GTI
5G Wireless Network White Paper: Towards a Low-Cost 5G

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1 Abbreviations

Abbreviation	Explanation
2G/3G	The 2nd/3rd Generation Telecommunication Technology
3GPP	The 3rd Generation Partnership Project
4G	The 4th Generation Telecommunication Technology
5G	The 5th Generation Telecommunication Technology
AAPC	Automatic Antenna Pattern Control
AI	Artificial Intelligence
ASC	Automated Site Creation
BS	Base Station
CA	Carrier Aggregation
DAS	Distributed Antenna System
DC	Dual Connectivity
DL	Downlink
eNodeB	Evolved Node B
FDD	Frequency Division Duplexing
gNB	NR node
KQI	Key Quality Indicators
LGBM	Light Gradient Boosting Machine
LTE	Long-Term Evolution
MCG	Master Cell Group
MDT	Minimization of Drive Tests
MIMO	Multiple-Input Multiple-Output
MLB	Mobility Load Balancing
MR	Measurement Report
MU	Multi-user
NR	New Radio
O&M	Operation and Maintenance
OMC	Operation and Maintenance Center
PCI	Physical Cell Identifier
PMI	Precoding Matrix Indicator
RF	Radio Frequency

RLC	Radio Link Control
RRC	Radio Resource Control
SCG	Secondary Cell Group
SOC	System on Chip
SUL	Supplementary UL
TCO	Total Cost of Ownership
TDD	Time Division Duplexing
TDM	Time Division Mode
UE	User Equipment
UL	Uplink
URLLC	Ultra-reliable and Low Latency Communications
VAE	Variational Autoencoder

2 Introduction

In recent years, 5G has profoundly changed our daily life and stimulated users' desire for higher performance and better user experience for more innovative services and applications. With the new services emerging, 5G killer experience and continuous coverage are the keys to business growth. It is one of the primary concerns how the network capabilities, such as extremely high data rate, massive connection, and traffic density, can be achieved for an optimal experience. Meanwhile, how to build cost-effective and efficient networks is the key to success.

Targeting a low-cost and efficient 5G network, the operators, network, and device vendors are deeply involved in facilitating innovative deployment solutions and products, including low-cost solutions in various scenarios, such as indoor products, urban area deployment, and solutions in the special scenarios, and the operation and maintenance optimization based on intelligence technologies and the green network architecture.

This white paper will serve as a platform to share and present the solutions and experience of the low-cost 5G network deployment, thus providing a reference to the industry partners so as to jointly promote the low-cost 5G industry maturity, drive its scale commercialization, and embrace the property of 5G ecosystem.

3 Construction Planning of 5G Low-Cost Network

3.1 Dense Urban/Urban Areas

Different 64T/32T/8T sites are deployed in dense urban areas/urban areas. SUL and Option 4 are utilized to reduce network construction costs with the existing site plans.

3.1.1 SUL and CA

3.1.1.1 Supplementary Uplink (SUL)

Supplementary Uplink (SUL) is defined to support the configuration on 2 uplink (UL) carriers for 1 downlink (DL) of the same cell. The UL carrier in lower bands, referred to as the SUL, is used when the cell coverage is limited. At any time, UE transmits on only 1 UL carrier, indicated by gNB, for one serving cell. SUL and downlink CA can be flexibly combined. Uplink and downlink band combinations can be configured based on UE capabilities and service requirements to achieve spectrum decoupling.

For the medium-frequency and low-frequency combination, the low-frequency bands can be used as SUL carriers, such as n28, making full use of the coverage advantages of the low-frequency bands to make up for the uplink coverage weakness of medium-frequency bands, such as n41 and n79. With the multi-network cooperation of high-frequency and low-frequency bands, the uplink transmission of low-frequency carriers is used when the uplink of medium-frequency bands can not meet the service needs to expand the effective range of uplink and downlink services and reduce the cost of network construction.

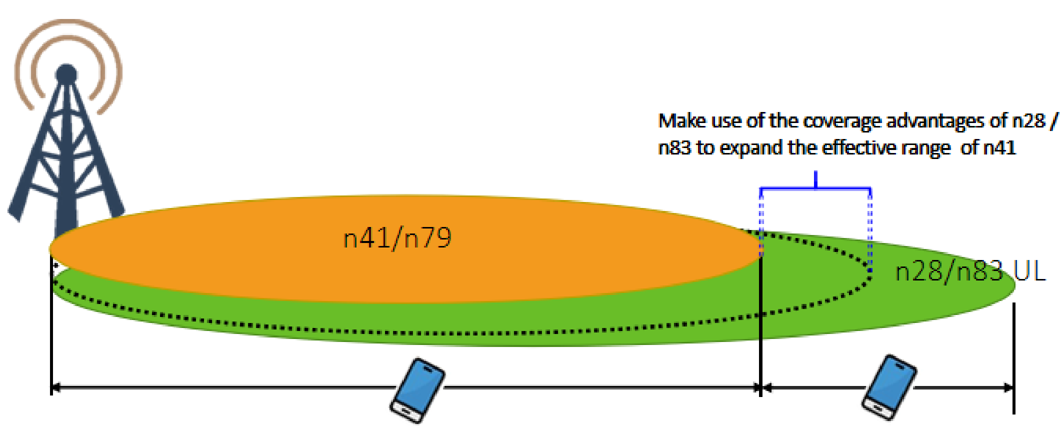

Figure 3-1 The SUL architecture

The SUL function transmits data in the time-division mode. The downlink is carried on the NR TDD carrier, and the uplink is carried on the NR TDD and SUL carriers. The SUL carrier is only used on the time slot corresponding to the NR TDD downlink time slot. At this time, the uplink symbol of the NR TDD carrier no longer transmits data.

In 3GPP Rel-16, uplink Tx switching is introduced to enhance the SUL capability. In the TDD-NR UL time slot, the UE can use dual streams to transmit data, while in other time slots, FDD-NR is used for uplink data transmission (1Tx).

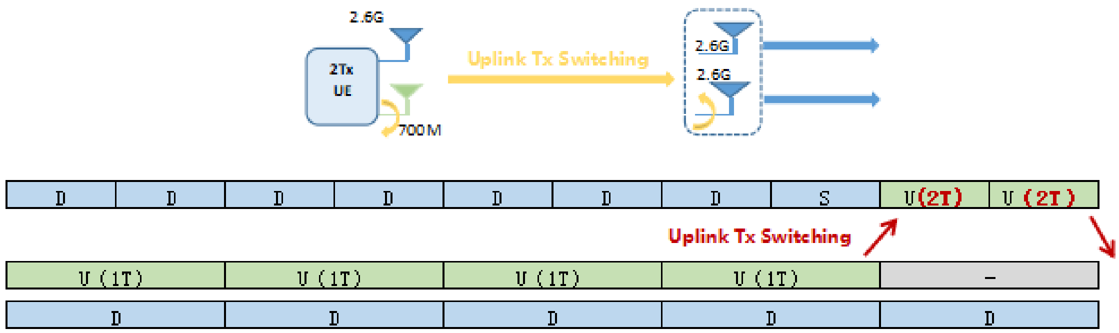

Figure 3-2 R16 TDM SUL

3.1.1.2 Carrier Aggregation (CA)

With the 5G large-scale commercialization, more spectrums are allocated or refarmed for 5G networks. Carrier Aggregation (CA) technology can aggregate the spectrum resources of the same frequency band or different frequency bands to better utilize network resources and improve user experience.

Figure 3-3 Carrier Aggregation

CA, introduced in 3GPP Rel-15, uses different uplink transmission channels (Tx) to support the carriers respectively, which is referred to as the concurrent mode.

Most mobile devices support 2Tx, however, in 3GPP Rel-15, 2 carriers are transmitted by 1Tx in TDD-NR uplink, which may result in capacity loss. Hence, uplink Tx switching is introduced in 3GPP Rel-16 to enhance CA capability. In TDD-NR UL time slots, UE can transmit data with the dual stream, while in other slots, FDD-NR is used for the uplink data transmission. It is referred to as the time division mode (TDM CA).

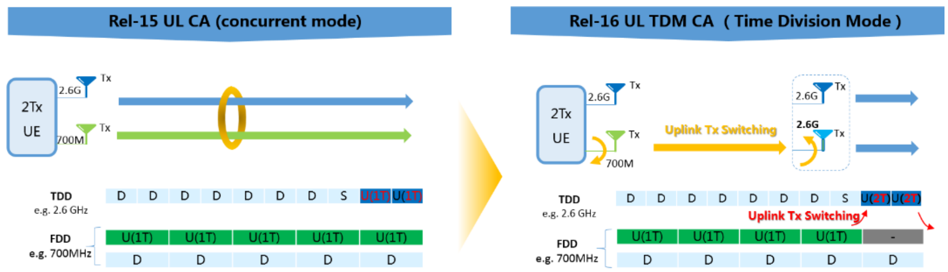

Figure 3-4 TDM CA

CA can flexibly deepen the coordination of multi-NRs with the concurrent mode or TDM mode. At the same time, the flexible coordination of multi-NR among inter-cell and inter-site is supported.

By further releasing the potential of spectrums, CA boosts the system performance, not only enhancing the UL coverage and lessening the latency but also one of the solutions which can benefit the downlink and uplink capacity.

3.1.1.3 Overall Architecture Comparison

CA is introduced in 3GPP Rel-15 and enhanced in Rel-16 through Uplink Tx Switching technology. CA can flexibly enhance the collaboration between multiple NR carriers (between cells or sites) through the concurrent mode or the time division multiplexing mode, further unlock the spectrum potential, improve single-user uplink and downlink peak rates, UL coverage, and reduce latency.

SUL is a new addition in Rel-15 and enhanced in Rel-16 through the uplink Tx switching technology. SUL can effectively improve the cell edge rate and edge-covering ability. In 2021, China Mobile organized the R16 technical verification, including the test of the SUL coverage and the performance improvement under the commercial network.

2.6 GHz TDD+700 MHz SUL commercial network verification results: Compared with 2.6 GHz TDD only, 2.6 GHz TDD+700 MHz SUL increases the uplink rate by 30% to 80% at the center and medium points and increases the uplink coverage by 7 dB when the cell edge rate is 5 Mbit/s, not only improving the network experience and capacity but reducing 5G network construction costs.

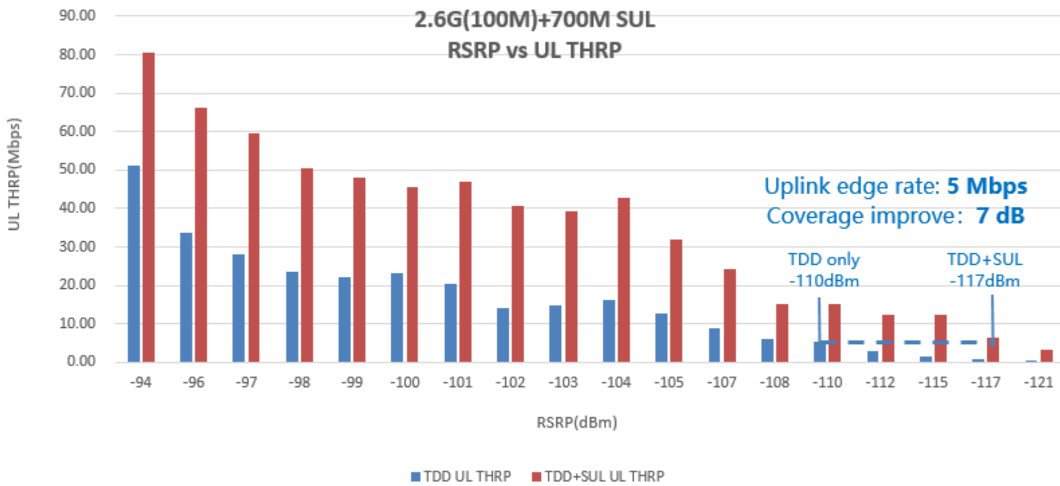

Figure 3-5 2.6G+700M SUL test results

3.1.1.4 Performance Comparison

For the convenience of the analysis and the description, the impact of the system performance is compared under the combination of 2.6 GHz (100 MHz, Pcell)+700 MHz (30 MHz) using the 5 ms frame structure.

Table 3-1 The Performance Comparison Between CA and SUL

	CA	**SUL**
5G uplink coverage	The maximum coverage depends on 700 MHz uplink coverage	The maximum coverage depends on 700 MHz uplink coverage
5G uplink peak rate	383 Mbps	383 Mbps
5G downlink peak rate	2060 Mbps	2060 Mbps(Using CA)

3.1.2 Option 4

There are three main methods for the future 4G evolution, Option 4 architecture, Option 5 architecture (a SA way of 4G base stations directly connected to 5GC), and 4G refarming to NR Option 2 (the same as the current SA option 2). Figure 3-6 qualitatively compares and analyzes the three methods in terms of performance, interoperability, power consumption, industry, and standardization.

	Option 4 (700M NR + "eNB+")	Option 5 (eLTE)	Option 2 (1.8GHz/1.9GHz NR re-farming)
Peak	(+) higher data rate due to NE-DC	(=) Similar as LTE	(+/=) up to refarmed spectrum bandwidth
Coverage	(+) dependent on 700M, better than LTE	(=) Similar as LTE	(-) **worse than** 700M, need mMIMO
Capacity	(+) NE-DC: 30MHz + 20MHz (1.9G) (+) NE-DC: 30MHz + 20MHz (1.8G)	(=) Similar as LTE	(-) need consider 700+1.8/1.9 CA
Inter-operability	(-) higher complexity due to too many handover scenarios	(-) medium complexity, need consider handover between LTE and eLTE	(+) simple due to NR Intra RAT handover
Power consumption	(=) no difference	(=) no difference	(=) no difference
Upgrade cost	(-) 4G SW upgrade to "eNB+" (-) Old 4G BBU may be replaced (-) 5G gNB SW upgrade	(-) 4G SW upgrade to eLTE (-) Old 4G BBU may be replaced	(-) New RRU SW support 5G NR (-) Old RRU/BBU may be replaced (-) need additional BBU card for 5G
Industry Support	(-) no chipset support, no terminal (-) no gNB/eNB support now	(-) no chipset support, no terminal (-) no eNB support now	(-) terminal need support 1.9GHz NR (-) consider HW/SW cost
Standard	(-) RAN4/5 need complete in Rel-17	(+) Rel-15 complete	(+) Rel-15 complete

Figure 3-6 The comparison of Option 4, Option 5, and Option 2

Option 4 network scheme can not only make full use of the existing 4G network but also increase 5G capacities. The technical characteristics are as follows.

- Based on Option 2, dual connectivity (DC) is applied in Option 4 with NR as the master cell group (MCG) and LTE as the secondary cell group (SCG).
- The panel data of Option 4 users are split by 5G NR.
- Signals are transmitted only by the 5G MCG, while LTE SCG is only used for the user plane transmission.
- The 5G logo is displayed at the terminal.

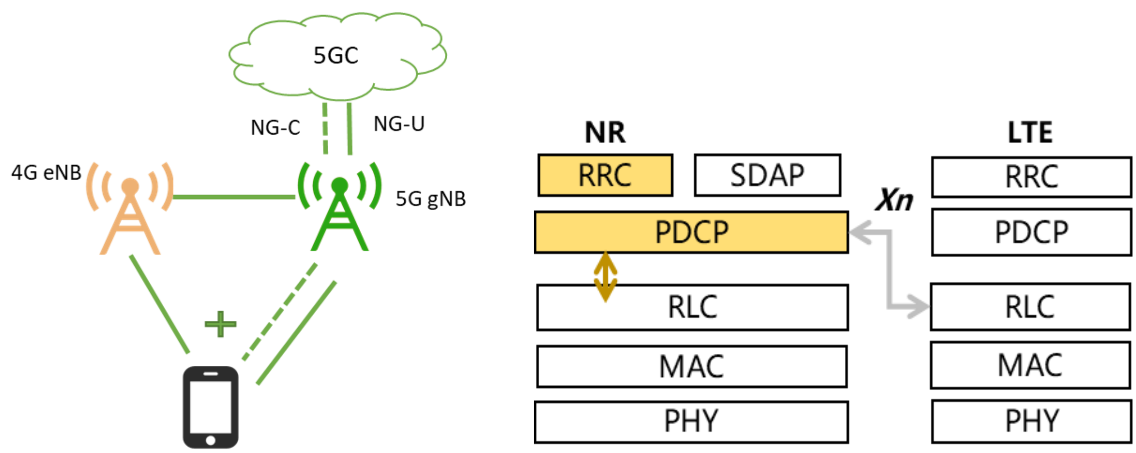

Figure 3-7 The Option 4 architecture

As shown in Figure 3-8, the uplink and downlink peak rates of Option 4 are theoretically analyzed. 700 MHz is applied as the NR MCG, while the 1800 MHz, F band, and A band are used as LTE SCG. The results show that Option 4 can effectively improve the 5G user experience.

