feeders.

The passive DAS system has a huge established market with mature technologies, and it is easily shared by multiple operators with multiple frequencies and multiple modes. In the 5G era, how to reuse the existing DAS to achieve faster and more cost-effective indoor 5G rollout is still a key concern of many operators.

It is difficult for the existing DAS to meet 5G capacity requirements.

As 5G is meant to offer higher capacity than 4G, ideally, DAS should be able to support 2x2 or even 4x4 MIMO. However, for many of the DAS systems already deployed, such kind of upgrade can be very costly and time-consuming. In addition, in the traditional DAS solution, the balance among the channels is required to ensure MIMO performance, which further increases the difficulty of upgrading the DAS system for 5G. How to get the landlords to agree is another matter sometimes even much more tough. Due to the above reasons, it is very difficult to deploy a multi-channel DAS system that meets the 5G capacity requirements.

It is difficult to reuse the existing DAS system with 5G higher frequency bands.

- The established DAS systems passive components such as power splitters, couplers, combiners and antennas work in a frequency band ranging from 800 MHz to 2.7 GHz, without capabilities to support any of the higher frequency bands of 5G.

- As feeder cables are often much longer indoors than outdoors, higher feeder loss due to higher frequency bands of 5G is another challenge. For example, there is over 15 dB feeder loss per 100 meter of the 1/2" feeder at 3.5 GHz frequency band, which is 6 dB higher than that at 1.8 GHz. It is therefore very difficult to achieve the same coverage of 4G and 5G directly connected using combiners.

Digital indoor distribution system

Digital indoor distribution system is a distributed radio system, which consists of BBU, convergence unit, and Pico RRU as a three-layer architecture. The BBU and Pico RRU implement the baseband and radio function respectively. Convergence unit is introduced to the system for easy extension and deployment, which provides not only power supply to Pico RRU via PoE interface, but also converges data from multiple Pico RRUs for transmission over optical fiber cables so as to reduce the number of required interfaces of BBU. All components are connected to carrier digital signals using Ethernet cable or optical fiber cable.

Digital indoor distribution system has the following advantages and becomes the preferred solution in high-value areas with large capacity and excellent experience.

It is much easier to deploy Ethernet cables than feeder cables.

It offers larger capacity with support of multi-band, multi-mode, and high-order MIMO

It can flexibly adjust the system capacity through software configuration.

System failures and faults can be monitored on an end-to-end basis, enabling quick response.

The digitalization of the indoor distribution solution is a trend of 5G evolution, but it also faces greater challenges in the following four aspects:

1. **High network performance**

   Digital indoor distribution system is not only expected to meet the requirements of consumer services, but also those of the vertical industries. Some industry applications, such as machine vision, have high requirements for per user uplink speed and per area system capacity. In addition, they have high reliability requirements up to 99.999%, which brings new challenges to the network

2. **High deployment cost**

   5G utilizes larger bandwidth and more transceiver channels. To provide better user experience, 4T4R has become a standard configuration for 5G indoor applications. In addition, in order to make full use of the valuable spectrum resources, support of more frequency bands and radio technologies are often required, which brings further challenges to business sustainability.

3. **High complexity of operation and maintenance**

   Pico RRU, as one of the key components of digital indoor distribution system, has to consume more power due to larger capacity and larger transmission power, which makes power management a challenging task.

   Although the active equipment is manageable, a large number of Pico RRUs are deployed dispersedly which increases the complexity of operation and maintenance. How to efficiently manage so many remote devices, monitor network performance and optimize resources, quickly locate faulty devices, poses challenges for operation and maintenance.

4. **High operation capability**

   Digital indoor distribution system provides high performance indoor network. However, facing diversified 5G service requirements, how to enable network potential, open network capabilities, and expand new services are challenges to 5G indoor network operation.

A holistic approach to the optimal 5G indoor solutions

The design of 5G indoor target network

The key demands for 5G indoor deployment include diverse service applications, various deployment scenarios and differentiated network capabilites. 5G indoor deployment, particularly from a RAN perspective, should be based on a flexible and capable network infrastructure, along with highly efficient O&M and support of diverse and demanding new services.

A flexible and capable network infrastructure should meet the following criteria:

It should be based on a flexible set of solutions to match various requirements of different deployment scenarios.

It should offer capabilities including downlink speed faster than 100 Mbps, network latency shorter than 4 ms, and the number of connections higher than 1,000k per square kilometers.

It should offer powerful integration and utilization of multiple frequency bands and radio technologies with future evolution capabilities.

It should be equipped with good coordination between outdoor networks and indoor networks.

