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ZTE TECHNOLOGIES

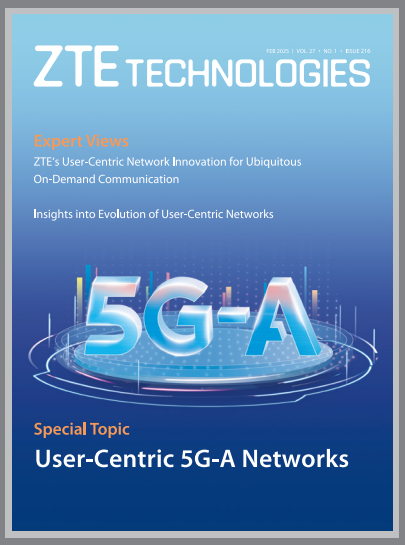
Expert Views

ZTE's User-Centric Network Innovation for Ubiquitous On-Demand Communication

Insights into Evolution of User-Centric Networks

Special Topic

User-Centric 5G-A Networks



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ZTE's User-Centric Network Innovation for Ubiquitous On-Demand Communication

As 5G-A becomes a key driver of the mobile industry's development and the demand for ubiquitous personalized services grows, ZTE has carried out all-dimensional network innovations across the time, frequency, spatial, and power domains, introducing user-centric solutions such as wireless intelligent orchestration, Cluster DXS, and D^3-ELAA.

Tang Xue

Vice President of ZTE

Gu Jun

Chief Engineer of RAN Product Planning, ZTE

5G-Advanced (5G-A) began commercial use in 2024 and has since been widely applied across various fields. 5G-A helps popularize XR applications in the consumer (ToC) domain, enabling people to obtain immersive experiences through wearable devices. By supporting network capabilities in the production domain, 5G-A continues to empower digital and intelligent industries in the business (ToB) domain. With 5G-A, the capability bases for ToX domain (new economy) are being expanded, including omni-domain sensing, computing, and control, as well as the integration of space, air, and ground, facilitating the development of the new economy. 5G-A has become a key technology for promoting the development of the mobile industry with its six scenarios and technical capabilities, including seamless 10-gigabit connectivity, ubiquitous intelligence, deterministic capabilities, space-air-ground integration, support for up to 100 billion connections, and omni-domain sensing. It not only improves network performance but also expands application scenarios, leading to higher-quality experiences and services.

In today's era of rapid digitalization and intelligence, the mobile industry is undergoing a major transformation from traffic-based operations to

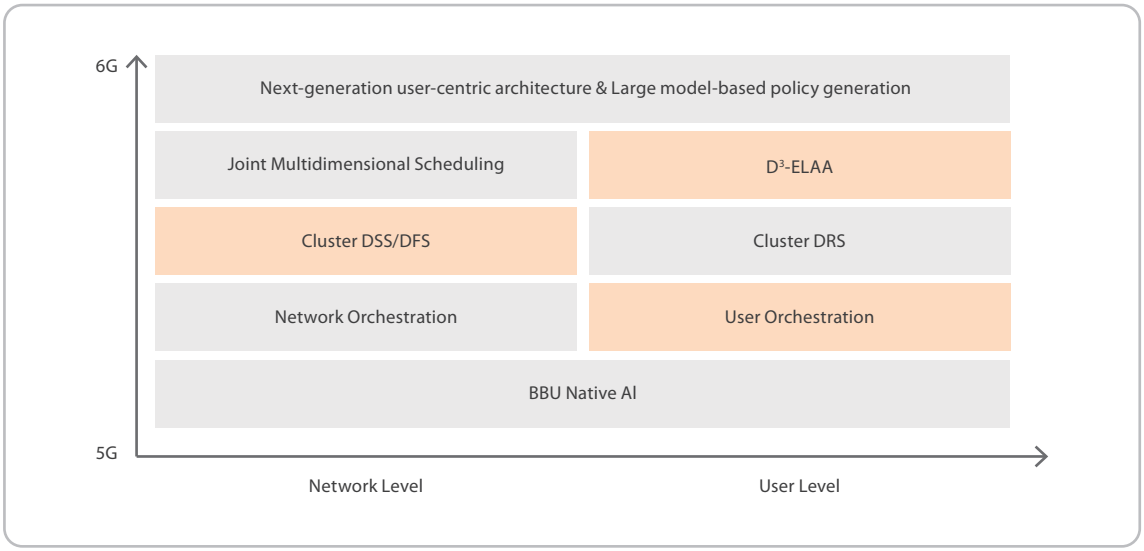

Fig. 1 User-centric solutions of ZTE.

experience- and service-oriented operations. As smartphones have become widespread and mobile applications have grown exponentially, users' demands for networks are no longer restricted to the provision of data traffic, but are more focused on network experiences and personalized services. Meanwhile, the development trend of ubiquitous intelligence has led to the wide connectivity of various intelligent devices, increasing demands for coverage, stability, and response speed. In response to these changes, traditional network models face growing challenges, giving rise to user-centric networks. User-centric network technology aims to provide more efficient, intelligent, and personalized network services centered on users.

Since 2019, ZTE, in collaboration with industrial partners, has carried out all-dimensional network innovations across the time, frequency, spatial, and power domains. The company has developed and introduced a series of user-centric innovative solutions, including wireless intelligent orchestration, Cluster DXS (including Cluster DSS, Cluster DFS, Cluster DRS), D^3-ELAA, power pooling, and a network-following-the-vehicle solution for high-speed rail scenarios, thereby enhancing network performance, expanding application scenarios, and upgrading operational modes. Regarding 6G, ZTE continues to innovate in areas such as pooled network architecture, distributed codebooks, cross-site high-precision synchronization, intelligent collaborative shaping, network-service collaborative perception and prediction, and integrated resource allocation based on large models, aiming to create an experience where users can get what they need anytime, anywhere, while addressing the future development requirements of immersive services, as well as ubiquitous intelligent agents and robots. The user-centric solutions of ZTE are shown in Fig. 1.