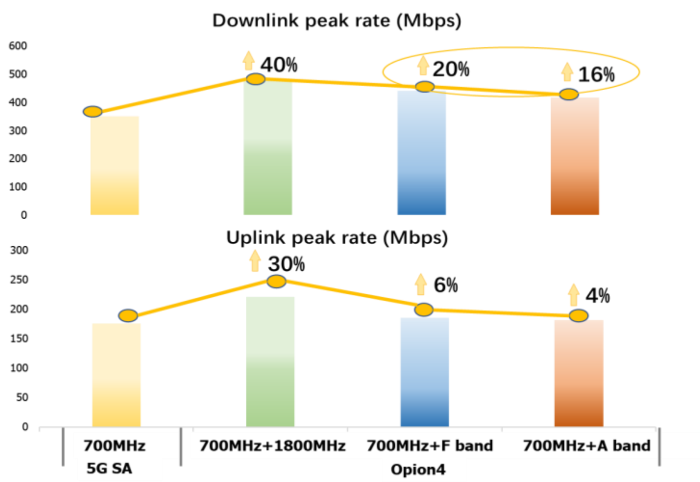

Figure 3-8 The theoretical analysis of the uplink and downlink peak rate of Option 4

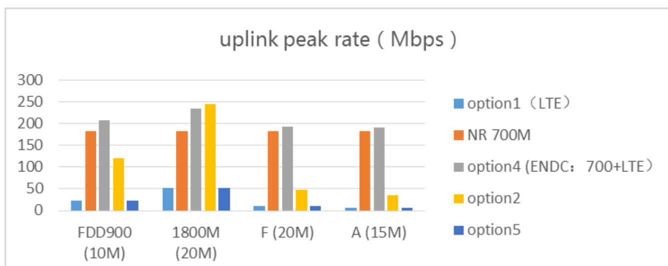

Figure 3-9 The theoretical analysis of the uplink peak rate of NR 700M and Option 1/2/4/5

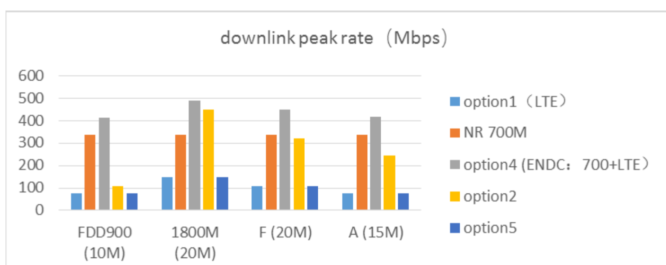

Figure 3-10 The theoretical analysis of the downlink peak rate of NR 700M and Option 1/2/4/5

In conclusion, theoretically option 4 can reduce network costs and promote the spectrum efficiency. Nonetheless, since different operators have various base station hardware conditions, the specific analysis is needed.

3.2 Indoor Scenarios

There are mainly three types of room deployment schemes, the passive DAS system deployment scheme, the active DAS system deployment scheme, and the extended equipment deployment scheme. The first two types are system deployment schemes, generally covering buildings, and the third type is the single point deployment scheme, which generally covers relatively small spaces, such as meeting rooms and parking lots. The passive DAS system is composed of BBU, RRU, and passive DAS, suitable for deployment in medium and low-capacity scenarios. The active DAS system deployment scheme is composed of BBU, HUB, and pRRU, suitable for deployment scenarios with medium and high capacities.

This section will introduce new innovative solutions around the cost reduction scheme of the active DAS system, the low-cost capacity enhancement scheme of passive DAS, and the low-cost extended equipment.

3.2.1 Low Cost Scheme of Active DAS System

In terms of indoor network construction, compared with 4G, 5G has improved the signal bandwidth, the transmission power, and the number of radio frequency channels. Therefore, reducing the cost of indoor network construction is a significant problem that operators need to solve.

Three low-cost solutions will be introduced. The first scheme is the joint of digital active DAS and DAS, the second scheme is the overlay solution of active DAS cell and passive DAS cell, and the third scheme is the BBU direct drive pRRU.

3.2.1.1 The Active DAS & DAS Joint Networking Architecture

The scheme is realized by increasing the transmission power of the pRRU and expanding the DAS at the end of the active DAS. The extended DAS is composed of a power distributor, cables, and antennas. The number of antennas can be 2~5, depending on the specific scenario. If the number is N, it is called N-point Joint Networking.

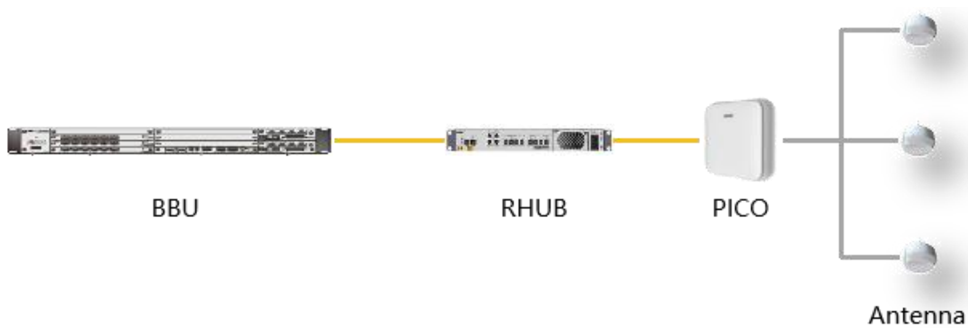

Figure 3-11 The new joint networking solution

The new joint networking solution reduces the network construction cost of a 5G network. This solution has the advantages of low costs, low power consumption, easy expansion of the passive distribution, digitization, excellent performance, various application scenarios, and flexible cell splitting of the active distribution. Aiming at medium-capacity and low-capacity value areas, the solution can save network construction costs and meet indoor capacity requirements.

The joint networking solution has the advantage of low costs. Taking the government office building (comprehensive partition building) as an example. Three schemes of the 2TR PICO, the three-point pRRU, and the dual-path passive DAS are adopted for construction respectively, and their costs are compared in Table 3-2.

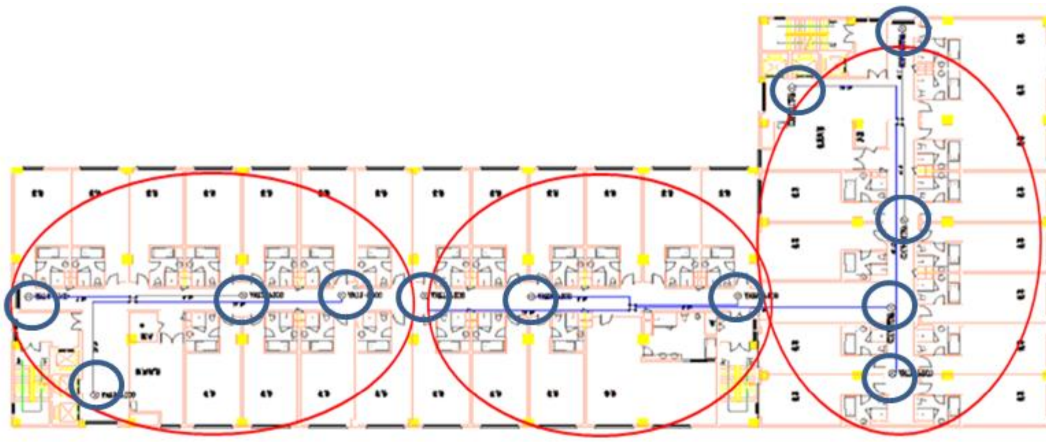

Figure 3-12 The joint networking solution in comprehensive partition building

In Figure 3-12, the red circle represents the joint networking, and the blue circle represents the extended antenna of DAS.

Table 3-2 Cost comparison of 4TR PICO, 2TR PICO, three-point PICO and dual DAS

Construction mode	Equipment cost	Integration cost	Reserve cost	Materials provided by Party A	Other cost	Total cost
2TR Active DAS	A1	A2	A3	A4	A5	A
Three-point Joint Networking	0.66*A1	1.24*A2	0.72*A3	0.61*A4	0.99*A5	0.72*A
Dual-path Passive DAS	0.25*A1	2.21*A2	0.62*A3	1.21*A4	2.11*A5	0.62*A

The three-point joint networking, with a cost of 72% of 2TR active DAS, can carry out low-cost construction; The cost of the three-point joint networking deployment is 14% higher than that of the dual-path passive DAS. However, when the uplink edge rate requirements are the same, the coverage distance of the three-point joint networking scheme is much longer than that of the dual-path Passive DAS.

The following figures show the performance comparison of the 4TR active DAS, the N-point joint networking, and the dual-path passive DAS.

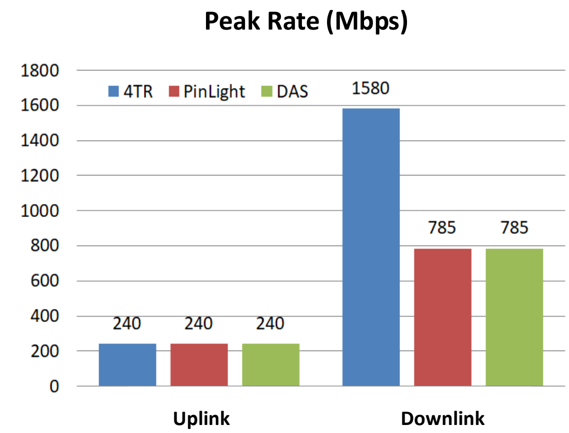

Figure 3-13 Comparison of peak rates of 4TR active DAS, N-point Joint Networking and dual-path passive DAS

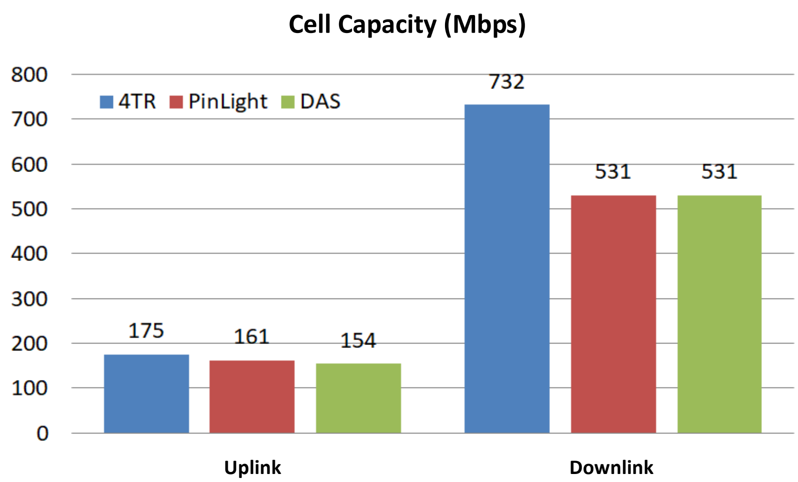

Figure 3-14 Comparison of cell capacity of 4TR active DAS, N-point Joint Networking and dual-path passive DAS

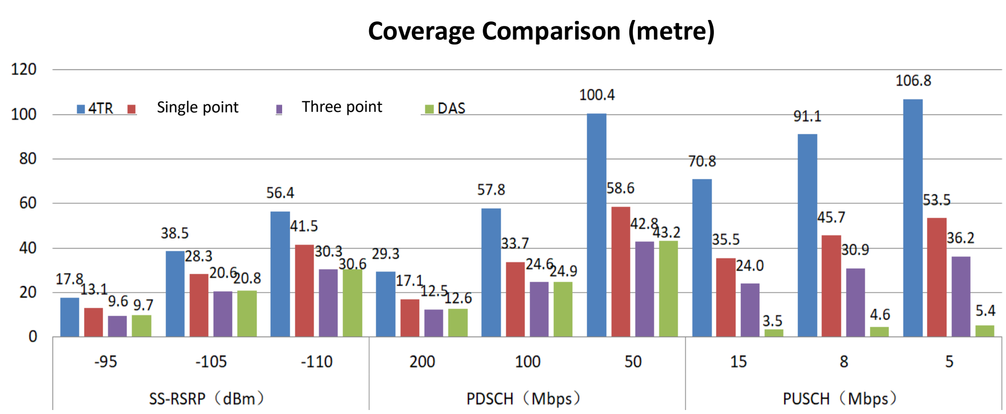

Figure 3-15 Comparison of coverage of 4TR active DAS, N-point Joint Networking and dual-path passive DAS

The aforementioned data manifests the performance improvement of the joint networking. The peak speed of a single user can reach more than 700 Mbps which can meet the needs of most medium and high-value scenarios. The cell capacity can reach 73% of the capacity of 4TR active DAS, which can meet the needs of most medium and high-capacity scenarios. If the capacity is limited, the cell can be split and expanded flexibly according to the capacity change. Under the same uplink edge rate requirements, the uplink coverage is about 10 times that of 2TR DAS.

In addition, the joint networking scheme can be superimposed with D-MIMO/air separation MIMO to achieve four flow effects in two channels to further improve the network performance.

3.2.1.2 Overlay Solution of Active DAS Cell and Passive DAS Cell

For middle-capacity and middle-traffic scenarios, It is difficult, costly, and prolonged to upgrade the existing passive DAS to meet the capacity challenge brought by the rapid growth of 5G services. The upgrading work includes supporting more TR channels, introducing 5G sub 6GHz bands, and the capacity expansion in the local area. However, the brand new build digital active DAS is not cost-effective, since the distribution of indoor traffic is unbalanced, with 80% of the traffic in 20% of the indoor areas. The collaboration solution can leverage the coverage advantage of the passive DAS and the capacity advantage of the digital active DAS to achieve the best cost-effectiveness. For example, in a shopping mall or an office building where passive DAS systems have been deployed, the active DAS can be deployed directly in areas where capacity enhancement is needed such as shops or VIP conference rooms. Compared with the traditional passive DAS expansion and the new building digital active DAS, the collaboration solution can save 50% and 20%~40% of the cost, respectively.

There are two collaboration solutions as following.

- When the passive and digital active DAS cells are overlapping with the same frequency, to ensure that the digital active DAS works normally and is not interfered with by co-channel DAS signals, the traditional way adjusts the DAS system to disable DAS signals in the corresponding area, which brings not only difficulties in engineering and network optimization but also poor experience to users. However, the collaboration solution simplifies the overlay deployment of digital active DAS and effectively improves the capacity and user experience in hot spot areas by solving the problem of different signal transmission power and transmission channels between different DAS systems and turning interference into gain.

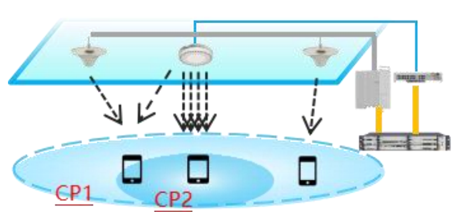

Figure 3-16 Overlay deployment for capacity

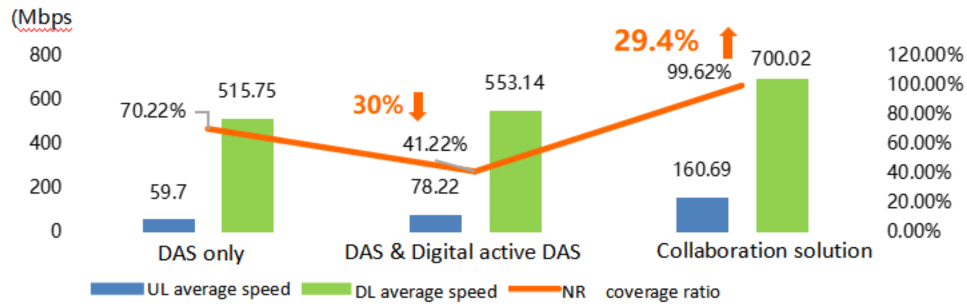

Figure 3-17 Collaboration solution has better performance in field drive test

- When the passive and digital active DAS cells are adjacent with the same frequency, it can reduce the handover and the interference to improve the user experience at the junction of the passive DAS and the digital active DAS. The typical scenarios are the areas between elevators and halls or between subway tunnels and platforms.

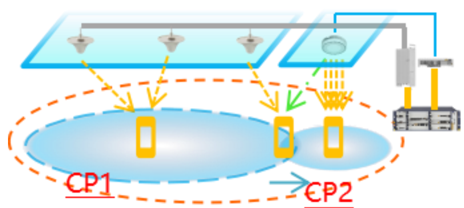

Figure 3-18 Junction deployment for experience

3.2.1.3 Simplified Architecture Scheme

The digital active DAS usually introduces a front haul hub between BBU and pico RRU to extend more radios for continuous coverage of the large area. However, it is not cost-effective for the following typical scenarios.