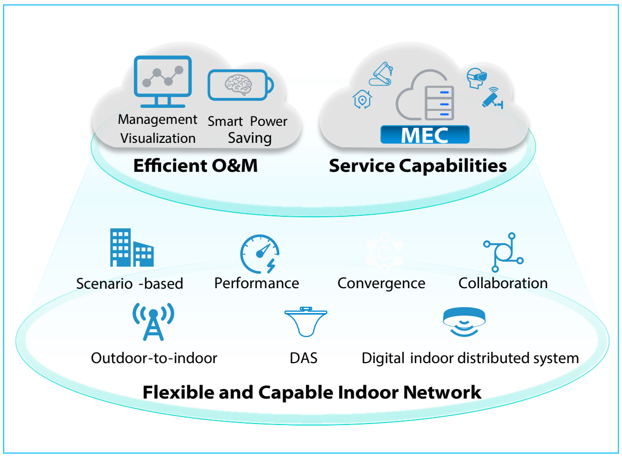


Figure 2 5G indoor network design

To fully realize the potentials of such promising indoor network infrastructure, O&M should help achieve much more efficient management of more complex networks with tools such as management visualization, and support of smart power saving features, and support of new services should be achieved with capabilities such as 5 meters indoor positioning service precision and multiple-access edge computation for enhanced and brand new applications and services.

5G indoor deployment principles

5G indoor deployment should first take into account service requirements, capability objectives, equipment deployment scenario characteristics, coverage, engineering, and cost. We suggest the following deployment principles to be considered:

1. Prioritizing various frequency bands for different types of services. Ranging from sub-6 GHz to millimeter-wave. 5G frequency bands can have very different propagation characteristics and different bandwidth, which can lead to very different deployment costs and service capabilities. It is recommended that sub-3 GHz frequency to be used for IoT and basic coverage, while C-band and millimeter wave bands for very high capacity.

2. Coordinating indoor and outdoor for both maximized performance and minimized cost. Macro cell coverage capability should be leveraged as much as possible to assist indoor coverage in nearby buildings, while for deep indoor coverage, of course, indoor systems should be deployed for the best results possible.

3. Choosing the most suitable indoor system solution:
   For where the indoor systems are deployed from scratch: the digital indoor distribution system with the 4T4R capabilities should be the priority for the high-capacity and high-value venues, and more cost-effective solutions should be otherwise considered.

   For where the indoor systems are already available: in the case of available digital indoor distribution system, then it is recommend to upgrade it to support 5G; if it is traditional DAS, reuse and upgrade is recommended to support sub-3 GHz 5G given that very high capacity is not required.

4. Taking separate yet necessary steps for indoor deployment. When 5G rollout is just in its early stage, it is understandable and often required to leverage various solutions for indoor in order to achieve shorter time-to-market and better efficiency, and when 5G rollout moves into more advanced stages, the ultimate goal of indoor 5G should be realized gradually by evolving to digital indoor distribution system.

Innovative 5G technologies can be leveraged together with small cell for indoor enhancement

At the initial stage of 5G network deployment, network planning needs to take the basic level of indoor coverage of buildings close to macro basestations into account to serve more users while indoor systems are not yet available for 5G. 64T64R macro AAU is recommended for deployment in very dense urban. 64T64R macro AAU outperforms 32T32R macro AAU in many aspects: better beamforming capability, deeper coverage; more streams, larger capacity; and more freedom of vertical beamforming enabling better coverage for high-rise buildings.

In addition, for buildings where indoor coverage cannot be achieved just by leveraging macro stations, outdoor small cells can be deployed.

Coverage for high-rise buildings can be further enhanced using innovative 3D coverage solution

In ultra-dense urban areas where there are lots of high-rise buildings, good coverage means good SSB coverage both horizontally and vertically.

To achieve this, one innovative way is to use one wide and power-enhanced beam of SSB for basic horizontal coverage, with neighboring cells coordinating in the time domain, and at the same time, to use multiple on-demand beams for vertical coverage, which can significantly enhance network coverage and capacity for high-rise buildings.