Radio Composer

Radio Composer is an intelligent orchestration solution based on the native intelligent architecture of the new-generation base station. Through the joint perception, which integrates terminal features, network features, service features, and cross-domain features, as well as scenario-based intelligent calculation and decision-making, precise resource allocation centered on users is accomplished. User orchestration enables intelligent guidance and intelligent scheduling of users in multi-layer networks, while network orchestration manages the network itself, enabling intelligent allocation of network resources such as multi-standard shared spectrum, TDD frame structure, and Massive MIMO beams.

This solution has been widely commercially verified by China's three major operators, fully demonstrating its dual benefits for both user experience and network

efficiency by enhancing edge rates, reducing latency, and improving spectrum efficiency. For example, in user orchestration, when a user accesses high-definition video services, the system guides the user to a network frequency layer with larger bandwidth and a more stable connection based on their higher requirements for bandwidth and stability. Thus, users can enjoy a smooth video playback experience, and network resources are fully utilized, avoiding waste. Actual test data from commercial verifications in Liaoning, Yunnan, Sichuan, Guangdong and other locations indicates that user orchestration has increased edge rates by over 300% and reduced latency by over 50%.

Cluster DXS

The Cluster DXS series of solutions, built upon the intelligent orchestration foundation, include Cluster DSS, Cluster DFS, and Cluster DRS.

- **Cluster dynamic spectrum sharing (Cluster DSS):** It alleviates the interference problem between 4G and 5G in traditional DSS through dynamic cluster-based spectrum sharing, achieving improvements in both user experience and spectrum efficiency.
- **Cluster dynamic frame sharing (Cluster DFS):** It meets the differentiated needs of uplink and downlink services in different scenarios through cluster-level frame sharing, realizing multiple functions with a single network and supporting the integrated development of ToB and ToC services.
- **Cluster dynamic radio sharing (Cluster DRS):** It enables dynamic multi-cell collaboration based on user experience requirements, transforming network resource strategies from being cell-centered to user-centered. This innovation safeguards the development of new business forms such as the low-altitude economy. In low-altitude communication scenarios, 5G-A base stations dynamically generate base station clusters centered on unmanned aerial vehicles (UAVs), adapting to flight trajectories and service characteristics of UAVs. Within these clusters, multiple cells conduct airspace collaborative transmission and reception, while inter-cluster interference is reduced through means such as collaborative scheduling and power control, ensuring stable real-time high-definition video transmission from UAVs. Cluster DRS not only solves the bottleneck for low-altitude UAV communication but also lays the foundation for enhancing the user-centric capabilities in 5G-A networks. In the future, Cluster DRS will be commercially applied in more fields, driving digital, intelligent, and green development. For example, in smart city construction, Cluster DRS can provide low-altitude coverage for urban transportation, environmental monitoring and public safety, realizing more intelligent urban management.

D^3-ELAA

The dynamic, distributed and deterministic-extremely large antenna array (D^3-ELAA) scheme is user-centered, aiming to achieve zero fluctuation in users' mobile experiences while supporting the long-term evolution of future wireless technologies.

Its key technologies include quickly identifying multiple base stations around users to form a "user-centered" base station cluster. Within this cluster, multiple cells conduct precise joint collaboration and form a dynamic, extremely large antenna array through technologies such as precise base station synchronization and distributed beamforming. This scheme offers several advantages.

- The dynamic networking of distributed base stations forms an extremely large antenna array, enabling a larger-scale antenna array based on the existing 5G commercial equipment. This breaks the capacity limitations of individual devices and achieves an optimal balance between capacity and cost.
- It overcomes the cellular boundaries of traditional mobile networks, providing users with a stable "full signal everywhere" experience and ensuring, continuous network connections while they are on the move. For example, during the user's movement, regardless of location, a good network connection is always maintained, enabling a seamless real-time HD video experience.

- It also offers stable network support for new applications and scenarios such as the Internet of Vehicles and immersive services. In the Internet of Vehicles scenario, vehicles need to communicate in real-time with surrounding traffic facilities and other vehicles to ensure safe and efficient driving. The D^3-ELAA scheme provides vehicles with low-latency, high-reliability network connections to meet these requirements. In immersive service scenarios, such as virtual reality games and remote medical services, D^3-ELAA delivers a ubiquitous, high-rate, low-latency network experience.

In the future, users' demands for personalized services will become stronger. To meet this demand, technologies will evolve in a more intelligent and precise direction. For example, AI and big data analysis technologies will be used to deeply mine and analyze users' behaviors, preferences, and usage scenarios, providing users with more personalized network services. Technologies like artificial intelligence generated content (AIGC) enables the generation of texts, images, audio, and video contents tailored to users' personalized needs, offering a richer and more diverse experience. In network services, the principles of AIGC can be applied to generate customized network configurations, service packages, and more, based on users' personalized requirements. Meanwhile, intelligent IoT technologies can be utilized to enable personalized services in fields such as smart homes, smart healthcare, and smart education.