- B2C: high-capacity but discrete and small area scenarios such as operator's business hall. The traditional way has a high cost for small areas and can not support over 200 meters the remote deployment of pRRU.

- B2B: mining/tunnel which has limited space for the deployment of extra hub equipment.

The simplified digital active DAS system, supporting the direct connection between BBU and pico RRU by reducing the front haul hub, is suitable for small areas which require less than 6 pico RRU for coverage. It has the following benefits.

- It saves overall TCO 6%~10% compared with the traditional way.

- It is more flexible and can support up to 10 km long distance pico RRU deployment with the local power adapter.

- Due to sharing the common BBU with the traditional solution, it can inherit all features and evolution.

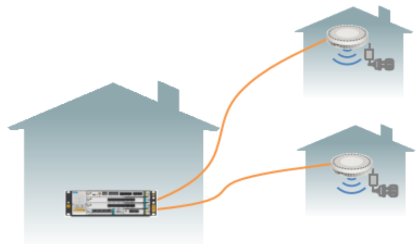

Figure 3-19 Simplified Digital Active DAS supporting direct connection between BBU and Pico RRU

Table 3-3 Saving items compared with traditional ways

Item	Saving Items Compared with Traditional Ways
CAPEX Saving	Hub
	Hub installation kit
OPEX Saving	Hub space rent fee
	Hub power consumption
TCO Saving	6%~10%

The digital active DAS such as QCell has the advantages of simple deployment, scalability, and manageability, and can better meet the needs of future service development. Hence it has become a preferred choice for high-value scenarios. With the growth of 5G services in high-value scenarios, QCell can split a few cells to meet the capacity requirement. However, as the number of split cells increases, inter-cell co-channel interference increases dramatically. When the interference reaches the threshold, the system capacity is saturated, the cell splitting cannot improve capacity, and the user experience becomes worse. SuperMIMO solution can collaborate with multiple distributed antennas of QCell as one massive MIMO antenna to serve a single UE or multiple UEs in a cell. In this way, user signals are enhanced while solving the problem of co-channel interference. This improves user experience and cell capacity and addresses the contradiction between interference and capacity.

To accurately match the high capacity and ultra-dense capacity requirements in the network development, SuperMIMO can meet two stages in Figure 3-20. For high indoor traffic scenarios, the supercell technology is used to reduce the multi-cell interference and the handover, and the system automatically performs space division pairing for multiple UEs to enhance the cell capacity. For the UEs in the overlapping area of edge signals, the number of MIMO layers can be increased by the collaboration of adjacent multi-antenna transceiver solutions. For scenarios with extremely high traffic, ultra-dense user distribution, and poor spatial isolation, it is necessary to achieve accurate beamforming gain and MU pairing to improve cell capacity through the collaboration of QCell's distributed massive antennas.

(a) Stage 1 high capacity **(b) Stage 2 Ultra high capacity**

Figure 3-20 SuperMIMO improves cell capacity in high value scenarios

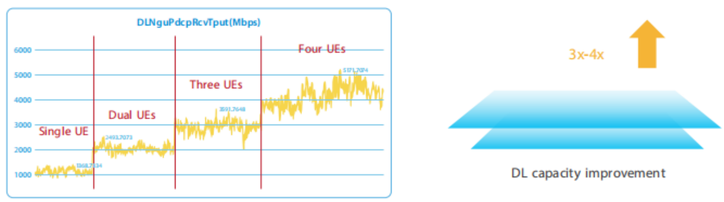

Figure 3-21 The test results and capacity improvement

3.2.2 Low Cost Capacity Enhancement Scheme of Passive DAS - MIMO Construction Scheme

With the outstanding advantage of low cost, the passive DAS, especially the single-path DAS deployment gains popularity for indoor scenarios. Based on the single-path DAS, various solutions are explored for the MIMO user experience.

3.2.2.1 Cross-floor MIMO based on Single-Path DAS

The traditional single-path DAS only provides the single-stream DL and UL transmission. However, for the buildings in which adjacent floors are covered by the single-path DAS from different radio frequency (RF) ports of the same BS, it is possible that the signal leakage from upper or lower floors could be strong enough for UEs to set up the data linkage, in addition to the existing single-stream connection. With the necessary BS software update, such a cross-floor MIMO solution would be practical without the reconstruction of the original DAS system. To enhance the MIMO performance, the theoretical calculation suggests a penetration loss of no more than 30 dB.

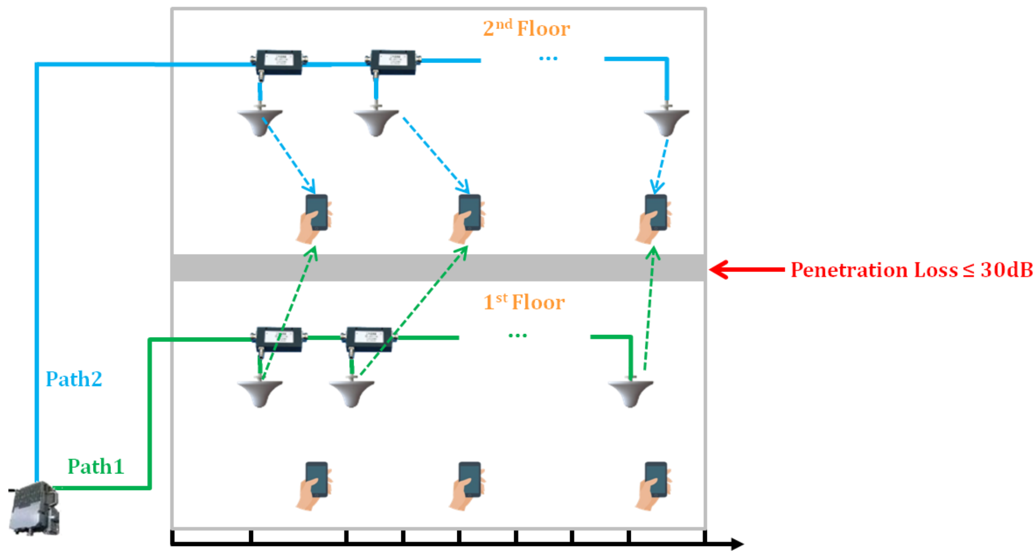

Figure 3-22 The cross-floor MIMO based on single-path DAS

3.2.2.2 Single-Path DAS and Single-Path Panel for Small Open Scene

For the buildings in which adjacent floors are covered by the single-path DAS from different RF ports of the same BS, the MIMO coverage of the local area could be achieved by the power extraction from adjacent RF ports. With the additional RF-coupler and the compact antenna design, certain areas on the 1st floor can be covered by the signal from Path2, as shown in Figure 3-23, thus dual-stream MIMO connection is provided to the UEs in this area. To further improve the feasibility of the solution, innovative transparent antennas are used for easier reconstructions.

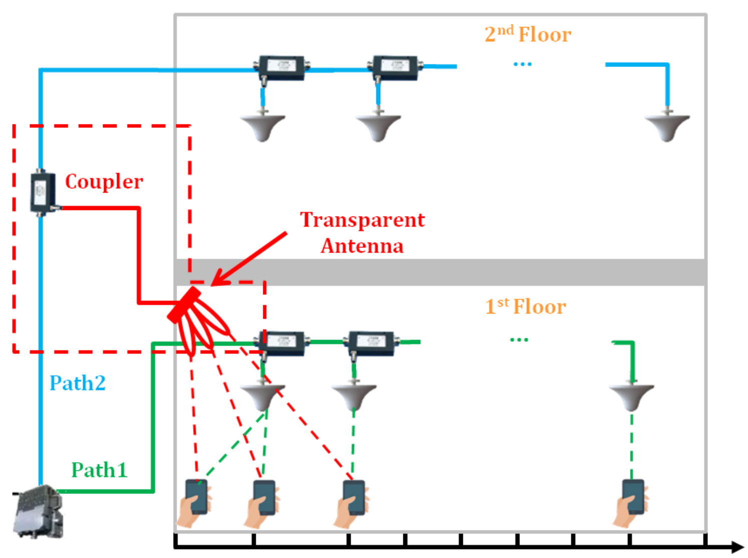

Figure 3-23 The local area MIMO under single-path DAS

With the development of mobile communication technologies and the increase in application scenarios, the types of antennas become increasingly varied, and the deployment is becoming more and more intensive. In dense areas and indoor scenarios, rigorous requirements are placed on the environment integration of the antenna deployment.

As a new type of camouflage antenna, transparent antennas provide a new idea for antenna deployment. Transparent antennas refer to antennas with optical transparency, which can be divided into transparent conductor antennas and transparent dielectric antennas, and the cost is about 100 dollars. The selection of materials for transparent conductor antennas includes transparent conductive films, transparent metal grids, transparent conductive solutions, etc. The selection of materials for transparent dielectric antennas includes transparent dielectric materials, such as glass and distilled water. The transparency makes antenna deployment more flexible and site selection more diverse, and can alleviate people's concerns about electromagnetic radiation due to the high integration with the environment.

3.2.2.3 Single-Path DAS and Single-Path Panels for Multi-Partition Scene

The two solutions above are intended to reduce deployment costs and improve performances in the new deployment scenarios. However, there is another solution intended for rebuilding the existing scenarios and optimizing the networks. The DAS + Panel Antenna with multi-channel joint transceiver technology is introduced to improve the MIMO user experience. It is a cost-efficient solution to achieve DAS MIMO with Fast deployment, high throughput, better capacity, and the lowest total cost of ownership.

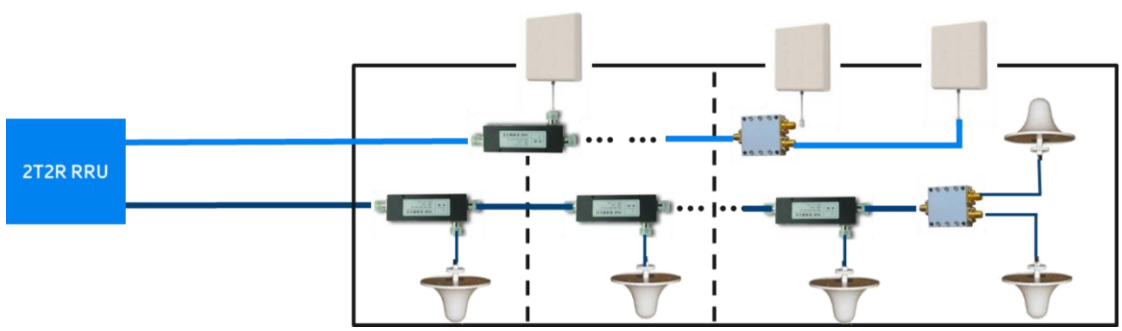

Figure 3-24 The DAS+Panel Antenna with multi-channel joint transceiver technology

The multi-channel joint transceiver technology can combine multiple distributed TRPs and use multi-antenna MIMO gain. The antenna gain of the DAS + Panel Antenna solution can achieve 10 dB, higher than 2*2 MIMO DAS deployment. In addition, the amount of panel antennas is much less than the amount of DAS in the equal coverage scenario and the amount ratio can be 1:5.

In conclusion, the performance of each solution improved a lot compared with traditional deployment scenarios. Also, the deployment cost of 2*2 MIMO DAS reduces by nearly 40% compared to the digital indoor system. The transformation cost of DAS+Panel antennas is nearly 60% less than the rebuilding cost of double-path DAS.

3.2.3 5G Low-Cost Extended Equipment

3.2.3.1 China Mobile 5G Femto

At present, a significant proportion of mobile data traffic originates indoors. End users expect to receive the same levels of service indoors as they do outdoors. However, achieving that will be a big challenge, since networks are required to cover the indoor "dead" zones which cater to the full range of consumer scenarios, including residential and small-medium enterprises.

Besides, Enriching businesses relying on high-quality networks and simple operation and maintenance in residential, small shops, enterprises, and other scenes will also be key enablers of great user experiences in indoor environments. 5G Femto can realize deep 5G coverage with intelligent and simple operation and maintenance (O&M) and provide safe and reliable high-quality network services to meet the diverse intelligent services and reduce the cost of public network construction.

Current CMCC 5G Femto products have a 100 MHz bandwidth of 2.6 GHz and 2T2R MIMO capability. 5G Femto can access the mobile core through the IP network, providing deep network coverage and capacity at low cost, and has the advantages of plug-and-play, simple operation, maintenance, safety, and reliability. CMCC also has 4G/5G dual-mode Femto and integrated PON and wifi products to meet various scenarios

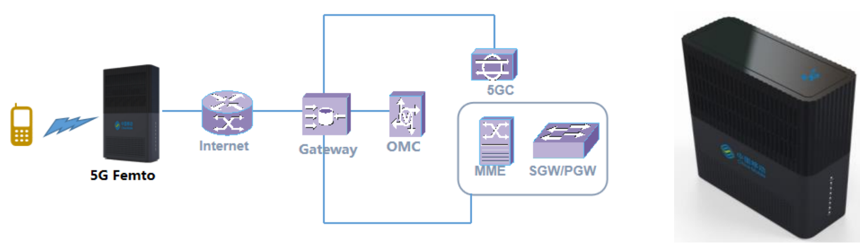

Figure 3-25 China Mobile 5G Femto

For scattered and weak coverage scenarios, the scheme of using 5G Femto can significantly save construction costs compared with the construction of a new outdoor macro station, which is an estimated cost saving of more than 70%. However, the macro station can meet more coverage requirements, and operators can choose by themselves when deploying.

3.2.3.2 4G Femto Evolved to 4G/5G Femto (Smart Node)

High-quality indoor mobile coverage plays an important role both for homes and enterprises. Residential and enterprise customers need dedicated indoor mobile solutions to ensure proper coverage and capacity.

4G indoor network today is providing basic coverage and capacity. Rolling out a new 5G network or transiting the consumer to 5G with a simple self-deployable 5G plug-in module will be a key success factor.

Premium indoor experience differentiators can be the followings.

- The modular design of 4G and 5G radios, support different 5G band variants, and future proof and adapts to CSP's (communication service provider) 5G roadmap and spectrum acquisition.
- Software upgradable with 5G SA, which allows further 3GPP release evolution.
- Increased capacity while offloading traffic from the macro network.
- Improved coverage and quality of service where you need it.
- Plug and Play design to minimize TCO from deployment to operation.
- Transparently supports authentication and security ensuring operator trust.

Modularity is the key feature of 4G/5G Femto (Smart Node). It can be deployed along with 4G Femto by being plugged into a 5G Femto module to provide 5G service on top. 5G Femto can also be deployed as a standalone unit to provide 5G SA service from day one.

Figure 3-26 4G/5G Femto (Smart Node)

The high-level system architecture for small cells as defined by 3GPP is depicted in the diagram in Figure 3-27. The 4G/5G Femto (Smart Node) uses 3GPP interfaces to connect to neighboring eNBs/gNBs and other 4G/5G Femto (Smart Nodes) and existing mobile core network nodes while offering 3GPP compliant air interface. The 4G/5G Femto (Smart Node) interconnects with the core network elements over IPSec Tunnel are established with SecGW.