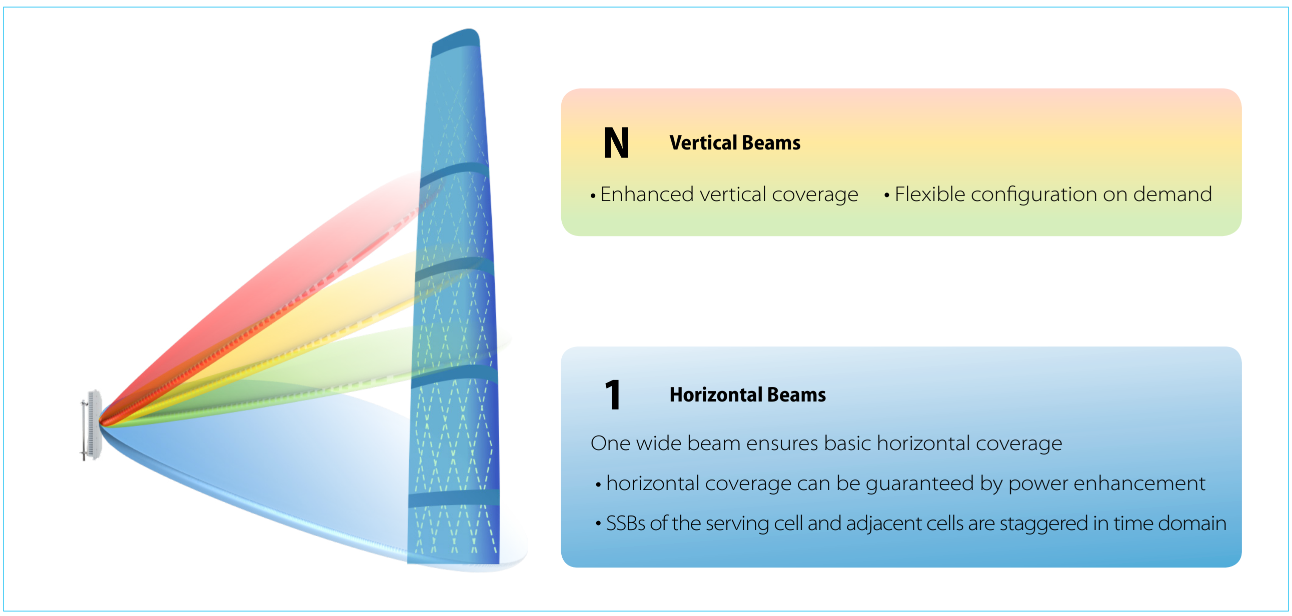


Figure 3 An innovative SSB coverage solution

This SSB coverage solution has the following three advantages regarding indoor coverage:

1. **The vertical coverage is enhanced while horizontal coverage can be guaranteed**

   One wide beam ensures basic horizontal coverage, the range of which can be achieved using adaptive power enhancement to the same level of multiple horizontal beams.

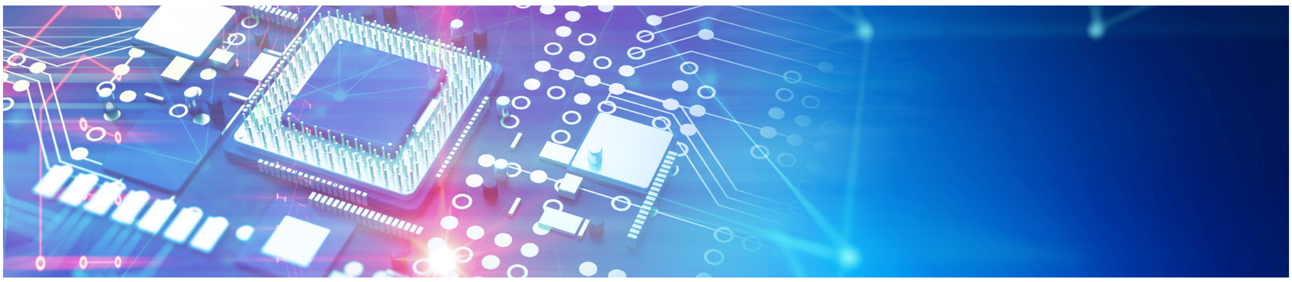
2. **More efficient SSB beam configuration saves resources and reduces power consumption.**

   Compared with horizontal multi-beam solution, the number of SSB beams configured in this innovative solution can be reduced by using fewer radio resources without affecting coverage performance. In addition, the time slot duty ratio of SSB beams is reduced, and the equipment's power efficiency can be further improved with symbol shutdown enabled when traffic load is not high.

3. **Effective interference avoidance**

   Single wide beam SSB with enhanced transmit power is staggered in time domain to effectively solve the problem of mutual interference between the serving cell and adjacent cells.

In a commercial network where the solution was deployed and tested with scenarios including high-rise buildings and streets, the result shows that the one power-enhanced wide horizontal beam can offer about the same level of coverage as that of 8-beam SSB. The on-demand vertical beam configuration increases the coverage rate of high buildings by more than 30%. Compared with horizontal 8-beam SSB solution, this solution increases network access capacity by 30% and service capacity by 5%, and reduces radio device power consumption by 10%.



Outdoor 5G small cell dedicated to indoor coverage

Outdoor small cells have many advantages: easier site acquisition, easier neighborhood-friendly deployment and more convenient deployment. Therefore they can be deployed easily in areas that are difficult for outdoor macro stations to cover, such as residential areas and business streets. In 4G era, outdoor small cells play an important role in supplementary coverage. 5G outdoor small cells include distributed micro base stations and integrated micro base stations, with a variety of appearances including columns ideal for street installation or panels easy to be disguised. Small cells should also flexibly support horizontal installation to enhance the coverage of high floors by turning the horizontal lobe into vertical. 4G and 5G dual-band outdoor small cells will be more widely used due to more advantages: it supports fast deployment with built-in anchor capability in the case of NSA deployment, and it also enhances both 4G and 5G coverage with just one unit.