Faced with the demand for ubiquitous personalized services, the continuous innovation of user-centric technologies requires closer collaboration across the industrial chain. Operators, equipment manufacturers, and content providers should strengthen cooperation to jointly drive the development and application of technologies. Operators can increase efforts in network construction to improve network coverage and performance. Equipment manufacturers can launch more advanced equipment and user-centric solutions to meet differentiated needs. Content providers can develop more applications and services optimized for mobile networks to enrich users' experiences. Through deeper collaborative innovation and application promotion across the industrial chain, a new future experience integrating networks and services will be co-created. ZTE TECHNOLOGIES

Insights into Evolution of User-Centric Networks

User-centric access networks are becoming a key element in the future of mobile communication systems. Through comprehensive analysis, ZTE has identified five key technology clusters driving their evolution.

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The user-centric network has long been a research hotspot in mobile communication research, attracting substantial interest from both academia and industry. With the emergence of diverse new demands and the development of new technologies, user-centric access networks are becoming a key feature in future mobile communication systems.

ZTE identifies “user-centric networks” as one of the critical topics of 6G, and is gradually integrating research outcomes into 5G-A networks to fully leverage their role as a technological bridge, empowering a wide range of new scenarios and services.

User-Centric Networks: The Core Path to a Stable User Experience

Traditional mobile networks deliver services in a "cell-centric" manner. This approach leads to an uneven user experience, with optimal performance at the cell's center, which deteriorates rapidly towards the edges and fluctuates significantly during user mobility. Such an approach is inadequate for meeting the demands of emerging 6G applications and scenarios, such as low-altitude internet of intelligence (IoI), vehicle-to-everything (V2X), and immersive communication services, all of which require a consistent and stable network experience.

User-centric networks represent a network architecture that departs from the traditional cell-centric approach. By dynamically adjusting network resources and coverage, they ensure that users consistently remain within an optimal service zone. Through intelligent collaboration among multiple transmit/receive points (TRPs), user-centric networks eliminate interference

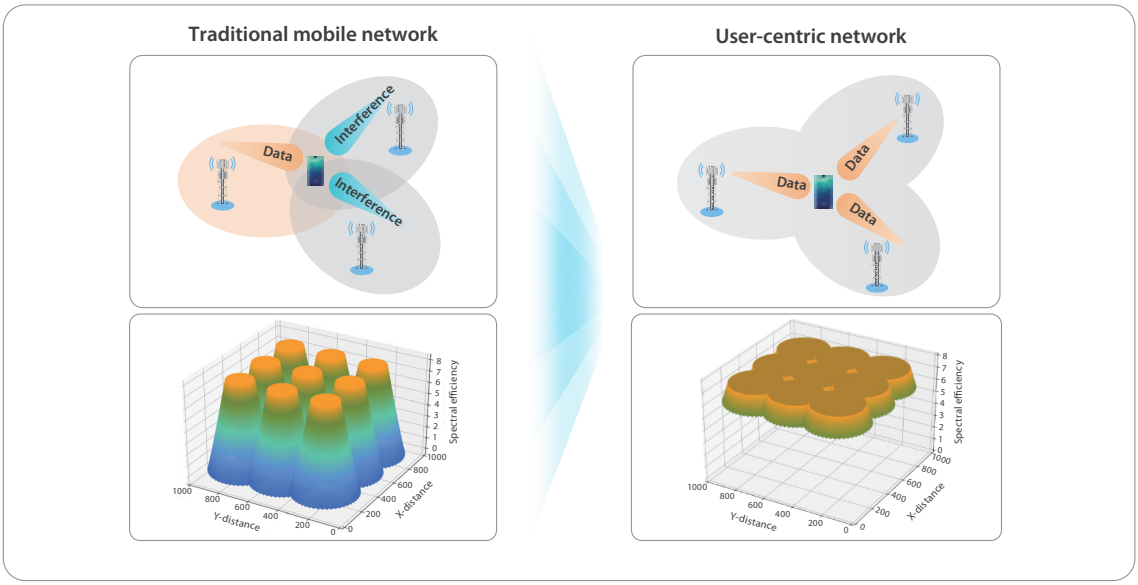

Fig. 1 Cell-centric network vs. user-centric network.

between TRPs, enhance spectrum utilization, and minimize the hardware challenges associated with increased RF and antenna requirements. This improves system scalability and reliability, ensuring stable and continuous network connections for users on the move (Fig. 1).

After a comprehensive analysis, we believe the evolution of user-centric networks involves five key technology clusters: foundational multi-TRP collaboration techniques, distributed multi-TRP coordination, mobility enhancement technologies, intelligent collaborative networking, and collaborative architecture pooling.

Multi-TRP Collaboration: Laying the Foundation

Placing the user at the center of network services requires multiple TRPs to serve the user simultaneously. These TRPs must coordinate with efficiency comparable to centralized base stations, relying on two key foundational technologies:

- **Improving air interface calibration and synchronization accuracy:** Time synchronization is a fundamental requirement for 4G and 5G communication systems, with a basic synchronization accuracy requirement of ±1.5 μs. For multi-TRP collaboration, synchronization accuracy must be improved to the picosecond level to keep latency and phase differences between TRPs within acceptable limits. Failure to achieve this precision renders coherent merging and demodulation of signals unfeasible. Air interface calibration typically includes two methods: self-calibration of TRP antennas and terminal-assisted calibration.
- **Intelligent management of TRP collaboration:** TRP collaboration relies on obtaining essential prerequisite information, such as resource allocation and channel state information, from other TRPs. This requires dynamic management of collaboration relationships and links. In user-centric networks, the wireless conditions and service requirements of each user affect collaboration associations and links, which must be managed intelligently.