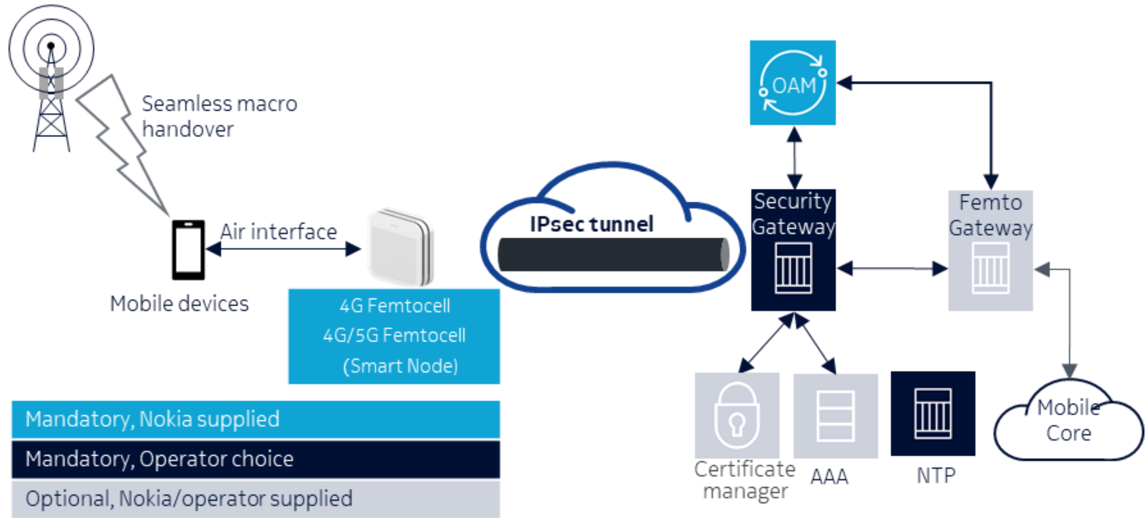

Figure 3-27 The Smart Node interconnects

3.2.3.3 SigWell

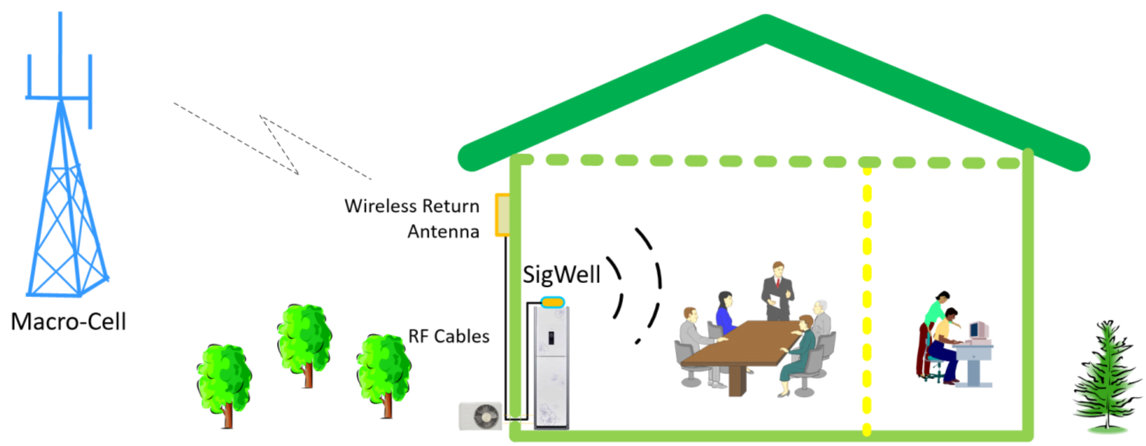

Figure 3-28 The wireless return scheme

To deal with the problems of severe 5G transmission loss and difficult indoor depth coverage, we have successfully independently developed SigWell products. SigWell can enhance 2G/4G/5G multi-network signal strength at the same time, support 2-antenna MIMO, and has the advantages of small size, as well as simple and fast deployment.

The multi-provincial test results of the current network show that in the indoor weak-coverage scene with an area of tens to hundreds of square meters, 5G SigWell coverage and performance are significantly improved, which can efficiently and quickly solve the user complaints caused by the indoor weak coverage. The product can be widely used in families, businesses, offices, basements, and other scenes with an area of tens to hundreds of square meters.

For scattered and weak coverage scenarios, the scheme of using 5G Sigwell can significantly save construction costs compared with the construction of a new outdoor macro station, which is an estimated cost saving of more than 85%. However, the macro station can meet more coverage requirements, and operators can choose by themselves when deploying.

3.3 Specific Scenarios

Due to the particularity of the deployment environment, special scenarios often require different schemes from macro network construction, and the cost will be higher. This paper will introduce low-cost construction schemes for high-speed railways, subways, sea areas, and rural areas.

3.3.1.1 High-Speed Railways - Multi-frequency Multi-mode Micro Repeater

The onboard repeater solution is to deploy an external antenna on the roof of the high-speed railways and add 5G repeater relay equipment in the high-speed railways. The repeater feeds the 5G signal into the car from the outside, which reduces the signal attenuation caused by the closed high-speed train car and the signal distortion caused by high-speed movement. The solution can completely overcome the penetration loss of high-speed train cars.

Since the repeater is to amplify the RF signals and does not involve baseband processing, it does not involve the transformation of the core network. As shown in Figure 3-29, the system architecture of the solution is simple, supporting the co-construction and sharing among four operators simultaneously. In addition, the repeater equipment has a relatively small footprint and low power consumption, aiming at convenient deployment. Moreover, the solution can improve the in-vehicle coverage to enhance the network performance and reduce station construction costs by more than 30% by doubling the distance between stations.

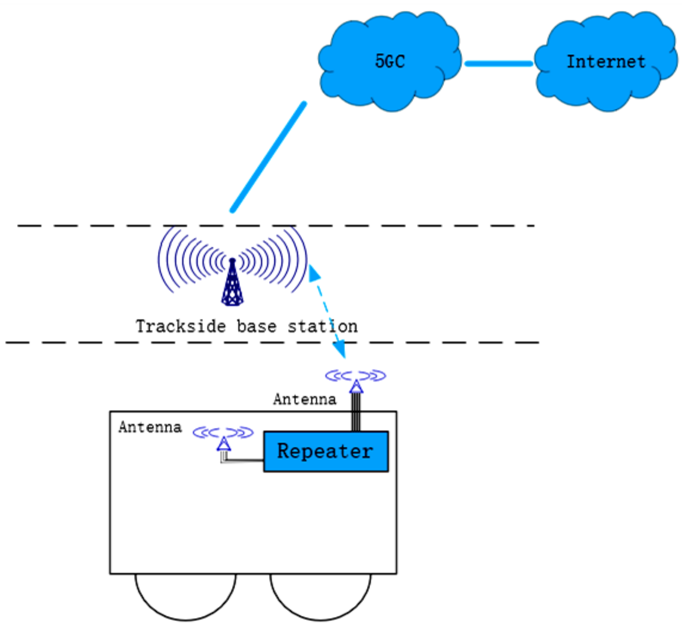

Figure 3-29 The repeater solution network architecture diagram

3.3.1.2 Subways - New Tunnel Wall Antenna Scheme

The New Tunnel Wall Antenna Scheme: The new tunnel wall antenna scheme and tunnel integrated equipment scheme are superior to the traditional leaky cable scheme in terms of the capacity and frequency bands in some new scenes. By connecting two pairs of 4T4R special antennas installed back to the wall, 5G 8T8R RRU can approximately reach the coverage capacity of traditional leaky cable under a certain station spacing. At the same time, it provides up to 4-stream downlink services. Compared with the two-channel leaky cable, the capacity of the new tunnel wall antenna scheme is greatly increased. Replacing the RRU+ antenna structure in the new tunnel wall antenna scheme with 5G 8T8R integrated micro station equipment can further improve the capacity of a single cell.

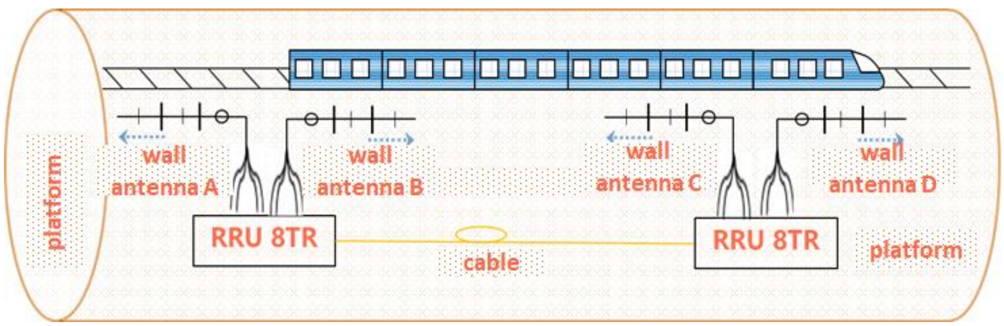

Figure 3-30 The new tunnel wall antenna scheme deployed in subway scenarios

Compared with the conventional leaky cable double cable construction scheme, the new tunnel wall antenna scheme can save about 50% of the construction investment cost, and can still save about 36% when considering the source investment.

According to the pilot verification, in the 2.6 GHz band, the average downlink rate of the new tunnel wall antenna coverage scheme is 65% of the leaky cable, and the average uplink rate is 40% of the leaky cable, which can still meet the existing requirements. In terms of the cell capacity, the special antenna scheme is 1.2 ~ 1.9 times that of the leaky cable coverage scheme. With the implementation of the MU scheme, the capacity of the new tunnel wall antenna scheme can be further improved.

Table 3-4 The comparison between the conventional leaky cable double cable construction scheme and the special antenna coverage scheme

	The traditional leaky cable coverage scheme		The special antenna coverage scheme	
	The average rate	The peak rate	The average rate	The peak rate
The UL rate for single user	70 Mbps	113 Mbps (theoretically)	28 Mbps	91 Mbps (theoretically)

The DL rate for single user	745 Mbps	866 Mbps (theoretically)	486 Mbps	800 Mbps (theoretically)
The DL rate of the cell	820 Mbps	840 Mbps	1 Gbps	1.6 Gbps

New Tunnel Wall equipment Scheme: multi-sector per radio 8TR splitting into two 4TR.

Similar as above, with the multi sectors per Radio being enabled one 8TR radio could split into two sectors and work as two 4TR radios.

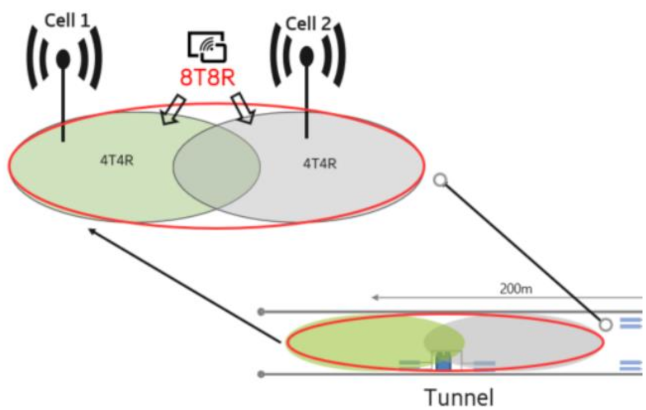

Figure 3-31 Multi-sector per radio 8TR splitting into two 4TR

The splitting of 8TR radio can also cut down on the cost of operators. It will cost less on the hardware because of the radio and optical modular. Meanwhile saving 20% on power consumption can tremendously reduce the cost of subway network operation for operators.

Table 3-5 The comparison of the multi-sector per radio 8TR splitting VS 2 * 4TR

Configuration	Power Consumption	Radio Cost	Optical Modular
8TR Split	80%	75%	50%
2*4TR	100%	100%	100%

Table 3-6 The test results of the multi-sector solution per radio 8TR splitting VS 2 * 4TR

Configuration	SS-RSRP(dBm)	MAC DL THP (Mbps)
8TR Split	-80.32	980.01
Two 4TR	-77.41	1078.39

In conclusion, the multi-sector solution can save the cost of subway tunnel network construction while having no negative effect on the signal strength or downlink throughput for that area, which is a cost-effective approach.

3.3.1.3 Rural Area - Two-Sector Networking Architecture

Rural areas usually have vast land while a smaller population, which means the capacity requirements are not intense and the distance between base stations could be larger than that in urban areas. Low bands with lower path loss and stronger propagation ability are more appropriate choices for this scenario. Meanwhile, 4T4R with high RF power is not necessary due to the low demand for MIMO. Therefore, a possible solution to reduce construction costs is using fewer RF units. Based on 4 RF paths, the two dual-polarized beams of the antenna could be designed to be separated to the left and right, respectively. The sector coverage could be extended from 120 degrees to 180 degrees, and only two RF units are needed for every base station compared with the traditional three-sector architecture. By reducing one RF unit and its antenna, the low-cost solution not only cuts down the construction investment of 15, 000 RMB but also reduces the power consumption by 30%.

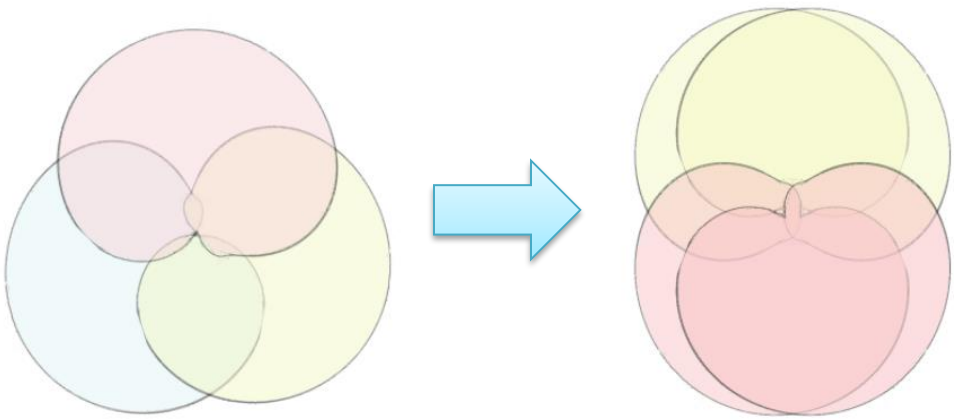

Figure 3-32 2 sectors of one BS and separating the 2 dual polarized beams

The two-sector networking architecture can be achieved through cell split.

Cell splitting is a solution to the challenge of network traffic surges. Without increasing spectrum and site resources, area splitting and capacity expansion can maximize the use of spectrum resources.

Additional hardware is not needed for soft splitting. For low-cost coverage in special 5G scenarios, a 4-channel RRU can be split into two 2-channel RRUs to cover different areas, which can improve the coverage of a single RRU and save the number of sites effectively.

In scenarios where omnidirectional coverage is required, a soft-splitting 2TR external antenna with a wide horizontal lobe can be used, while in road scenarios, a soft-splitting 2TR external antenna with narrow horizontal lobes can be used to form a linear coverage. 17 dBi high-gain antenna can be customized to enhance coverage.

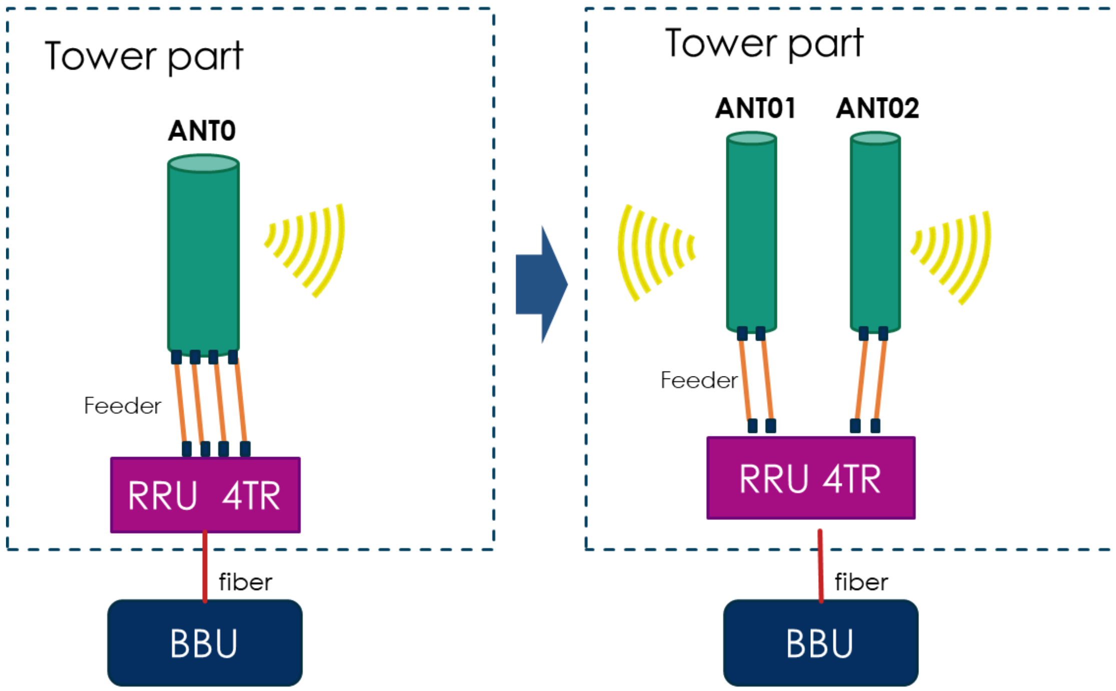

Figure 3-33 The cell split

CICT RRU supports 5G RRU splitting technology. The coverage distance of a single cell would be shortened after soft-splitting. Due to the reduction of the channel numbers, the overall transmitting power is reduced, and the uplink and downlink drop points of cells would be earlier than those of cells without splitting. The downlink coverage shrinks by about 10%, while the uplink coverage shrinks by about 6-8%.

For the overall total coverage cost reduction, the above uplink 3Mbps plan, two RRUs are normally deployed, and the average road coverage distance of a single RRU is 1.75km; split deployment of a single RRU, the road coverage distance of a single RRU is 2.4km. Compared before and after splitting, the coverage distance of a single RRU increased by 37%.

3.3.1.4 The Sea Coverage - Side-by-Side Antenna

Coverage requirements for sea areas seem to be similar to those of rural areas to some extent, yet there are some differences. Since it is difficult to build base stations in the sea, it is important to strengthen the coverage of coastal base stations; the farther, the better. For the NR TDD system with Format0, the maximum cell coverage radius can reach 60 km theoretically by optimizing the PRACH demodulation performance, together with the appropriate number of GP symbols. For the NR FDD system with Format1, the maximum cell coverage radius can reach 100 km.