Multi-channel joint DAS solution increases passive DAS capacity

In order to improve the investment efficiency of 5G indoor deployment, if the existing DAS can support 2.6 GHz , reusing it also for 2.6 GHz NR can be really beneficial, or if it supports only frequency bands other than 2.6 GHz, refarming the 4G bands to 5G is also an option. In addition, the capacity of passive DAS can be improved using multi-channel joint DAS solution.

Introduction

Multi-channel joint DAS solution can solve the problem that it is difficult for the existing DAS to offer higher-order MIMO by adding more feeder channels. The following key technologies are required for the multi-channel joint DAS solution:

1

For a typical 2T2R DAS system, two sets of the 2T2R RRU with antennas and feeder channels for two adjacent cells can be utilized together to achieve a virtual 4T4R network in overlapping areas without deploying any new antennas and feeder channels to enhance network performance while reducing interference between cells.

2

The innovative 5G algorithm is used to reduce the negative impact on MIMO performance brought by unbalanced signal transmission power between different DAS channels.

Multi-channel joint DAS solution has the following advantages: the traditional DAS system network architecture can be reused to save cost substantially, let alone the often painful site acquisition; with just software features, single-channel DAS dual-stream and dual-channel DAS four-stream can be easily achieved , which can greatly improve the performance of the traditional DAS network; in addition, this solution is compatible with 5G terminals with no restrictions.

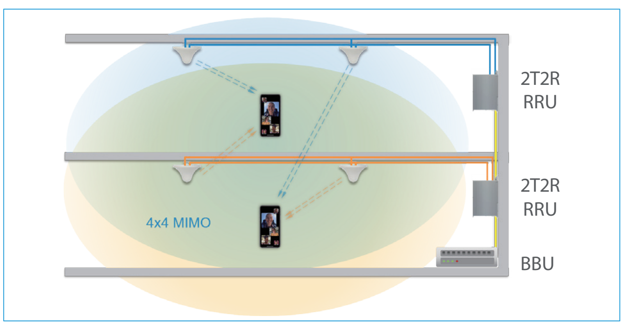


Figure 4 Multi-channel joint DAS

Application scenarios and capacity improvement of the multi-channel joint DAS solution

In accordance with the characteristics of the existing DAS, the multi-channel joint DAS solution can be used in the following three typical scenarios:

1. **Four streams can be achieved by combining two sets of two streams from two adjacent floors:**
   The existing DAS has to have dual channels and supports 2x2 MIMO. 4x4 MIMO can then be achieved in the overlapping coverage area of the two adjacent floors. in the overlapping coverage area of the two adjacent floors.

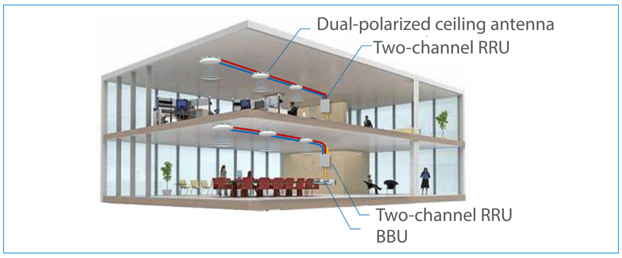


Figure 5 Cross-floor four-stream

2. **Two streams can be achieved by combining two separate streams from two adjacent floors:**
   2x2 MIMO can then be achieved in the overlapping coverage area of the two adjacent floors.

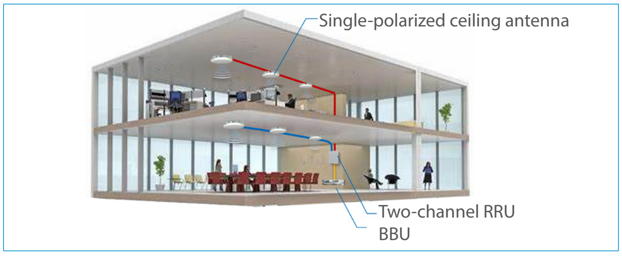


Figure 6 Cross-floor two-stream

3. **Four streams can be achieved by combining two sets of two streams from one same floor:**
   The existing DAS has to have two sets of dual channels deployed by two operators respectively and can be shared between the two operators. 4x4 MIMO can be achieved in the overlapped coverage areas on the same floor.

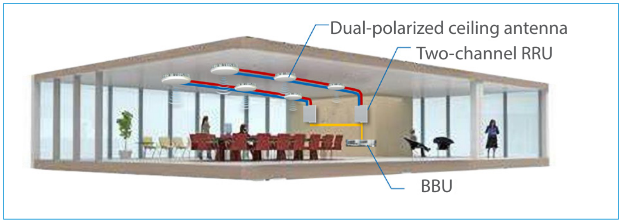


Figure 7 Same-floor four-streams

The test results in commercial networks have shown that the multi-channel joint DAS technology can deliver substantial gains in various scenarios, without any changes of the existing network architecture.