Deepening TRP Collaboration: Maximizing Performance

User-centric networks enhance the user experience through intelligent collaboration among multiple TRPs. The levels of collaboration between TRPs are categorized based on the type of data exchanged (Fig. 2):

- **Level 1:** Light interaction between TRPs to reduce interference.
- **Level 2:** Exchange of service data between TRPs

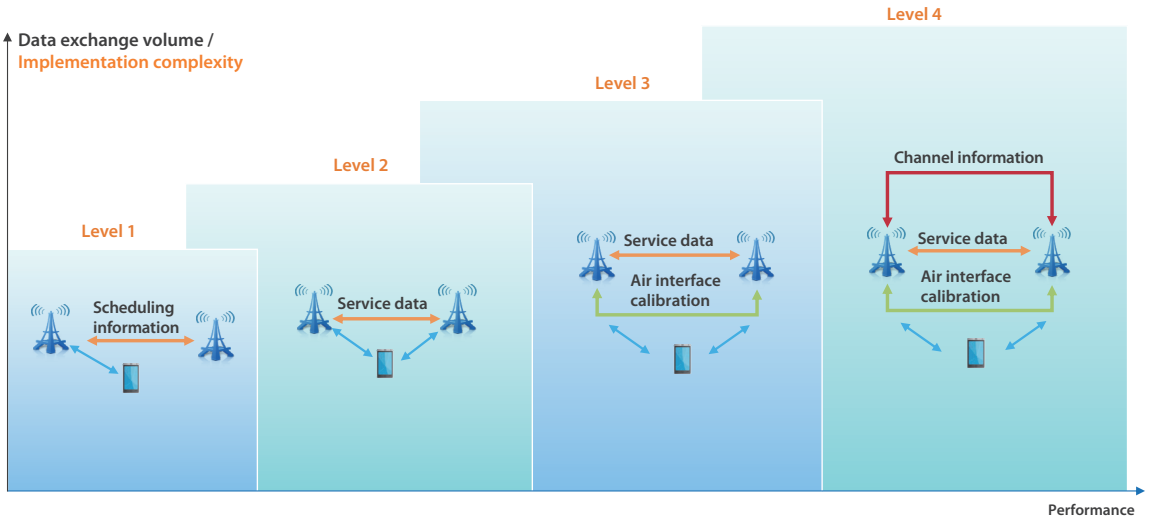

Fig. 2 Four levels of multi-TRP collaboration.

through simultaneous multi-link transmission and reception improves the signal-to-noise ratio and enhances the demodulation capability of the base station.

- **Level 3:** In addition to service data exchange, air interface calibration and synchronization are performed between TRPs, enabling time and phase alignment during transmission and reception, thus achieving coherent power combining.
- **Level 4:** Beyond service data exchange and air interface calibration and synchronization, air interface channel information is also shared between TRPs. This enables joint beamforming and increases spatial dimensions, surpassing the shaping capabilities of individual RF units.

The more comprehensive the data exchanged between TRPs, the greater the performance enhancements, while the implementation complexity also increases exponentially. In 5G-A and 6G systems, Level 4 multi-TRP collaboration is targeted, where user-centric, extreme coordination among multiple TRPs delivers distributed Massive MIMO services. Distributed Massive MIMO dynamically adjusts TRPs based on user trajectories, offering more flexibility in handling interference and improving wireless performance. This approach is applicable to both high-capacity scenarios and low-latency, low-altitude coverage environments.

Mobility Enhancement Technologies: Reducing Handover Impact

The objective of user-centric networks is to offer consistent, efficient service regardless of user location, ensuring seamless handovers during mobility. Traditional inter-cell mobility management is based on L3 measurements and triggered by RRC signaling, requiring complete cell reconfiguration, which results in data transmission interruptions and significant signaling overhead. The performance impact from frequent handovers can be particularly severe.

To mitigate these effects, mobility enhancement technologies focus on two areas: reducing handover interruption latency and improving handover robustness.

- **Reducing handover latency:** In 5G-A, an LTM (L1/L2-triggered mobility mechanism) has been introduced to facilitate inter-cell mobility based on L1 measurements. Handover decisions are initiated by L1/L2 instructions, simplifying signaling configuration and reducing the negotiation process between base stations. This approach significantly reduces handover latency and minimizes handover failures.
- **Improving handover robustness:** The 5G standard introduces dual active protocol stack

(DAPS) and conditional handover (CHO). DAPS allows the UE to maintain connections with both the source and target cells during handover until the target cell explicitly signals the release of the source cell connection. CHO enables the UE to select the target base station based on measurement results, reducing handover failures.

By leveraging intelligent or sensing-assisted communication, UE movement can be predicted, enabling more precise beam management. This approach optimizes beam selection and tracking, improving user experience.

Intelligent Collaborative Networking: Ensuring Real-Time Experience

In traditional service models, services are typically generic and standardized, which may fail to meet the UE-specific requirement. As a key feature of 5G-A/6G networks, user-centricity is characterized by flexible and reconfigurable intelligent networking capabilities. These capabilities adapt to evolving demands and environments, supporting emerging application scenarios and service models.

User-centric networks dynamically detect user behavior and service demands, adaptively constructing flexible cells. This network architecture includes the following key capabilities:

- **Intelligent insight into scenarios and service needs:** Network services are based on user location, real-time context, and data. By using intelligent algorithms, the network automatically adjusts service strategies to ensure users remain in the optimal service state.
- **User-centric collaborative set generation:** Based on actual user needs, the network dynamically adjusts service areas and constructs flexible cell collaboration sets, ensuring stable services for both users and applications.
- **Continuous learning and iterative optimization:** Utilizing machine learning and adaptive algorithms, the network continuously learns user behavior and needs, gradually optimizing service models and enhancing its understanding of user requirements to improve service quality.
- **Deployment and management of diverse network architectures:** Different user scenarios and applications demand varying network architectures. The network can flexibly organize and deploy resources, swiftly responding to new service demands. With efficient connection management and adaptive topology mechanisms, the network dynamically optimizes resource allocation based on user intent and interest sensing.