In addition, users in the sea area are mainly distributed in the offshore areas, while fewer are in the open sea. Therefore, high-capacity demands in the offshore could be fulfilled by massive MIMO products in the mid-bands, and low bands could be deployed in the far away area. For a 4T4R base station, based on the PMI (precoding matrix indicator) beamforming algorithm, two 4-

path antennas could be used together to make the arrays beamforming to a narrower beam, increasing the antenna gain by 3dB. The solution could expand the coverage distance by 20%, and the increase in the hardware cost is less than 3, 000 RMB.

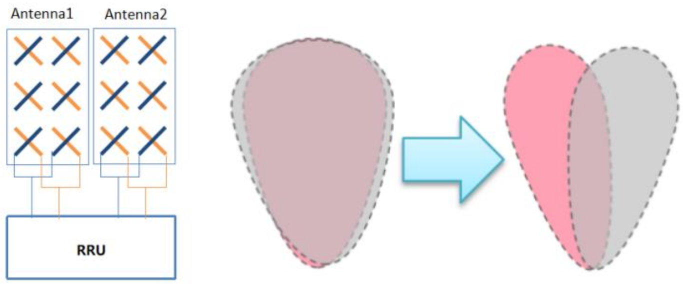

Figure 3-34 The beam becomes narrow after the beamforming and 2 SSB works simultaneously

4 Operation And Maintenance Optimization

4.1 Autonomous Networks

4.1.1 Intelligent Optimization

4.1.1.1 MDT

The technology of Minimization of Drive Tests (MDT) obtains the relevant parameters needed by network optimization through the way that the mobile terminal reports the measurement report or collects the measurement results from the base station side, in order to reduce the cost of network optimization and maintenance.

Similar to the MR (measurement report) data collection, MDT technology is mainly used to collect measurement data from terminals and wireless networks. Its uniqueness is to support the GNSS precise location information collection, the interior MDT scene of Bluetooth and WLAN location information measurement and acquisition, and azimuth, barometer sensor data collection. MDT also supports the association of the original data and other measurements, idle state terminal measurement report collection, and abnormal event measurement data collection. Therefore, compared with MR data collection, MDT is more applicable to a wide range of scenarios, including urban, rural, road, residential, industrial, high-speed rail, coastal, mountainous and other scenarios.

In addition, compared with the traditional road test, MDT has advantages including energy conservation and emissions reduction, reduce road test cost, shorten optimization cycle, etc. It can bring about higher customer satisfaction and acquire more comprehensive and more real network information.

4.1.1.2 Base Station Self-starting/PCI Conflict /Confusion Optimization/ANR

Base station self-starting: The base station self-starting technology enables the base station to automatically enter the normal working state, realizing "plug and play" and saving the cost of manual configuration. This process completes the functions of the BTS self-check, automatically obtaining IP addresses, establishing channels with OMC, automatically downloading updated software versions and configuration files, and automatically establishing cells. This technology can reduce manual intervention and reduce the cost of network construction and maintenance. At present, the main equipment of the existing network already has this function.

PCI conflict /confusion optimization: There are 1008 PCI in the 5G network. Generally, when the planning is reasonable, it can ensure that cells in a region use different PCI. However, if the PCI is incorrectly configured by OMC so that the terminal receives two or more cells that use the same PCI, PCI conflicts and confusion will occur. Aiming at these problems, the function of PCI conflict

/confusion optimization is applied. This function can automatically find PCI conflict/confusion problems in the 5G network without human participation, optimize and adjust the PCI configuration, eliminate network PCI conflict/confusion, and reduce call drop rate and interference. This function is recommended to be enabled on the whole network and work in the controlled mode.

Figure 4-1 shows a test area. After the PCI conflict and confusion optimization function is enabled, the OMC automatically reports 30 pieces of PCI conflict and confusion information. It is recommended to modify 2 pieces of PCI information. After the modification, the network management alarm is recovered, and the wireless connection rate, the wireless drop rate, and the handover success rate of the network are improved.

Figure 4-1 A test area for PCI conflict /confusion optimization function

Table 4-1 Network performance comparison

Time	NR wireless connection rate	NR wireless drop rate	NR-NR handover success rate	PCI conflict /confusion optimization function
9:00:00	99.54%	1.12%	99.31%	OFF
12:00:00	99.58%	0.54%	99.78%	ON

ANR - Automatic Neighbor Cell Relationship: The network can automatically add, delete or update its neighbor relationships and maintain the NCRT according to the UE's measurement report automatically. ANR function can reduce the operator from the burden of manually managing NCRTs. It is recommended to apply relevant functions and working modes according to the specific requirements of the current network.

Figure 4-2 shows the test area of ANR, including 19 base stations. Table 4-2 shows the number of logs reported by OMC. It can be seen that the adjacent cells and their relationships are automatically modified, which greatly reduces the amount of manual configuration.

Table 4-3 shows the performance comparison before and after the ANR function is enabled. It can be seen that the wireless connection rate, the wireless drop rate, and the handover success rate of the network are improved.

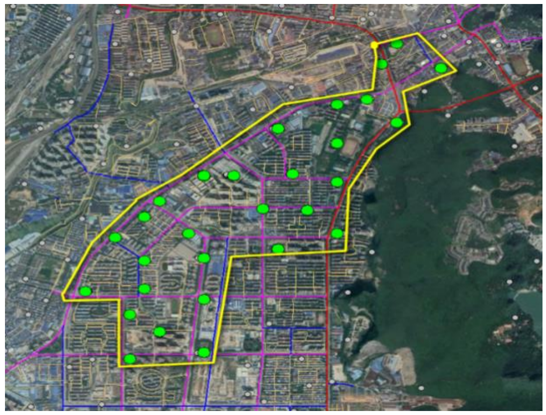

Figure 4-2 A test area for ANR function

Table 4-2 The number of Logs of ANR

ANR Function	Logs
Add NR Neighbor cell Relationship	2312
Modify NR Neighbor cell Relationship	689
Add LTE Neighbor cell Relationship	333
Update NR Neighbor cell Relationship	2518

Table 4-3 Network performance comparison for ANR

Time	NR wireless connection rate	NR wireless drop rate	NR-NR handover success rate	NR-LTEhandover success rate	ANR function
2021/9/27	99.54%	0.60%	97.62%	98.92%	OFF
2021/9/29	99.58%	0.37%	98.53%	98.96%	ON

4.1.1.3 MRO/BS Self-healing

MRO-Mobility Robustness Optimization: In the mobile network, improper setting of handoff parameters will affect the system performance and user experience, even cause users to drop calls. The MRO function can detect abnormal handoff scenarios and optimize mobility parameters to reduce abnormal handoffs to improve the handoff success rate and network performance.

BS self-healing: In the network operation stage, the premise that the base station and other network elements can maintain normal services is that the hardware and software units of the equipment can work normally and the cell can provide normal services. The self-healing function requires the NE to monitor hardware, software, and cell performance in real-time. When hardware, software, or cell faults occur, the device can find and resolve the faults by itself or assist O&M personnel to locate the faults through alarms, thus reducing the workload of operators and greatly reducing the difficulty and cost of network maintenance.

4.1.1.4 ASC (Automated Site Creation)

Rolling out a radio site typically involves many steps and a lot of interactions, ASC (automated site creation) aims to minimize the wasted effort and site visits to increase the speed of network rollout.

The operational procedures of ASC are shown as below.

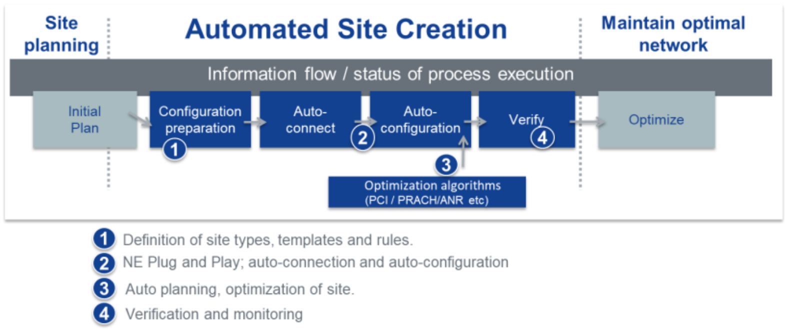

Figure 4-3 The diagram of ASC

Radio site need support plug and play function, so that may cooperate with its upper management system to achieve the complete ASC process, normally ASC runs in closed-loop mode. By running ASC, it might take a couple of minutes instead of hours to roll out a site.

4.1.1.5 RACH Optimization

RACH optimization automatically detects PRACH conflicts with neighbor cells and inconsistencies in configuration and re-configures the cells, which supports 3 use cases below.

- Fresh allocation - change all.
  - When it is hard to fix conflicts.
  - When it is unable to find values for new cells.
  - If the RACH success rate is poor for an area.
- Conflict resolution - minimal changes.
  - When new cells are on air and start serving.
  - When minimal changes are preferred.
  - If individual cell has the poor RACH success rate.
- Inconsistency resolution - within one cell.
  - When the cell is having no conflicts but the RACH success rate is poor.

RACH optimization runs either in open-loop or closed-loop, to save manual operational effort and improve network KPIs.

4.1.1.6 MLB (Mobility Load Balancing)

MLB aims to automatically distribute cell load evenly among cells or to transfer part of the traffic from congested cells, utilizing optimizing the intra-RAT and inter-RAT mobility parameters. The process of MLB includes:

- Detection
- Traffic offloading
- Protection to find right target sells and ensure their load level
- Revert

Machine learning algorithms may be adapted to predict network congestion states without affecting end-user experience. As Figure 4-4 shown below, where the x-axis is the real-time while the y-axis means the service quality/overall user experience, reactive MLB is not able to fully prevent congestions leading to dip in network service quality, while in comparison, ML MLB due to its predictive behavior can overcome this situation.

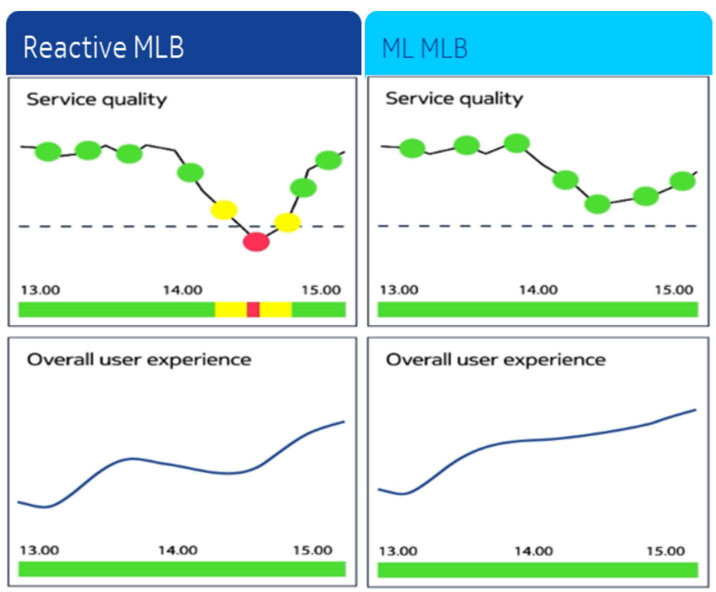

Figure 4-4 The comparison between the reactive MLB and ML MLB

4.1.1.7 NR Network Coverage Optimization

Massive MIMO is an evolution of multiple-antenna technology and is widely regarded as a key 5G network technology. This technology integrates more RF channels and antennas to implement three-dimensional precise beamforming and multi-stream multi-user multiplexing. Massive

MIMO achieves better coverage and larger capacity than conventional technologies. 4G massive MIMO supports more than 200 broadcast beam combinations. 5G massive MIMO is a huge step up, supporting thousands of broadcast beam combinations. The pattern adjustment scope varies based on AAU types. Completely manual configuration and adjustment of broadcast beam combinations cannot achieve the optimal performance of massive MIMO due to its complexity. If massive MIMO modules are deployed on a large scale, the adjustment workload is heavy, and it is difficult to complete the adjustment manually.

According to the results of tests carried out by multiple operators on the live network, massive MIMO intelligent optimization can improve the RSRP and UE throughput and maximize operators' ROI.

Solution Description:

When massive MIMO intelligent optimization is enabled, the RAN Manager:

- obtains coverage optimization area information and objectives, such as the proportion of weak coverage areas, from the NMS.
- obtains DT data, performance counters, traffic statistics, engineering parameters, configuration parameters, and other basic information, including electronic maps, antenna patterns, frequency bands, and AAU types.

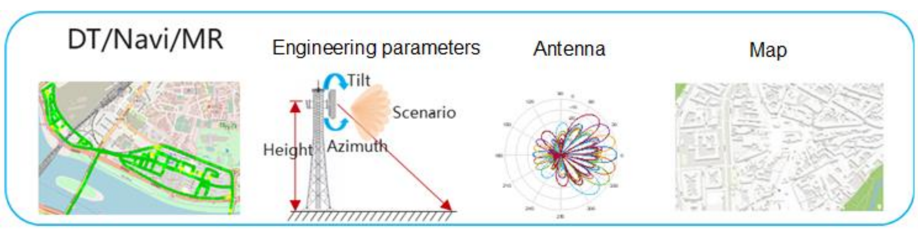

Figure 4-5 Multiple dimensions of data collection

- creates grids for DT/MR data, identifies problematic grids and converges them into problematic areas. Then the RAN Manager selects the best scenario-based beam, azimuth, and downtilt configurations for problematic cells. In this step, antenna hardware must meet the corresponding configuration requirements.

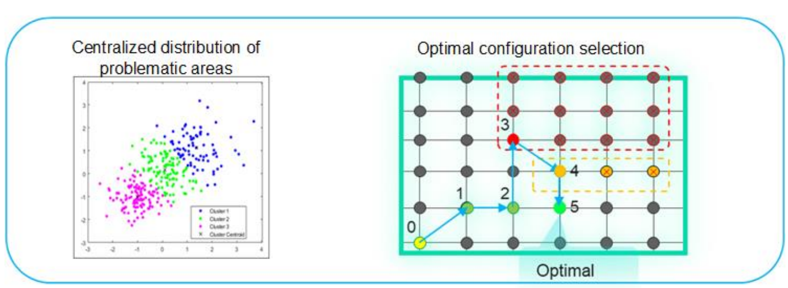

Figure 4-6 Locating the problematic area and finding the optimal configuration

- performs iterative reinforcement AI learning based on the preset optimization objectives to obtain the optimal optimization suggestion.
- automatically delivers the massive MIMO pattern parameter combination, downtilt, and azimuth parameters of problematic cells and their neighboring cells based on the common massive MIMO pattern AI model.
- evaluates and verifies the optimization suggestion based on user experience after issuing the suggestion. If the KPIs do not meet the requirements, the RAN Manager rolls back the optimization suggestion.

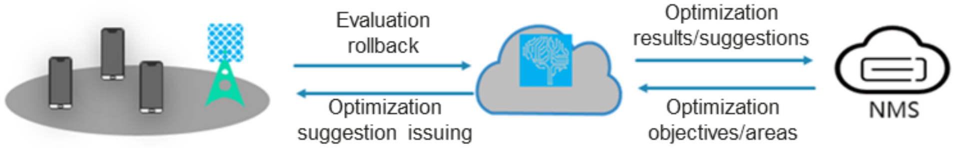

Figure 4-7 Evaluating and verifying the optimization suggestion

In 5G network deployment, the number of 5G UEs is small. An operator in China applies AI technologies and automation to optimize the massive MIMO broadcast beams. The RAN Manager can automatically identify problems found during drive tests, such as weak coverage, poor SINR, overlapping coverage, overshooting coverage, and frequent handovers. Based on experience rules, coverage predictions, and 5G weight parameter optimization, the RAN Manager provides the parameter adjustment suggestion on mechanical tilts, azimuths, and broadcast beam weights. This enables 5G coverage and performance to be quickly improved to ensure a better experience.

This solution increases the average coverage of 5G massive MIMO cells by 15.8% and the road coverage by 91%. In addition, the optimization efficiency is significantly increased compared with conventional optimization methods.