Applicable scenarios	Performance improvement on the lower or the same floor			Performance improvement on the upper floor**
	Average DL speed	Near-point DL speed	Overall SSB RSRP (dB)	Near-point DL speed
cross-floor four-stream	15.67%	38.86%	1.5-3	22%
cross-floor two-stream	72.03%	84.33%	2	59.87%
same-floor four-stream	35%	65%	2	Not applicable

*Table 3 Performance improvement by using multi-channel joint DAS technology in different scenarios**

**Tests based on 100 MHz at 2.6 GHz band.*

***Only near-point results on the upper floor is available due to weak backlobe signals from the lower floor.*

The capacity gain of the multi-channel joint DAS technology is closely /dependent on how well the two adjacent floors are isolated. The test results have shown that the higher the isolation, the lower the downlink speed and the average rank, as shown in Table 3. Therefore, it is recommended that the DAS multi-channel joint DAS solution should be deployed in an environment where the floor isolation is less than 30 dB.

Isolation (dB)	Scenario	Performance improvement (vs. single-floor dual-channel DAS)		
		Average DL speed	Near-point DL speed	RANK
0	Same floor	40%	56%	97%
10	Low penetration loss through Floors	23%	36%	59%
20	Medium penetration loss through Floors	15%	22%	52%
30	High penetration loss through Floors	No obvious gain		

Table 4 Performance improvement with cross-floor dual-channel DAS four-steam under different isolation

Enhanced digital indoor distribution system for more efficient network

With various advantages such as easy deployment, large capacity, and better manageability, digital indoor distribution system can better meet future service development requirements, and has become a much preferred choice for 5G indoor coverage deployment. However, with many challenges towards 5G evolution such as performance, cost, O&M and service, much enhanced solutions are more necessary than ever.

Enhanced digital indoor distribution system can offer much better performance

Enhanced digital indoor distribution system can leverage more technologies to realize enhancements in the following aspects:

User speed enhancement:

In the coverage overlapping areas of multiple 4T4R Pico RRUs, virtual 8T8R can be formed to offer higher downlink speed.

Capacity enhancement:

As digital indoor distribution system supporting multi-band and multi-RAT with great flexibility, the carriers can be configured in accordance with the actual service demands. In addition, the system can be split into multiple cells just by software means to increase the capacity. However, it should be noted that after cell splitting, the co-channel interference among cells will also increase, which can be managed to some extent using specific baseband algorithm.

Low latency:

One of the key promises of 5G is low latency, which can be achieved by introducing MEC or distributed UPF.

High reliability:

Firstly, the network planning and design should take redundancy into consideration for high-value areas. Different Pico RRUs can be connected using different optical fiber links to baseband units to ensure redundancy. Also, multiple Pico RRUs can be deployed in one area to achieve coverage redundancy. Secondly, the digital indoor distribution system can achieve end-to-end management and quick fault identification and response. Furthermore, digital indoor distribution system can also support self-healing. When a Pico RRU fails, the nearby RRUs can increase their coverage by reducing the cell bandwidth and increasing the transmission power.

Enhanced digital indoor distribution system can significantly reduce cost

1 The deployment solution should be tailored for the need

While Pico RRUs account for a large part of the overall cost, the cost of Pico RRU is mainly determined by the number of transceiver channels and supported frequency bands. The more frequency bands and channels, the higher the cost. It is therefore necessary to use different configurations for different deployment scenarios which can be categorized as performance-priority scenario, balanced performance and cost scenario, and cost-priority scenario.

- Performance-priority scenarios include transportation hubs and stadiums where very high network capacity is required. Triple-band and 4T4R radio equipment should be the priority, ensuring very wide bandwidth and high speed of network services.

- Balanced performance and cost scenarios, such as small shopping malls and hospitals, requires medium network capacity. Dual-band and 2T2R radio equipment should be the priority ensuring good experience with lower CapEx.

- Cost-priority scenarios such as office buildings require relatively low network capacity. The active + passive hybrid mode is recommended. Each channel of 4T4R Pico RRU is connected with external ceiling antenna through feeder to the coverage area directly, avoiding unnecessary penetration loss, enhancing coverage, and reducing the number of required Pico RRUs.

2 Network sharing is another important way to reduce the cost of 5G deployment

RAN sharing has many advantages:

- Multiple operators can reduce network construction costs by network sharing and accelerate 5G network deployment.
- It is often much easier for the landlords to accept one indoor system shared by multiple operators than multi indoor systems owned by their respective operators.
- By sharing spectrum resources, the operators can all enjoy wider spectrum bandwidth for enhanced user experience.