Future of Collaborative Architecture: Decoupling and Pooling

Network resources (e.g., bandwidth, storage, and computing power) can be virtualized and pooled for flexible allocation to different users and applications. The network is capable of monitoring and analyzing resource utilization in real-time, adjusting to user demands and network conditions, and automatically reconfiguring network nodes and resources to deliver optimal service. Collaborative architecture pooling includes baseband pooling and uplink/downlink decoupling.

The uplink/downlink decoupling architecture aggregates spatial resources from multiple TRPs, facilitating the adaptive selection of TRPs for uplink and downlink based on optimal principles. Meanwhile, multi-TRP pooling enables a TRP to support either uplink, downlink, or both, providing flexibility to adapt to different scenarios, network requirements, and traffic loads.

The evolution of user-centric networks will open a new chapter in mobile communications, creating a more seamless and smooth communication environment for users. It will meet the demands for stable network experiences in emerging applications and scenarios such as low-altitude IoI, V2X, and immersive services. This evolution will provide users with "full-bar" coverage everywhere, while laying a solid foundation for a smooth transition to 6G networks. ZTE TECHNOLOGIES

Shifting Paradigm to User-Centric 5G-A Networks: D³-ELAA

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As 5G-A commercialization unfolds and the mobile AI era advances, emerging services and application scenarios are placing higher demands on user experience and differentiated service assurance. ZTE has introduced dynamic, distributed and deterministic-extremely large antenna array (D³-ELAA) technology, bringing core concepts such as 6G's "cell-free" into early application within 5G networks. This technology actively drives a shift from network-centric service strategies to a user experience-centric model, empowering a wider range of application scenarios and accelerating the continuous evolution of future networks.

5G-A Needs to Shift from "Cell-Centric" to "User-Centric"

Traditional mobile networks are designed around a cell-centric architecture, providing "best effort" service capabilities. This means that cell-center users enjoy optimal network performance, while cell-edge users often experience significant degradation due to path loss and interference from neighboring cells. As users move, their experience fluctuates noticeably, and handovers can lead to service interruptions, affecting service continuity and quality.

As 5G commercial networks scale up and the demand for new services, scenarios, and value continues to rise, the traditional cell-centric architecture is becoming increasingly inadequate to meet these evolving needs:

- **Development of new business:** With the rapid growth of 5G services, new applications such as glasses-free 3D, cloud computing, XR metaverse, and ultra-HD live streaming are becoming part of our daily lives. These emerging services demand higher, more stable uplink and downlink speeds, as well as low latency, to ensure a seamless and reliable experience.
- **Expansion into new scenarios:** The new era requires 5G-A networks to deeply integrate with various industries, supporting high-reliability, low-latency applications in sectors such as industrial manufacturing, mining, energy, steel, healthcare, and education. It also calls for the expansion of 5G-A into emerging scenarios like vehicle-to-everything (V2X) and low-altitude communications, where stringent deterministic network requirements for applications such as autonomous driving and remote control must be met.
- **Extension of new value:** 5G-A is not only a critical phase in the technical evolution of 5G networks but also plays a pivotal role in realizing the commercial potential of 5G. By leveraging 5G-native intelligence for precise user identification and accurate experience assurance, operators can introduce differentiated service

packages that effectively increase average revenue per user (ARPU). For example, service packages tailored to specific use cases—such as live streaming, gaming, or guaranteed high-speed connectivity for high-speed rail users—can be engineered to meet distinct performance requirements. By integrating user experience metrics into service offerings, operators can further enhance ARPU while accelerating the full commercial potential of 5G-A, ensuring the network's long-term scalability and operational efficiency.

The development of new applications, scenarios, and value urgently requires 5G-A networks to shift from the traditional "cell-centric" model to a "user-centric" approach, enhancing the flexibility and robustness of the network to deliver consistent and superior service experiences anytime, anywhere.

Driving Massive MIMO Evolution with a User-Centric Approach

Enhancing network performance has always been a key pursuit in mobile communications. Looking back at the 4G era, the introduction of multiple-input multiple-output (MIMO) technology significantly boosted network capacity and performance. During the Pre5G phase, ZTE introduced Massive MIMO, which allowed more users to be served simultaneously on the same time-frequency resources. This technology dramatically improved beamforming gain, spatial multiplexing gain, and spatial diversity gain, leading to a substantial increase in spectrum efficiency and laying a solid foundation for 5G's high performance.

In 5G-Advanced, Massive MIMO technology needs to evolve towards a higher system performance. From a theoretical perspective, increasing the number of transmit and receive antennas on both the base station and user device sides is a key method to further enhance spectral efficiency and unlock the full potential of Massive MIMO. However, for the already deployed 5G commercial networks, operators are more focused on improving the capabilities and performance of Massive MIMO based on existing networks and equipment, ensuring a smooth and efficient upgrade.