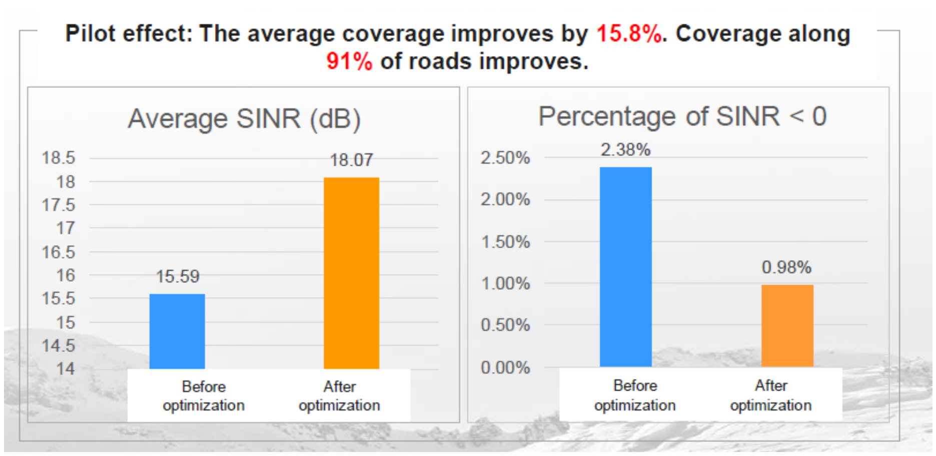

Figure 4-8 Pilot result of the NR network coverage before & after the optimization

4.1.1.8 NR Network UE Throughput Optimization

Wireless network parameter configurations vary by scenario. For example, there are thousands of parameters related to the air interface. Different parameters, such as handover, coverage, and power control parameters, have different impact scopes on performance counters. The combinations of parameters increase exponentially. It is difficult to achieve the optimal combination through only manual commissioning due to the many types of parameter optimizations, wide value ranges, complex scenario factors, and mutual dependencies among parameters. There are millions of parameter combinations.

Figure 4-9 Thousands of parameters related to the air interface

In addition, wireless network scenarios are complex and diversified. Therefore, the parameter settings need to be configured according to each scenario, which requires a large number of experts for analysis and processing and is difficult to achieve optimal efficiency and performance. Conventionally, only expert experience can be used to analyze problems and optimize parameters. However, manual optimization on the entire network is inefficient. In certain cases, the parameter settings used in a cell may bring negative gains in other cells.

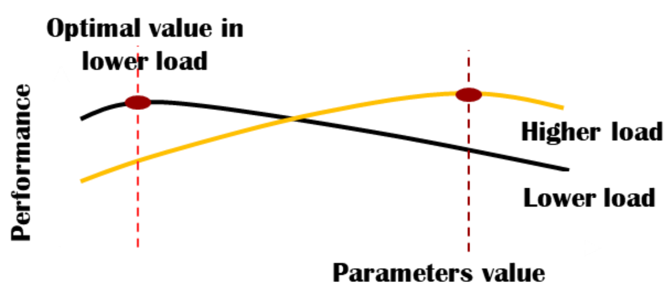

Figure 4-10 Parameter settings varying by scenario

For RAN O&M, multi-parameter optimization is the most basic capability, and all optimization tasks are performed based on parameter adjustments. The objective of the multi-parameter optimization solution is to ensure that all parameters of each cell can be automatically adjusted without affecting network KPIs. The vigorous development of AI technologies makes automatic multi-parameter optimization possible. With automatic multi-parameter optimization, the RAN manager:

- obtains the parameter optimization area information and optimization objective, such as the target network KPI values, from the NMS.
- automatically collects live network data (including MR data) based on optimization requirements and preprocesses the data, including data filtering and association.
- automatically sets scenario-specific parameters: The deep learning AI algorithm is introduced to the RAN Manager to perform joint modeling analysis on KPI data of a large number of cells. In addition, the RAN Manager automatically identifies networking scenarios based on the collected MR data on the live network and configures initial parameters based on the scenarios.

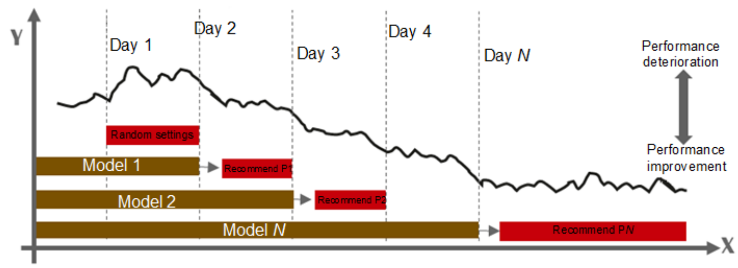

Figure 4-11 Iteratively optimizing the model

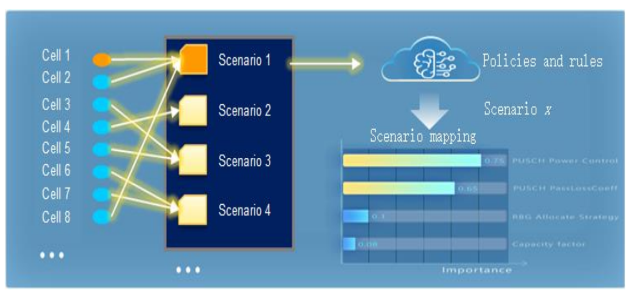

Figure 4-12 Mapping different scenarios with proper parameters

To cope with new network challenges, many operators have been exploring and innovating network intelligence and automation capabilities. In conventional routine optimization, telecom operators need to manually identify network coverage or capacity problems through DTs or network KPI statistics. Based on manual optimization experience, the RAN manager provides suggestions on the parameter adjustment, such as RF and network configurations, and then issues the network optimization policy. After the AI technology and automation capabilities are introduced, modeling is performed based on the multi-dimensional characteristics of cells on the live network, such as coverage, networking, traffic, and radio parameter configurations, and the average UE throughput in a cell. The RAN manager can automatically identify low-rate areas on the network and automatically optimize 13 power parameters that are closely related to the single-user throughput of the cell based on this model while ensuring the overall network performance. In the test area, the average downlink UE throughput of cells (more than 1000) increases by 14.5%.

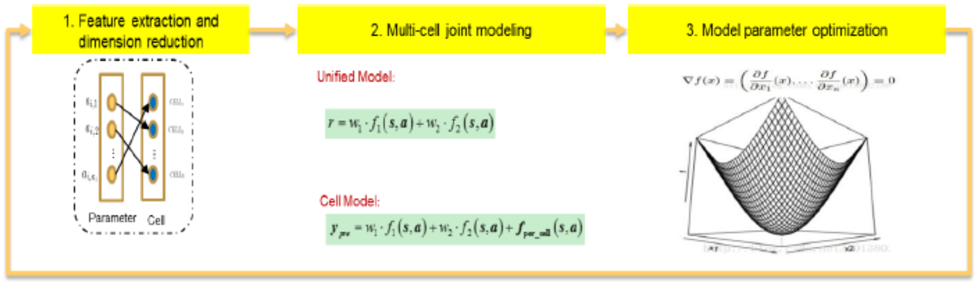

Figure 4-13 Modeling and iterative optimization for multiple cell parameters

In addition, the RAN Manager can automatically identify the cells subjected to load imbalance based on the live network data. The RAN manager also adjusts related parameters and load-balancing policies based on cell configurations and traffic models to achieve optimal balancing between sectors. In the pilot area, the load balance rate of the multi-band and multi-layer network increases by 75%, and the optimization efficiency is increased.

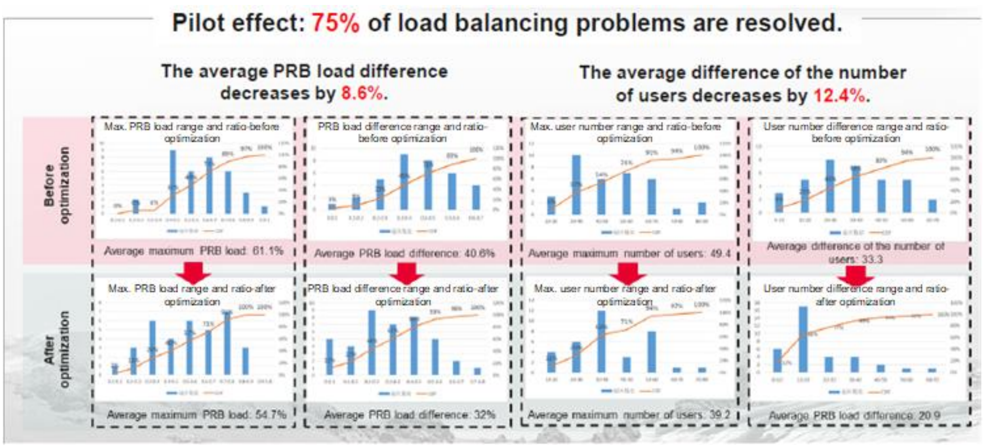

Figure 4-14 Pilot result of load balance with intelligent multiple parameter optimization

4.1.1.9 Automatic Antenna Pattern Control

The massive MIMO antenna has a 5-dimensional weight value, plus a combination of beams, cells, and cell clusters, and needs to consider different service scenarios and types. There are thousands of antenna weight combinations. Traditional optimization methods are inefficient and lack accuracy, and cannot meet real-time service requirements. The industry urgently needs new optimization solutions. ZTE innovatively launches the AAPC (Automatic Antenna Pattern Control) antenna weight self-optimization solution.

AAPC automatically collects and evaluates the real measurement data of the user, which is used to intelligently estimate the optimal antenna weight and evaluate effects automatically and efficiently. In addition, the system can make the fine adjustment within a period promptly and in scenarios such as tidal and sudden changes. The antenna beams should meet scenario requirements and be precise and flexible, effectively improve network coverage and quality, increase service traffic, and improve user experience. It has deployed and applied more than 100000 sites of 65 projects worldwide, improved O&M efficiency, and reduced costs.

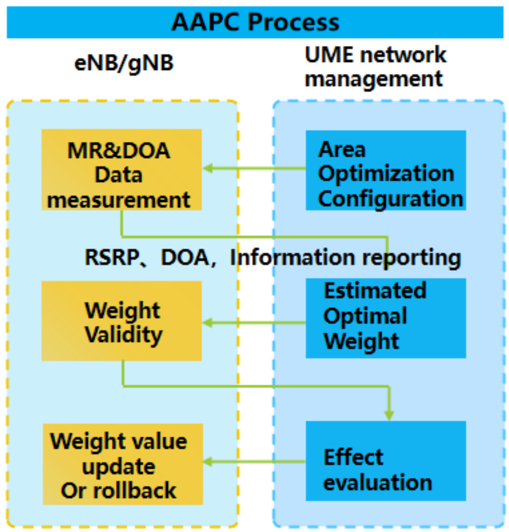

Figure 4-15 Automatic Antenna Pattern Control

4.1.2 Intelligent Maintenance

4.1.2.1 Anomaly Detection Application

Anomaly Detection Application aims at helping operators to work more efficiently by combining the user's perception of KQI (Key Quality Indicators) data and key performance data of the network, designing two different algorithms to satisfy the characteristics of different network performance data for user plane KPI and control plane data and calculating anomaly detection score results to get hot-spot abnormal ranked cells. Traditional operation solutions use the same math or experienced-rule thresholds for all the sites and also for a long time to select abnormal cells, while for the new solution, different anomaly threshold results will be calculated for different operation sites by the algorithms which could fit the fault handling capacity. In the current network operation process, each data dimension has its threshold and an abnormal cell could have more than one abnormal dimension. It is comprehensively evaluated a cell in multiple dimensions, and there are no valid ways to combine multi-dimensions to detect abnormality in the current wireless network. The anomaly detection is designed to solve it by using VAE (Variational Autoencoder) -based algorithms which can raise the precision to 88%. The result is shown in Table 4-4.

Table 4-4 The Precision Rate of the Anomaly Detection Application

Area	Total number of work orders	The correct detection number of work orders	Precision rate

Area1	52	46	88%
Area2	79	67	85%
Area3	66	60	91%
Total	197	173	88%

The solution can output a list of hots-pot abnormal cells. It provides services to users through data visualization and cooperates with intelligent root cause analysis to improve the operation and maintenance efficiency. Figure 4-16 shows the architecture of the anomaly detection application..

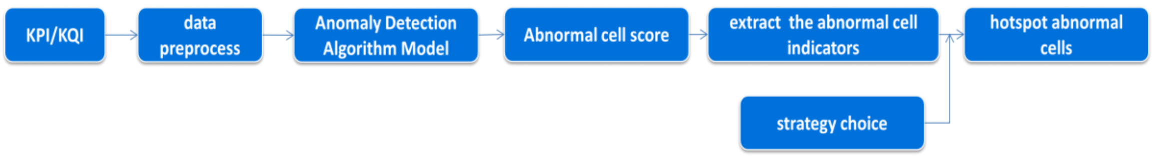

Figure 4-16 The Architecture of the Anomaly Detection Application

It costs 2 persons per year to detect the abnormal fault. With Anomaly Detection Application, it can save human costs and can get the anomaly detection result within 1 min. It is a solution with high integration, high precision, high efficiency, and high compatibility.

4.1.2.2 Root Cause Analysis Application

Root cause analysis application aims to combine AI with expert experience, and solve problems such as fault handling and capacity management in complex scenarios through machine learning methods, help people to make better analyses and decisions, and improve the efficiency of operation and maintenance. There are three-level root causes to solve capacity, interference, and load-balancing solution network orders. Figure 4-17 shows the three-level architect. The first-level root cause: Using the LGBM (LightGBM) algorithm, the rough root cause can be classified combined with the fault label information in the work order.

- The first-level root cause: Using the LGBM algorithm, the rough root cause can be classified combined with the fault label information in the work order.
- The secondary root cause: Combined with the expert experience/the comprehensive alarm/the neighboring cell configuration/the PM performance correlation data, the system delimits the problem of the local cell or the adjacent cell.
- The third-level root cause: Combined with AI algorithms, the root cause classification can be further refined, such as the interference type identification or load balancing for high payload cells.

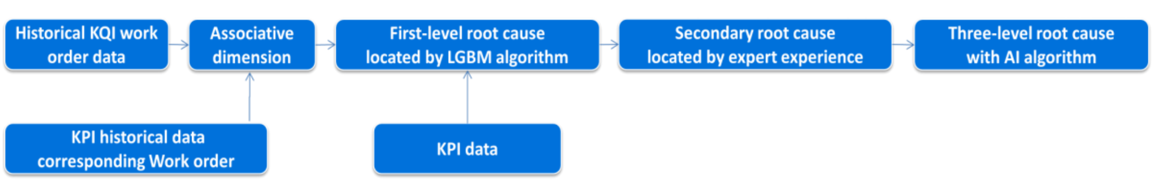

Figure 4-17 The Architecture of the Root Cause Analysis Application

The solution is deployed in 3 areas, for the interference type, the precision is up to 90%, while for the load balancing solution, it is up to 78%. The result is shown in Table 4-5. The operators could use it to find correlations between different KPIs and the root causes. With traditional operation solutions, the average time of one root cause analysis in interference type is 3 days and in load balancing is one week. With Root Cause Analysis Application it can be shortened to 1 minute.

Table 4-5 The Precision Rate of the Root Cause Analysis Application

	The root cause of the interference type			The root cause of the load balancing		
Area	Total number of work orders	The correct root cause number of work orders	Precision rate	Total number of work orders	The correct root cause number of work orders	Precision rate
Area1	241	217	90%	9	7	78%
Area2	1113	1010	91%	30	24	80%
Area3	560	490	88%	50	38	76%
Total	1914	1717	90%	89	69	78%

4.1.3 Intelligent Management

4.1.3.1 Interference Intelligent Analysis Application

In order to detect and identify the interference in the network more efficiently, the "interference intelligent analysis application" is developed to assist routine interference optimization activities.

the "interference intelligent analysis application" provides 2 main functions, Interference type identification and External interference source locating.

Before deploying the tool, it needs to deploy the interference feature library which was off-line trained with historical traffic data. Once the tool is deployed in the network, it would collect and analyze the existing network data automatically and periodically. The analysis result with found interference can be queried and invoked. For external interference, the user may set a new task to analyze and locate the position range of the external interference source.

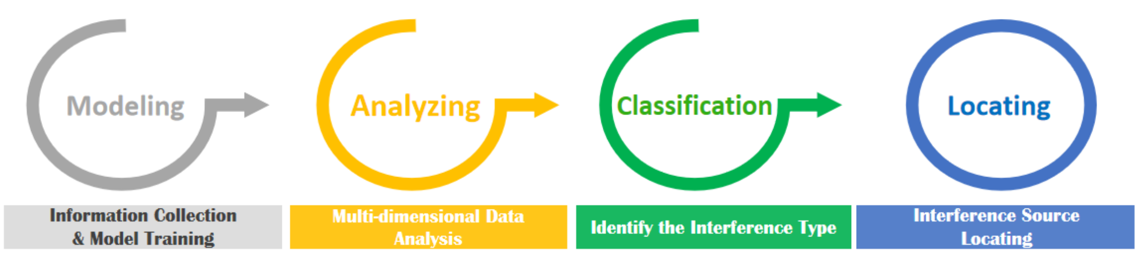

Figure 4-18 The diagram of the "Intelligent Interference Analysis" tool

During the analysis, the tool will collect network data, such as time domain data, frequency domain data, and RB-level NI data, to generate a visual interference diagram. It will compare current data with the interference models embedded in the interference library automatically, and determine the type of the found interference.