The digital indoor distribution system needs to have the following capabilities to meet the challenges of RAN sharing:

Ultra-wide bandwidth:
Pico RRU needs to support two 100 MHz NR cells or three 100 MHz NR cells when multi-operator independent carrier sharing mode is implemented.

High transmission power:
5G frequency can have higher propagation losses, and the bandwidth is often much wider. Therefore, higher transmit power is required to ensure good network coverage. Particularly in multi-operator independent carrier sharing mode, each carrier must be allocated with power, so the total transmit power is even higher.

High integration:
A single Pico RRU supporting multi-band and 3G, 4G and 5G can really help site acquisition. However, the sharing of 3G and 4G also requires more bandwidth capability and transmission power.

Enhanced digital indoor distribution system can improve O&M efficiency

1 Accurate and visual O&M

Indoor digital distributed system is often deployed with many units of Pico RRUs in relatively small areas, which requires more efficient network operation and maintenance:

Precise fault identification: management visualization displays the status of each active equipment. With a large number of Pico RRUs located inside the building and even hidden in the ceiling, it can be difficult to quickly identify the accurate location of the faulty equipment. Therefore, visual management should be able to directly generate 3D indoor maps with detailed locations of the equipment on each floor.

Precise network KPIs: digital indoor distribution system usually combines multiple Pico RRUs into one cell, which reduces the number of cells, avoids inter-cell interference and handover while meeting the network planning capacity targets. However, the granularity of performance statistics based on network equipment O&M is usually only at the cell level, and makes it difficult to know the performance of each Pico RRU. Therefore, O&M visualization should generate performance data and network optimization suggestions on the basis of each Pico RRU unit.

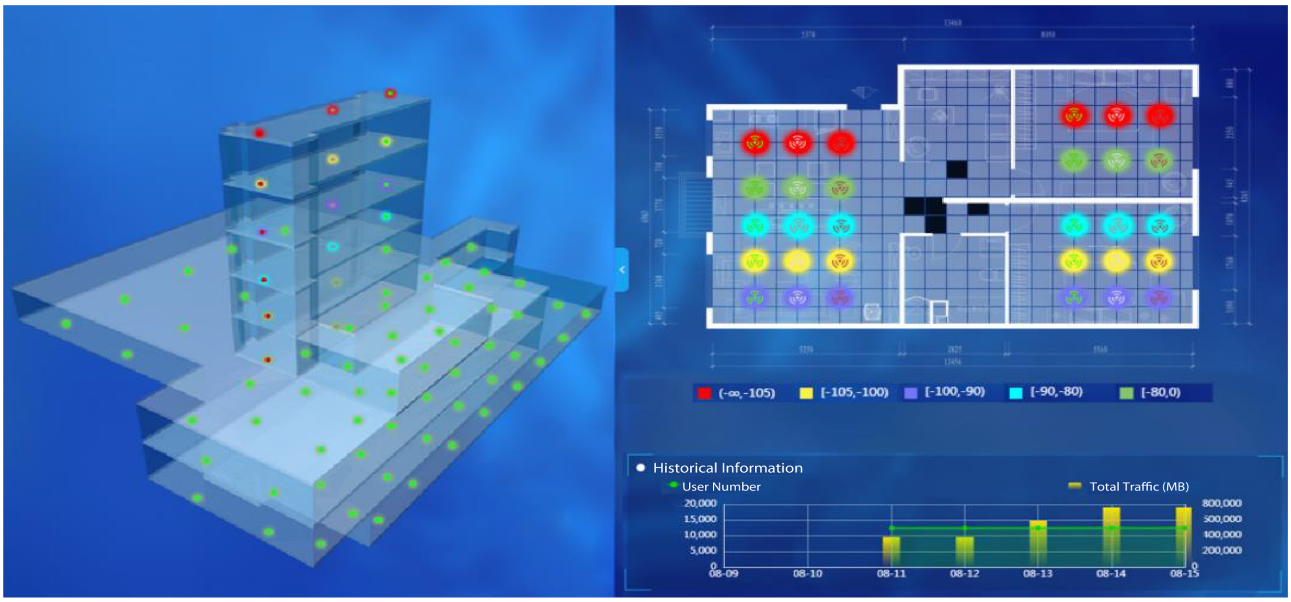


Figure 8 Precise Visual O&M

2 AI-based efficient energy saving

Network power saving can be implemented at various levels:

Symbol shutdown:
The PA of the RF unit is shut down on the symbol timeslots without data transmission.

Channel shutdown:
When the traffic is low, some channels of the RF unit are shut down. For example, the 4T4R RF unit shuts down two channels, and only 2TR2R is used to transmit and receive data.

Cell shutdown:
Define the coverage layer and capacity layer. During low-traffic, shut down the cells in the capacity layer.

Device shutdown:
When there is no traffic, the RF unit is powered off or put into deep sleep mode.