As a result, ZTE has integrated the user-centric approach into the evolution of Massive MIMO, creating the D^3-ELAA solution. By dynamically adjusting network coverage based on the user's location, this solution ensures that users are always at the center of network coverage, thereby significantly

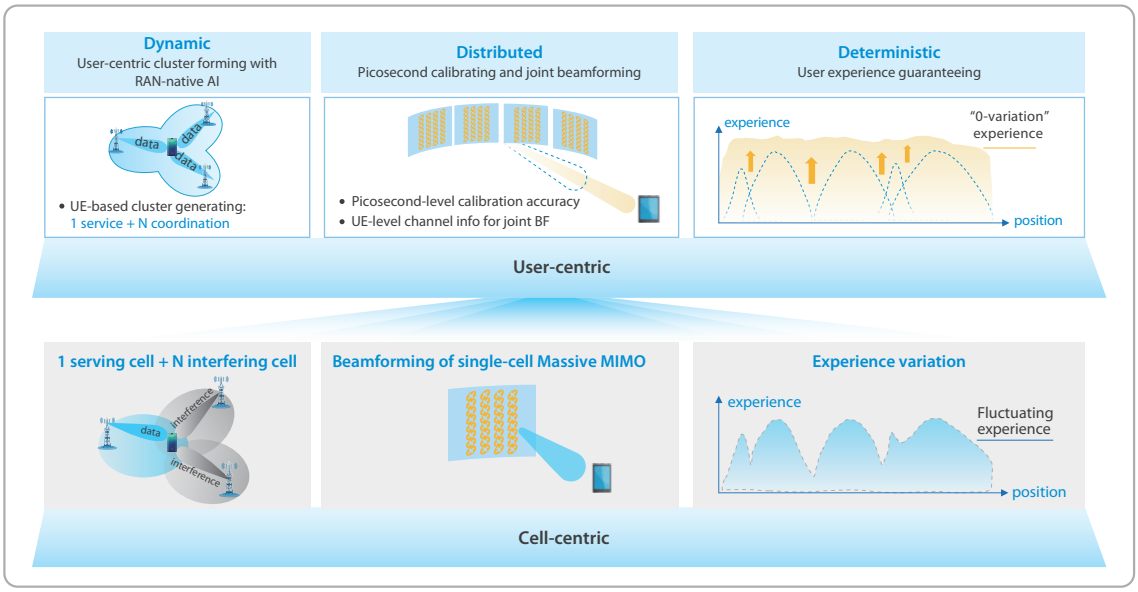

Fig. 1 Key capabilities of ZTE D³-ELAA solution as compared to traditional networks.

enhancing the overall user experience.

Key Technologies of D³-ELAA

The D³-ELAA solution employs a distributed base station architecture and dynamic networking to create an extremely large antenna array, ensuring a deterministic user experience. This innovative approach overcomes the constraints of traditional cellular architectures, enabling the network to deliver ultra-stable, high-performance user experiences (Fig. 1).

Dynamic: Forming User-Specific Clusters with RAN-Native AI

In traditional mobile communication networks, resource allocation strategies are typically based on service types. However, transitioning to a user-centric service model complicates resource management. To address this, ZTE leverages RAN-native AI to dynamically optimize resource allocation.

By applying machine learning, the network can analyze historical data and trends to gain deeper insights into user service demands and predict mobility patterns. Based on these predictions, the network dynamically forms personalized, cooperative cell clusters tailored to each user, ensuring they remain at the center of the service cluster at all times.

Furthermore, by continuously forecasting user mobility in real-time, the network can proactively adjust the structure of these clusters, ensuring a seamless and stable service experience as users move across the network. This enhances the network's ability to deliver optimized, uninterrupted connectivity.

Distributed Massive MIMO: Enhancing Network Service Capabilities

Multiple base stations within a user's service cluster can collaborate to further enhance the user experience. While various cooperation methods (such as coordinated scheduling and joint transmission) are already used in the industry, these primarily focus on reducing or eliminating inter-base station interference. The D³-ELAA solution goes a step further by improving time synchronization accuracy between base stations from the microsecond to the picosecond level and incorporating user-level joint beamforming algorithms, enabling multiple base stations within the user's cluster to perform joint beamforming. The distributed deployment of these base stations effectively forms a larger-scale antenna array, resulting in significant gains in power, channel count, and beamforming flexibility, translating into a remarkable improvement in user experience.

Deterministic Experience Improved

By forming user-centric clusters and enabling coordinated collaboration within them, the D^3-ELAA solution greatly improves the user service experience. This is particularly beneficial for users at the cell edge, where issues like edge interference and frequent handovers—common causes of service interruptions—are effectively mitigated. As a result, the user experience is significantly enhanced, and the network's ability to provide deterministic service assurance is strengthened.

ELAA: Surpassing Single-Device Capabilities

The D^3-ELAA solution leverages existing 5G commercial equipment to create a much larger antenna array. At the cell edge, users typically receive signals from two or more neighboring cells, with relatively stable signal strength. In such cases, D^3-ELAA employs joint beamforming technology, allowing geographically dispersed base stations to combine and create an ELAA. For instance, in overlapping coverage areas, three individual 64T64R cells can be combined to form a 192TR service array, delivering a significantly enhanced service experience. This extremely large antenna array surpasses the limitations of individual equipment, striking an optimal balance between performance and cost.

D^3-ELAA: Pioneering a Zero-Fluctuation Mobile Experience

"Plug-and-Play" for 5G Commercial Networks

The D^3-ELAA solution brings the user-centric concept of 6G into commercial 5G networks. From the initial design phase, full consideration was given to ensuring compatibility with existing 5G commercial systems and equipment. By enhancing the intelligent computing and coordination capabilities of radio equipment, D^3-ELAA seamlessly adapts to current 5G commercial networks and is fully compatible with commercial devices, requiring no terminal upgrades or replacements. Users can immediately experience significant improvements brought by the system upgrade.

Reduce Interference, Enable "Upgrade Action"

Wuhan Institute of Technology has completed comprehensive 5G coverage; however, network interference in some overlapping 5G coverage areas affects user experience. In line with the Ministry of Industry and Information Technology's "Upgrade Action" initiative, D^3-ELAA was commercially validated on campus. Following its introduction, network speeds in areas such as the student cafeteria, research center, and dormitories increased by up to six times, delivering a "full signal everywhere" experience to users.