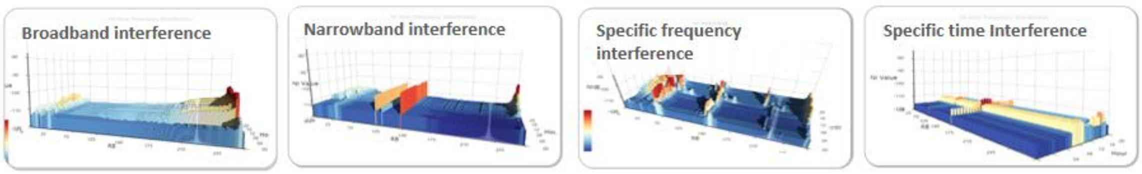

Figure 4-19 The visual interference diagram

Through the data analysis, China Mobile improved the ResNet algorithm. Figure 4-20 shows the Algorithm Process. AI technology of image recognition is applied to intelligent interference identification. The main process is to collect the interference data of the operations and maintenance center system and combine the expert experience of the current network to label and correct the interference type. The image processing and model training are performed on the interference frequency domain information to perform the online identification of interference types for the cells. As shown in Table 4-6, the identification accuracy rate is 94% and the efficiency exceeds 300 cells/second.

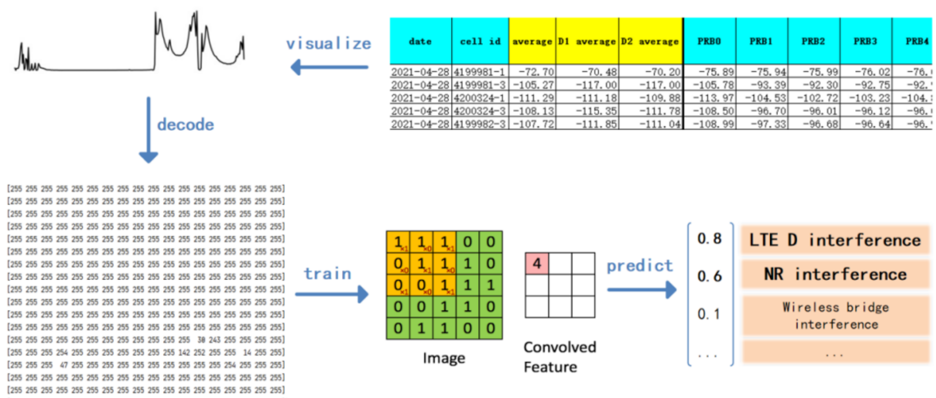

Figure 4-20 The Algorithm Process of the Wireless Interference Intelligent Analysis Application

Table 4-6 The Validation Results of the Interference Intelligent Analysis Application

Interference Type	Accuary	Recall	Precision	F1-score
700M	1.00	1.00	0.99	1.00
LTE D	1.00	1.00	1.00	1.00
NR	0.84	0.72	1.00	0.84
Pseudo base station	1.00	1.00	1.00	1.00
Jammer	0.89	0.82	0.99	0.89
Signal of SARFT	1.00	1.00	1.00	1.00
Wireless fridge	0.89	0.80	1.00	0.89

Clock source failure	1.00	1.00	1.00	1.00
Smart light	0.82	1.00	0.69	0.82
800M	1.00	1.00	1.00	1.00
Router	0.91	1.00	0.84	0.91
Average	0.94	0.94	0.96	0.94

Now, the "interference intelligent analysis application" has been deployed in many cities, and helps operators to improve the efficiency of interference optimization. With the network scale of 1000 sites, the tool can find all interference within 4 hours automatically. With the interference source locating function, the average time of finding an external interference source can be shortened from one week to one day. And the interference locating accuracy can reach less than 80 meters.

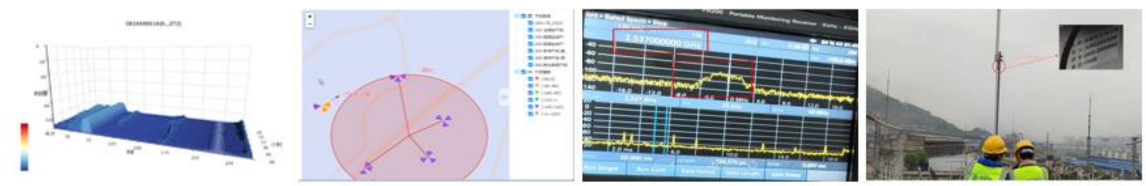

Figure 4-21 The application of "Intelligent Interference Analysis" tool

4.1.3.2 Load Balancing

The proposed load balancing mainly uses machine learning algorithms to find the relationship between division critical point data and the load performance, and train the models with a linear regression model to solve the best load division critical point. According to the set corresponding relationship, the re-selection and switching threshold between various frequency bands are obtained to adjust the parameters of the current network and optimize the network resources by using the best load division critical point to achieve the purpose of load balancing.

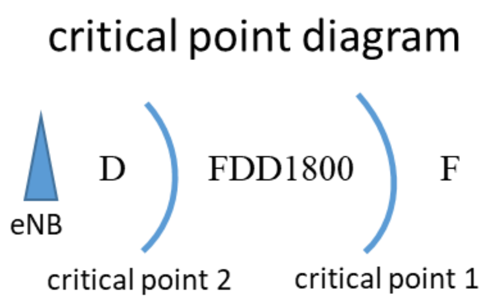

Figure 4-22 The Illustration of the Critical Point Diagram

The traditional load balancing method relies on the experience of the parameter adjustment and optimization method of the 5G wireless network operator. While by using the load balancing algorithm model, the load division critical point can be optimized intelligently and automatically. It can greatly reduce labor costs and enhance the user experience. The critical point diagram is shown in Figure 4-22.

The load balancing algorithm model was launched as a trial in Kunming and Honghe city, Yunnan Province. In Kunming city, the load balance algorithm improved the proportion of load-balanced cells from 35.71% to 85.71%; in Honghe city, the algorithm improved this proportion from 0% to 70%, and the trial results show good performance, which proved the algorithm to be very effective in the load balancing of the 5G wireless network. The growth of the balanced cells is shown in Figure 4-23. With the application, the average time of balancing the capacity can be shortened from one week to one day.

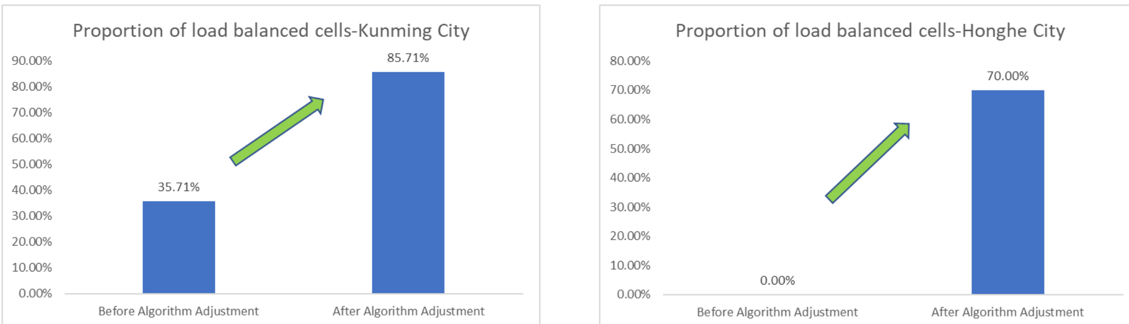

Figure 4-23 The Growth of the Balanced Cells

4.1.3.3 Macro-Micro Collaboration

When microsites are deployed to improve the blind area coverage of macro sites, the mismatch of the X2 interface and blockage of OMC (Operation and Maintenance Center) communication from different manufacturers cause difficulties to live network operation and maintenance. Given these problems, the macro-micro collaborative solution is proposed to deal with the conflict of these two stations' configuration and the coordination and optimization of macro and micro sites networking are carried out. Moreover, the PCI (Physical Cell Identifier) allocation algorithm in the scenario of newly added pico sites is presented in Figure 4-24. Using the interference to macro sites caused by new PCI planning of new picocells in the wireless network will be solved. In terms of the PCI interference optimization algorithm, MDT (Minimization of Drive Tests) data is also added to the process of the algorithm verification. The verification results are shown in Figure 4-25. After several iterations, the rate of interference and conflicts in the area is reduced to zero. In addition, Large-scale trials will be carried out soon to verify the algorithm results. The research on switching neighbor parameters and VONR macro-micro continuous collaborative optimization will also proceed.

The architecture of the macro-micro collaboration solution is shown in Figure 4-26. With the solution, the planning time of microcells could reduce by over 50%. Relying on macro and micro OMC northbound data, the parameter table of site engineering, and other data to achieve macro-micro collaboration and the application in the business middle-platform with the form of flexible microservices.

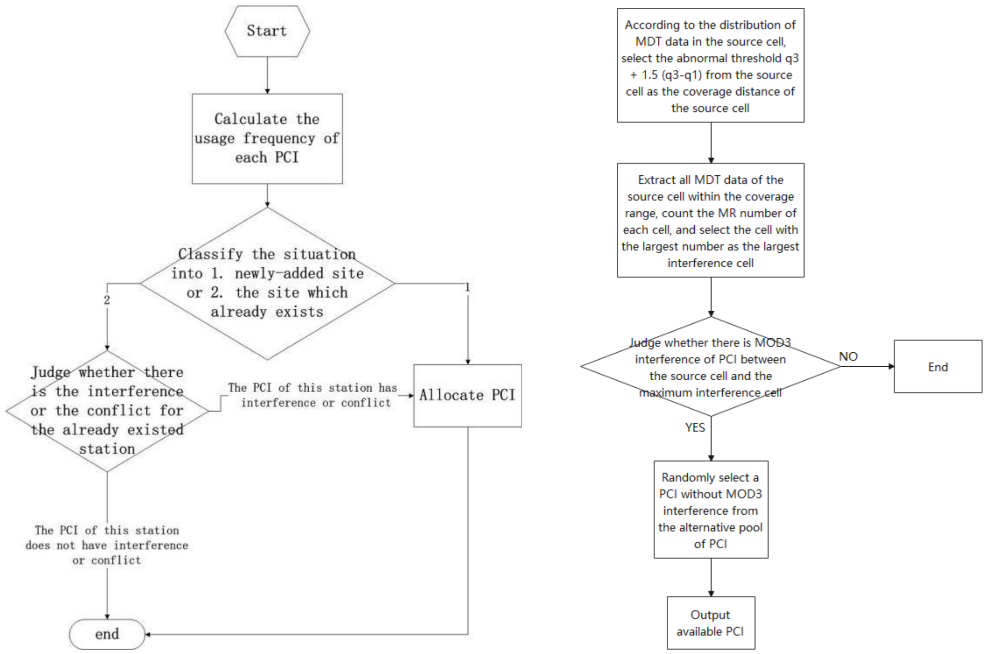

Figure 4-24 The PCI Interference/Conflict Detection Algorithm Based on the Distance and MDT

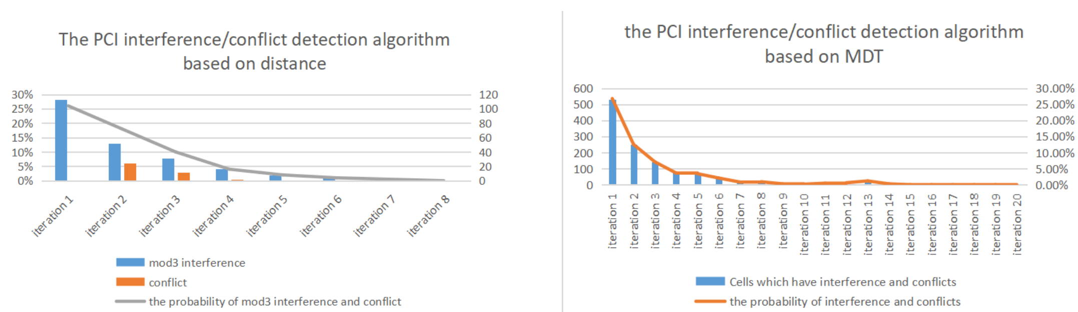

Figure 4-25 The Validation Results of PCI Interference/Conflict Detection Algorithm Based on Distance and MDT

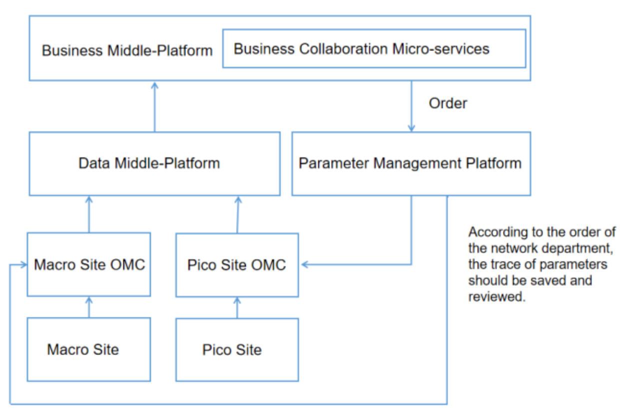

Figure 4-26 The Architecture of the Macro-Micro Collaboration Solution

4.2 Green Network

4.2.1 Radio Energy-Saving Technologies (Attaching the Evaluation of Base Station Energy Consumption and Supported Basic Functions)

As operators' networks consume more and more energy, reducing the energy consumption of main equipment is key to saving energy. Reducing the power consumption of the main equipment of wireless sites has become the top priority for everyone. For a typical carrier, the power consumption of wireless sites accounts for about 45%, and that of wireless base stations as main equipment accounts for 50%. In the power consumption of a wireless base station, the power consumption of radio remote units (RRUs) accounts for a large proportion, and that of the power amplifiers in the RRUs also accounts for a large proportion. In actual networks, traffic has a clear tidal effect in most cases. When the traffic is light, the base station continues to run, which leads to a lot of energy wasted.

Reducing unnecessary power consumption is a key measure to saving energy but is faced with many challenges. The volume of network traffic varies greatly during peak and off-peak hours. Regardless of the traffic volume, the equipment continues to run, and the power consumption is not dynamically adjusted based on the traffic volume. As a result, resources are wasted. The capability of "zero bits, zero watts" needs to be constructed. However, in a typical network, the features of different scenarios vary greatly. Therefore, how to automatically identify different scenarios and formulate appropriate energy-saving policies has become the key to saving energy. The following are examples of scenarios and their characteristics.

- Business district: high requirements on user experience, clear tidal effect, and light traffic at night.
- Residential area: high requirements on capacity, heavy traffic the whole day, and no apparent traffic fluctuation.
- Suburban area: low requirements on capacity, light traffic, sparse sites, and long site coverage distance.

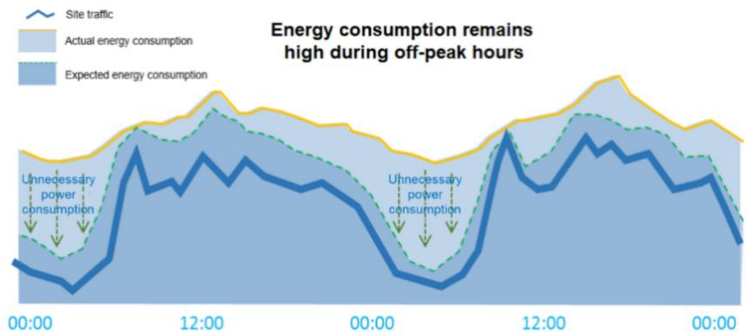

Figure 4-27 Challenges facing conventional energy saving

The AI-based intelligent energy-saving technology collects historical and spatial feature data of each cell on the network to analyze the change rule of radio resource utilization and automatically identifies the coverage characteristics of cells and fully considers the network coverage, distribution of UEs, and scenario characteristics based on the prediction and evaluation results of coverage scenarios and traffic variables. In this way, the energy-saving policy is adaptive or selected based on the operator's policy.

Figure 4-28 shows the online energy-saving solution for Radio networks based on the layer- and domain-based principles.