The traditional energy-saving methods cannot be precisely customized for differentiated configurations, greatly affecting the energy saving effect. With AI and big data technologies, the efficiency of power saving can be greatly enhanced with the best balance between energy consumption and performance and meanwhile imposing little impact on the network KPIs.

Self-learning of scenario characteristics:

It models the characteristics of cell scenarios in accordance with the network topology and performance data to predict future traffic.

Self-configuration of energy saving parameters:

Various energy-saving policies are automatically orchestrated based on scenario characteristics and traffic prediction, and power-saving settings of various policies are automatically configured.

Self-optimization of power-saving methods:

After the power saving strategy is implemented, its settings are automatically optimized and adjusted according to the data such as MR, KPI and user perception to ensure best balance between network performance and power saving gains.

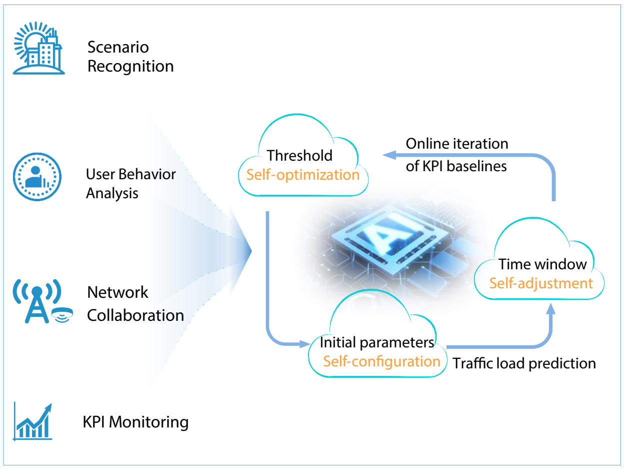


Figure 9 Energy Saving Strategy

Enhanced digital indoor distribution system can help realize more new service potentials

One of the promises of 5G is enhanced and new services also for indoor, with expanded network capabilities and added values, which can be achieved by introducing innovative technologies.

Multi-access Edge Computing (MEC) is one such technology and can provide latency- and capacity-sensitive applications access to radio access network like never before. By deploying contents and applications close to digital indoor distribution systems, MEC can deploy them close to the network edge indoors, with computation and communication taking place locally. This relieves the pressure on backhaul network bandwidth, reduces service delay with respect to multi-level transmission and forwarding, and therefore optimizes user experience. In addition, MEC helps operators share their indoor network capabilities with third-party content and service providers in development, integration, and deployment of local applications to provide more customizable services.

With MEC's computing power and open platform interfaces, digital indoor distribution system provides high-precision indoor positioning information. In this way, more value-added services, such as indoor navigation, and precise marketing, can be enabled based on indoor location information.

Other services at some types of venues, such as stadiums, factories, and industry parks, also require edge capability indoors. The traditional MEC solutions, however, are often costly and slow to deploy. MEC solution integrated inside 5G base station, on the other hand, leverages the existing infrastructure to achieve very quick and cost-effective deployment. This brings much better flexibility to the operators to meet the demands on applications such as AR, VR, factory automation, automated guided vehicles.

Improved coordination between indoor and outdoor networks is required to further enhance indoor coverage

When 5G deployment is at its early stage and/or when 5G spectrum resources are limited, it is often the only choice to use the same frequencies for both outdoor and indoor, thus interference is inevitable, including interference on the public control channels and on the service channels, resulting in the deterioration of network performance and user experience. Therefore, indoor and outdoor coordination solutions are also required to improve indoor performance.

Indoor and outdoor coordination should be carefully planned at network planning stage, and the corresponding parameters should be optimized after base station commissioning, so as to reduce further cost. Indoor and outdoor coordination solutions should take into account network planning and evaluation, interference passive avoidance, and active interference mitigation coordination.

- *First, network planning and evaluation should consider the impact of outdoor cell signals on the performances of indoor cells on a quantitative basis. While the RSRP signal at indoor cell edge is higher than that at outdoor cell, by different margins including -3 dB, 0 dB, 3 dB, 5 dB, 10 dB and 15 dB, the UE performances at different indoor locations are analyzed, which can provide a very useful reference for indoor coverage planning and optimization, helpful for network parameter configuration.*

- *Secondly, passive interference avoidance has the interfered side to utilize beam management to avoid interference by the public control channel on the service channel, including SSB and CSI-RS beam management. For example, many operators have adopted 7 or 8 horizontal beams scanning broadcast in Massive MIMO macro cell. However, the existing indoor distribution systems, including both digital indoor distribution system and traditional DAS system, all utilize single beam transmission scheme, and misalignment of macro and indoor SSB beams will inevitably cause interference. Therefore, by aligning the broadcast beams of indoor cell with those of macro cells, including the number of their respective SSB beams and their offset settings, can reduce the interference of the SSB signals from the macro cells on the indoor cells' service channel.*