Enhanced User Experience, Supporting New 5G Packages

Thailand's AIS has launched a range of new service packages, including high-performance plans with enhanced speeds, gaming packages tailored for gamers, and live-streaming packages designed for content creators. These packages aim to provide more personalized service experiences based on specific user needs. Commercial validation of D^3-ELAA at Suranaree University of Technology (SUT) demonstrated a 2.3-fold overall average experience improvement during user mobility, with a performance increase of over sevenfold at cell edges. This ensures lag-free cloud gaming and smooth high-definition video streaming, even during user movement, delivering an exceptional high-bandwidth service experience.

Over the past five years, 5G has generated significant commercial value and social benefits. With the commercialization of 5G-A and the advent of the mobile AI era, new services and application scenarios are emerging, placing higher demands on user experience and differentiated service assurance. D^3-ELAA, built on innovative service concepts, enhances spatial coordination capabilities to ensure users enjoy stable and continuous network connectivity during mobility.

ZTE will continue to integrate and strengthen the user-centric approach across various dimensions, empowering wireless resources with enhanced coordination capabilities to drive higher-quality experience assurance and support the continuous upgrades and evolution of future communications. ZTE TECHNOLOGIES

Cluster DRS: Enabling 5G for Low-Altitude Communication and Beyond

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The "Cluster" concept has been jointly developed by China Telecom and ZTE since 2021. The cluster dynamic spectrum sharing (Cluster DSS) solution in the frequency domain improves user experience by enabling efficient 4G and 5G spectrum sharing, while the cluster dynamic frame sharing (Cluster DFS) solution in the time domain supports versatile 5G capabilities. By extending the "Cluster" concept to the spatial domain, the cluster dynamic radio sharing (Cluster DRS) solution enables low-altitude, three-dimensional coverage on 5G commercial networks, delivering ultra-stable user experiences and expanding across industries to fully unlock the potential of 5G.

The Cluster Concept

Traditional wireless networks, from 2G to 5G, typically rely on uniform resource allocation strategies, including spectrum usage, uplink/downlink time slot ratios, and inter-cell coordination methods (e.g., joint reception and transmission, handovers). While these uniform strategies offer benefits like simplified network management and reduced inter-cell interference, they can limit network flexibility and performance.

As 5G evolves, networks face diverse challenges, including increasing user demands, deeper integration with various industries, and the emergence of new scenarios. In this context, relying on a uniform service strategy limits the network's ability to adapt and scale to these diverse needs.

To overcome these challenges, China Telecom and ZTE introduced the "Cluster" concept. This approach groups base stations with similar service characteristics and requirements into clusters. Each cluster uses a tailored resource allocation strategy, while different clusters employ differentiated approaches. By adapting strategies to the specific needs of each cluster, the network enhances scalability and flexibility.

The "Cluster" concept optimizes network performance across frequency, time, and spatial domains, unlocking greater network value.

- **Frequency domain:** Cluster DSS improves 4G/5G spectrum sharing capabilities.
- **Time domain:** Cluster DFS accelerates the digital transformation of 5G fully-connected factories.
- **Spatial domain:** Cluster DRS facilitates the rapid growth of the low-altitude economy and expands to more 5G application scenarios.

These adaptive approaches allows the network to better meet the demands of evolving 5G applications and industries, ensuring sustained growth and efficiency.

Cluster DRS with Advanced Spatial Coordination for Low-Altitude Communication

As 5G commercial networks continue to scale, China Telecom has set its sights on the "ToX" domain, addressing emerging applications like the low-altitude economy and vehicle-to-everything

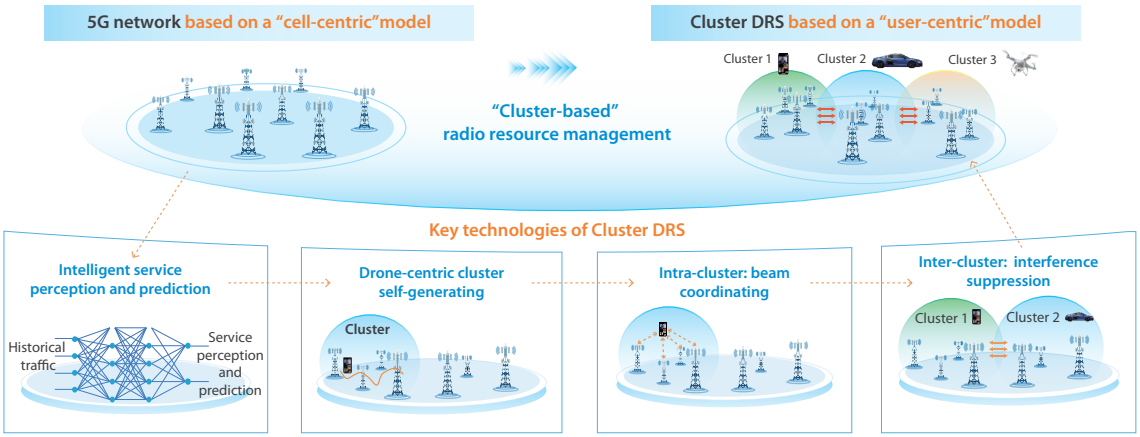


Fig. 1 Key technologies of Cluster DRS.

(V2X). The low-altitude economy, a growing strategic sector worldwide, presents a new frontier for economic development. Drones are being increasingly deployed in key areas such as emergency response, logistics, agricultural protection, geological surveys, power grid inspections, and security patrols. As drone deployments scale up, critical requirements like HD video transmission and real-time control are becoming more urgent.

China Telecom's extensive, high-quality 5G network covers vast areas across the nation. As communication demands from low-altitude operations increase, extending this robust 5G infrastructure to cover low-altitude airspace becomes essential, specifically for real-time data transmission and wide-area connectivity.