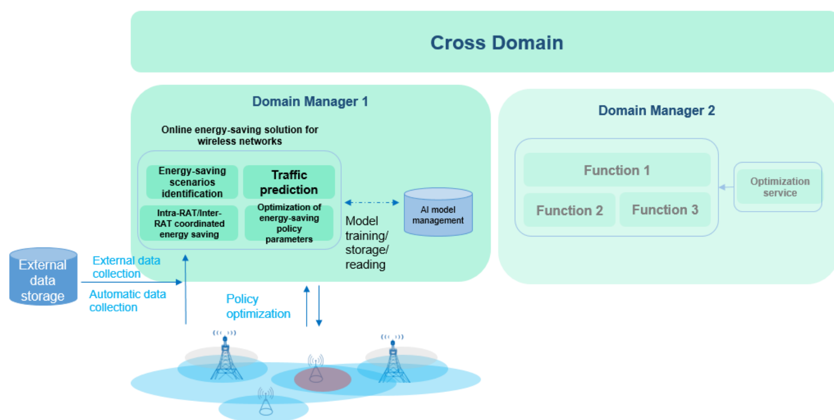

Figure 4-28 Architecture of the online energy-saving solution for wireless networks

The overall solution is as follows:

- The system obtains data on the live network, including engineering parameters, MRs, and weather data.
- Based on big data analysis, the system uses AI technologies to automatically identify network energy-saving scenarios, predict trends in network traffic, such as busy or idle hours and areas and traffic/energy consumption trends, identify multi-cell co-coverage, and automatically generate energy-saving policies.

- The system automatically delivers energy-saving policies and implements network-level AI-based intelligent energy-saving policy management and coordinated management and control of site energy-saving scheduling.
  - The network-level AI-based energy-saving algorithm is used to implement automatic precise energy-saving feature enabling and energy-saving parameter optimization with lossless performance based on different network scenarios/models, base station configurations, and networking modes (multi-frequency networking and 2G/3G/4G/5G multi-RAT networking). In addition, the solution implements the "one site, one policy" and multi-site collaboration to quickly and efficiently start network-wide energy saving.
  - Precise energy-saving scheduling control (such as carrier shutdown and power adjustment) is implemented for sites under the control of network AI. Main RAN energy-saving measurements include the following.

4.2.1.1 Symbol-Level Silence

The basic principle is that when the gNB detects that some downlink symbols have no data to send, it powers off the RF hardware during the current cycle. The symbol-level silence can reduce the energy consumption of base stations by 10~15% and has no effect on the user's latency.

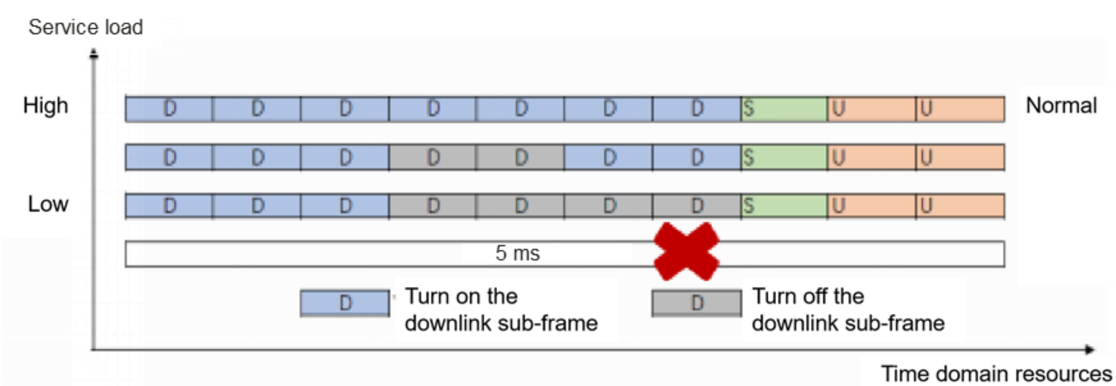

Figure 4-29 Symbol-level silence

4.2.1.2 Channel Silence

The technical principle is that the multi-channel base station (64/32 channels) reduces the power consumption of the base station by closing part of the radio frequency channel of the base station when the load is low, which can reduce base station energy consumption by 20%.

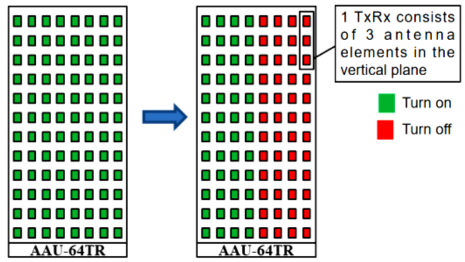

Figure 4-30 Channel silence

4.2.1.3 Machine-Level Silence

There are currently two ways to implement machine-level silence: shallow dormancy and deep dormancy. In shallow dormancy, the base station turns off analog devices such as AAU power amplifiers. In deep dormancy, the base station turns off the power amplifier, radio frequency, and digital channels, and lets only the most basic digital interface circuit run. Shallow dormancy can reduce the base station energy consumption by 34% while deep dormancy can save energy by 55%.

- Carrier shutdown: Operators' networks are evolving to support multiple bands and RATs. Some band resources and RF modules in the capacity layer are disabled when the traffic load is low, and only the band resources of the coverage layer are retained to carry traffic, reducing network energy consumption.
- Deep dormancy: AAU deep dormancy can be used when there is no 5G traffic at night to further reduce energy consumption. Deep dormancy refers to disabling the power amplifier, RF module, and digital channels of the 5G AAU, so only the most basic digital interface circuit is running, decreasing energy consumption. Compared with symbol-level silence, channel silence, and carrier shutdown, deep dormancy saves the most energy.
- Real-time monitoring of impacts on network KPIs and energy-saving benefits is implemented to achieve manual visualization and management of energy-saving benefits on mobile networks.

In typical network configurations, the power consumption of base stations can be reduced by 10%~15%, and the emission of about 2 million kg of carbon dioxide can be avoided for every 1000 base stations each year.

4.2.1.4 BBU Dormancy

In the case of the medium / low load, the power consumption of the BBU can be reduced by turning off the clock or reducing the frequencies of the devices in the baseband board. When the energy-saving start time is up, and all AAUs/RRUs connected to a baseband board in the BBU are in the sleep state, the baseband board can be put into dormancy at the same time, which further reduces the energy consumption of the BBU. When the baseband board is in a shallow sleep state, the processor processing various channel data of the cell can be turned off; When the baseband board is in a deep sleep state, to achieve the best energy-saving effect, the baseband board can also be directly powered down. When the energy-saving stop time is high or the load of the same covered cell is high, the BBU can also be triggered to wake up from the energy-saving state, then wake up the AAU/RRU, and restore the base station to normal operation. The power saving ratio can reach 10%~70% according to the degree of the shutdown.

4.2.1.5 Liquid Cooling

Reducing the energy consumption of the air conditioner in the communication room is the key work of the existing network energy conservation. With the increasing concentration of BBU, the cooling way of the communication room sites should change. It is considered to introduce liquid cooling technology in the communication computer room. There exist four types of liquid cooling technologies suitable for communication rooms.

- Cabinet-type liquid cooling: the BBU equipment is placed in the liquid cooling cabinet, and the back of the cabinet is equipped with liquid cooling pipes. The CDU and water pump are used to circulate the liquid cooling pipes continuously so that the heat generated by the BBU equipment is absorbed into the liquid in the liquid cooling pipes, and the heat in the liquid cooling pipes is discharged into the atmosphere by the external radiator, which circulates in turn to achieve the effect of heat dissipation. According to the test results in communication rooms, the PUE can reduce by 0.3 in the room with 5 BBU concentrations or 10 BBU concentrations.

- Cold plate liquid cooling: fix the liquid cooling pipeline (one-to-one specific design for different boards, and the liquid cooling pipeline is mainly arranged on the high-power heating device) to the BBU board card, and use the coolant to flow evenly and circularly through the liquid cooling plates of each BBU equipment to export the heat generated by the heating device through the liquid cooling pipe; The heat generated by the equipment is dissipated by the external heat sink to realize the indoor and outdoor cold and heat exchange.

- Immersion liquid cooling: immerse the BBU equipment directly in the coolant, so that the heating electronic components, such as CPU, motherboard, memory module, hard disk, etc., can contact the insulating and chemically inert coolant (electronic fluoride) directly, and the heat generated by the electronic components can be taken away through the circulating coolant.

- Spray liquid cooling: place the BBU equipment in a specific spray cabinet, store liquid and open holes on the top of each layer, and spray specific coolant directly into the equipment to achieve the purpose of equipment cooling.

4.2.1.6 Energy-Saving Platform

The energy-saving platform provides one-stop closed-loop solutions for data collection, analysis, training, generation and distribution of energy-saving strategies, and emergency support. It breaks through the traditional energy-saving mode, aiming at the current network status where multiple networks overlap and the tidal effect of business is obvious and realizes the overall network energy saving across network standards, manufacturers, equipment, and time periods. Based on a series of AI technologies such as perception, clustering, prediction, and decision-making, it generates dynamic energy-saving strategies covering all 5G scenarios, enabling optimal decision-making for various energy-saving technologies. At the same time, the whole 5G energy-saving process monitoring and intervention is implemented, and the energy-saving cells sleep or are woken up in real-time, according to business changes, to maximize energy saving while achieving "no decrease in perception, no increase in complaints, and no deterioration in performance".

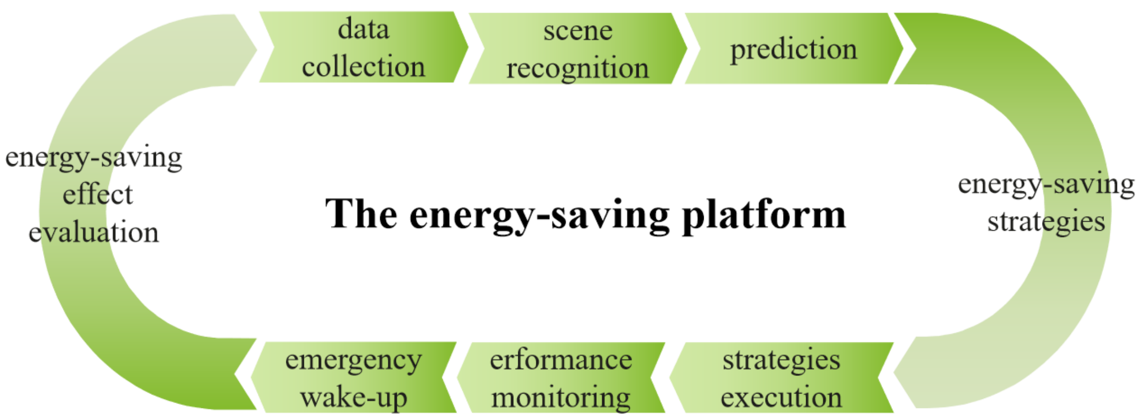

Figure 4-31 The Energy-Saving Platform

4.2.1.7 Tidal Power Amplifier Technology

Current energy-saving technologies for radio include Micro Sleep TX, MIMO Sleep and Deep Sleep, etc. Operators can achieve energy-saving by partially or overall shutdown radio when there is no traffic. With the increasing and dynamical variations of 5G traffic load in a live network, a more flexible option is provided to save energy during normal working time (non-shut-off cycle), which is called Tidal Power Amplifier Technology. Tidal Power Amplifier Technology supports tracking and predicting traffic load by machine learning. The integrated algorithm in the digital IF chip automatically adjusts the voltage of the power amplifier according to the different traffic loads. The power amplifier is always working at the best efficiency point which maximizes the energy efficiency of the radio without performance loss. Laboratory data show that Tidal Power Amplifier Technology can reduce about 15% power consumption of 5G radio during typical traffic load.

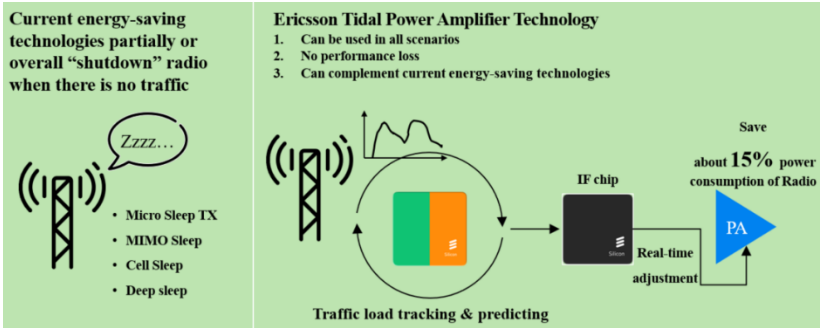

Figure 4-32 Tidal Power Amplifier Technology

Furthermore, Tidal Power Amplifier Technology can be used in all scenarios and complement current energy-saving technologies to save more energy. As the 5G network is evolving toward a green and low-carbon direction, Tidal Power Amplifier Technology together with current energy-saving technologies can help operators save electricity costs to enhance the commercial value of the network and fulfill their social responsibility while moving towards a sustainable future.

4.2.2 Green Network Architecture

4.2.2.1 CRAN Centralization

To realize the flattening and centralization of communication room sites, traditional DRAN sites are gradually evolving into CRAN sites. Based on the CRAN architecture, through carrier frequency optimization, equipment integration, supporting transformation and other measures, the centralization of base station equipment and the lightening of supporting equipment can be achieved, reducing energy consumption, improving maintenance efficiency, and saving operating costs.

Taking China Mobile as an example. The C-RAN transformation has achieved an energy saving of more than 30%.

4.2.2.2 Coordinated Development of 4G and 5G

By analyzing the network load, service requirements, and network quality, based on the cell- and carrier-level mechanisms, on-demand joint scheduling and coordinated sleep mechanism, coordinated development of 5G and 4G networks can be realized, and the network-level energy consumption can be reduced.

For the cell level, when the load is low, the 4G and 5G users of the mixed-mode site are migrated to the neighboring cell, and the original cell goes to sleep.

For the carrier wave level, in the dual-carrier scenario, the UE switches to the energy-saving state after a single carrier wave meets the sleep activation threshold.

Accelerating the migration of users and services from 2G, 3G, and 4G to 5G facilitates the utilization of the high energy efficiency of high RATs while promoting the refarming of legacy bands.

User migration can be accelerated in the following ways.

- Raising the access rate: Develop potential users based on user profiles to promote user device upgrades and urge users to enable the 5G function by precisely identifying those who have not enabled the 5G function.
- Increasing the camping ratio: 1. Promote default SA enablement on terminals and all base stations to support SA. 2. Optimize networks, including the interoperation parameters, license configuration, and network-assisted terminal energy-saving parameter configuration. 3. Enhance the coverage, by, for example, increasing the transmit power of weak-coverage areas. 4. Precisely build networks to facilitate wider and deeper coverage while raising the population coverage rate.
- Developing services: Promote the 5G terminal-package matching through precise marketing.

4.2.2.3 Simplified Green Site Solution

The wireless station is evolving towards simplified and green, including simplified deployment, simplified equipment room, simplified tower space, green temperature control, and clean energy supply.

The transformation of construction mode is from distributed to centralized, from geometric superposition to logical integration, from pure gird supply to the introduction of clean energy. The key to site energy saving is to reduce the demand for site equipment rooms and to reduce supporting resources and AC equipment, which is expected to reduce carbon emissions by 25~30%.

The simplified site, from a traditional equipment room to an all-in-one cabinet site, to all devices installed on the tower, and to an all-solar powered pole site, brings lower footprint and higher energy efficiency, which can effectively save rent cost and power consumption, and builds extremely compact and low-carbon networks.

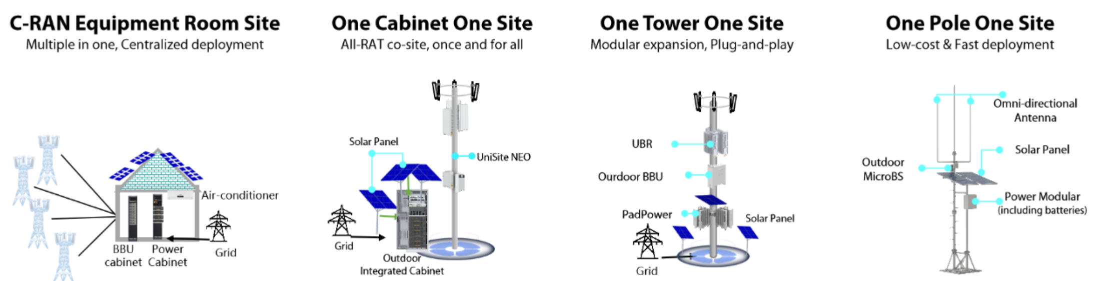

Figure 4-33 The transformation of construction mode

5 Summary

Aiming at sharing the deployment experience key strategies of the low-cost and energy-saving 5G network, GTI Low-Cost 5G Network White Paper conducted to the deployment solutions and products of reducing the costs of construction, maintenance, and network optimization. With global 5G commercialization accelerating and the trend of deep 5G network coverage, new technology solutions should be developed to realize low-cost and deep coverage, hence industrial cooperation on research and development is called for. By keeping innovation to unleash the network potential and supporting the green strategy, the network performance will be boosted, and a smart 5G network with high efficiency can be inspired.