- *Finally, interference coordination between outdoor and indoor can be carried out in two ways. Inter-cell PRB randomization, as the first way, is an effective anti-interference method for service channels. Its principle is to divide different starting positions of RB allocation for different cells, then each cell selects a fixed RB allocation sequence according to the current cell type. When the RB usage of a cell is not high, the frequency domain resources can be scheduled for different cells, so as to reduce interference and improve throughput. The second way is dynamic multi-beam coordination which adjust the beams of outdoor and indoor cells in a coordinated and collective manner through exchanging beam measurement data via Xn interface.*

Conclusion and outlook

5G networks will empower all walks of life and promote digital transformation of the whole society. Indoor coverage will be the key battlefield of the 5G era. To meet the requirements of diversified 5G indoor coverage services, diversified deployment scenarios, differentiated network capabilities, the existing indoor coverage solution needs to be evolved and optimized towards 5G. 5G indoor network performance is and always will be a key to the success of 5G in its mission to further digitize and transform our world. In order to achieve the goal, three aspects need to be considered for indoor: a flexible and capable network infrastructure, along with highly efficient O&M and support of diverse and demanding new services. As discussed in this white paper, certain solutions for all these three aspects have their respective advantages and downsides, which is however not all the potentials of 5G indoor end. We have reasons to believe that in the future we will witness more and more new applications and services becoming available, with the underlying technologies further evolving in various directions, including accurate match of network capabilities to a great variety of 5G terminals, much more personalized service requirements in various scenarios, support of multi-band and higher-band capability, and heterogeneous network convergence.

Supporting a huge variety of 5G terminals with adaptive network capabilities

The diversity and complexity of 5G applications and services come with a matching large number of 5G terminals at indoor, such as XR terminals, wearable devices, AI devices, and IoT terminals, can have very different requirements on network capacity, bandwidth, latency, reliability, and power efficiency, which can only be met by a more powerful yet flexible 5G indoor network.

Meeting personalized service requirements in various scenarios

5G indoor network is expected not only to meet the requirements on coverage and capacity, but also to meet personalized service requirements in complex scenarios of different indoor environments. For example, higher spectral efficiency is required to increase network capacity for venues like university campus. In shopping centers, the network is required to provide data analysis capability for user and consumer behavior analysis. In smart factories, 5G needs to provide low power consumption, high-density sensor access and indoor asset location functions.

Multi-frequency and high-frequency

Sub6G

Most of the operator today have chosen Sub6G as the main frequency bands for more efficient network coverage. With the phase-out of 2G, 3G, and 4G services, more frequency bands will be refarmed to 5G to guarantee more capacity for the operator.

Special frequency bands

In special scenarios where the required uplink bandwidth of the industry private network is high, inter-frequency and special frame structures are used to meet the uplink bandwidth requirements. For example, the frame structure such as 1D3U in 4.9GHz spectrum can be used in areas such as factories and underground tunnels to meet the high-definition video backhaul requirements and avoid interference on the public network.

Millimeter wave

With the increase of the penetration rate of 5G terminals and the maturity of the millimeter-wave supply chain, more millimeter-wave networks can be deployed in large stadiums, exhibition centers, and other hotspot places to meet the requirements for large capacity. In addition, millimeter wave is also applicable to scenarios such as FWA (Fixed Wireless Access) and IAB (Integrated Access Backhaul).

Unauthorized and Dedicated Frequency

The Federal Communications Commission (FCC) recently approved the new regulation announcing the use of the 1200 MHz spectrum in the 6 GHz frequency band (5.925 Ghz–7.125 GHz) as an unauthorized spectrum. In Europe 3.7 GHz-3.8 GHz are reserved for vertical industry applications. In the future, more and more private wireless networks will deploy over these private unauthorized spectra by using Wi-Fi 6 or NR-U technologies.

Heterogeneous Network Convergence

The future indoor network will be a multi-frequency, heterogeneous and integrated architecture with 4G, 5G and WiFi, and will even be integrated with non-3GPP wireless technologies such as UWB, BT, RFID and Zigbee to meet the requirements of consumer applications and industry applications.

Glossary

AAU	Active Antenna Unit
AI	Artificial Intelligence
AGV	Automated Guided Vehicle
AR	Augmented Reality
BT	Bluetooth
CPRI	Common Public Radio Interface
CSI-RS	Channel State Information Reference Signal
DAS	Distributed Antenna System
eMBB	Enhanced Mobile Broad Band
MIMO	Multiple Input and Multiple Output
mMTC	Massive Machine Type Communications
MR	Measurement Report
URLLC	Ultra-Reliable and Low Latency Communications
PoE	Power over Ethernet
PRB	Physical Resource Block
RB	Resource Block
RFID	Radio Frequency Identification
RSRP	Reference Signal Received Power
SSB	Synchronization Signal and PBCH block
VR	Virtual Reality
UPF	User Plane Function
UWB	Ultra Wideband