However, the low-altitude airspace, with fewer physical obstacles, experiences more pronounced cell overlap than ground-level environments, leading to stronger inter-cell interference. This makes it challenging to ensure stable, real-time communication in low-altitude scenarios. To overcome these challenges, Cluster DRS was introduced, shifting the network architecture from a cell-centric to a user-centric model. By leveraging existing 5G commercial networks, Cluster DRS enables comprehensive three-dimensional coverage in low-altitude areas, addressing the specific needs of various industries.

Key Technical Principles of Cluster DRS

Cluster DRS transforms traditional cell-centric resource management into a user-centric model. By leveraging the flight trajectory and service characteristics of drones, Cluster DRS enables deep resource coordination across multiple cells, dynamically centering around the drone. This ensures seamless service continuity and consistency, creating an efficient communication model that serves both low-altitude and ground users simultaneously. Fig. 1 provides an overview of the core innovations in the Cluster DRS solution.

- **Intelligent service perception and prediction:** By integrating the base station's native intelligence with machine learning models like long short-term memory (LSTM), Cluster DRS can perceive and predict the flight paths and traffic patterns of drones. This allows for proactive resource allocation tailored to drone behavior, ensuring smooth and uninterrupted communication.
- **Drone-centric cluster formation:** Cluster DRS dynamically generates a collaborative cluster of multiple base stations based on the drone's real-time flight trajectory and service requirements. This drone-centric cluster is adjusted based on the drone's flight trajectory, providing continuous and seamless coverage for drone operations.
- **Deep multi-cell coordination in the cluster:** Within each drone-centric cluster, deep coordination among multiple base stations allows for optimized spatial beamforming. By sharing beamforming data, base stations can collectively adjust beam directions and power levels based on the drone's movement and position. This creates highly efficient, directional communication links,

significantly enhancing communication capacity, spectrum efficiency, and ensuring high-speed, stable data transmission.

- **Inter-cluster interference management:** Cluster DRS employs intelligent inter-cluster interference mitigation strategies, minimizing interference between clusters. This ensures high-quality communication both among drones and between drones and ground users, maintaining network performance across the coverage area.

Through its innovative network architecture and intelligent scheduling strategies, Cluster DRS unlocks new communication capabilities for drone applications. It not only boosts communication efficiency and reduces operational costs but also injects new vitality into the drone industry, fostering its growth and expanding its potential applications.

Applications of Cluster DRS

Cluster DRS not only improves service reliability in drone operations but also accelerates the digital and intelligent transformation of the low-altitude economy, unlocking new possibilities for industrial applications.

Empowering Smart City Parks with Patrol Drones

In Century Park, Shanghai, which now operates under a 24/7 "open green space" policy, enhanced security and emergency response measures have become critical. To address these needs, the park has upgraded its smart surveillance system by introducing drone security patrols.

Overcoming the challenges of low-altitude communication, the innovative Cluster DRS solution enables real-time transmission of high-definition video from patrol drones. This extends the existing 5G coverage from ground level to an altitude of 300 meters, ensuring a stable uplink speed of 50 Mbps. By utilizing shared 5G network resources via a virtual private network, the system guarantees ultra-stable performance for drone operations.

Enhancing Security Inspections at Concerts

In Shaoxing, Cluster DRS was deployed to support low-altitude drone inspections during the Oxygen Music Festival, ensuring event security. Field tests demonstrated a 40%–50% reduction in drone handovers in low-altitude network environments, along with an approximately 30% increase in uplink speeds. This enabled the stable transmission of 4K ultra-HD video, ensuring reliable, real-time surveillance in low-altitude conditions.

These real-world applications highlight Cluster DRS as a critical enabler for stable and efficient drone communication, supporting a variety of industries and enhancing 5G potential in low-altitude scenarios.

Expanding Beyond Low-Altitude Communication

Initially developed to address the demands of low-altitude communication, Cluster DRS provides deterministic communication services for drones by ensuring reliable 5G connectivity and mitigating inter-cell interference. These challenges are not unique to low-altitude operations—they also persist in other domains. For example, autonomous driving in V2X networks requires dependable uplink HD video transmission and high-reliability control, while waterway communication increasingly demands ultra-HD video streaming. In all these scenarios, high cell overlap is a common issue, making Cluster DRS an ideal solution for improving waterway coverage and supporting various V2X applications.

Conclusion

The Cluster family of technologies, built on a foundation of base station intelligence, and enhanced by big data and advanced AI capabilities, seeks to strike an optimal balance between limited network resources and growing service demands. By precisely aligning requirements with resources in the spatial domain—based on user and service characteristics—Cluster DRS enables 5G networks to quickly adapt to emerging applications and scenarios, unlocking the full potential of 5G and facilitating its continuous evolution and expansion as new technologies and use cases emerge. ZTE TECHNOLOGIES

Cluster DFS: Building an Integrated ToB/ToC Service Network

Hao Yupeng
Chief Wireless Product R&D Planner, ZTE

As 5G empowers a wide range of industries, its user base has expanded from individual consumers to enterprise customers across sectors like healthcare, education, transportation, energy, and industrial manufacturing. Effectively and flexibly utilizing wireless network resources to meet the diverse needs of these industries has become a key focus of 5G network research.

Cluster DFS: Enabling Fast, Automatic UL/DL Frame Structure Adjustments

Based on real-world commercial network scenarios, different environments exhibit varying data traffic demands. For example, live sports broadcasts primarily rely on real-time data collection, requiring high uplink bandwidth and low latency during live streaming. This necessitates an uplink-heavy frame structure. Once the live broadcast ends, the demand shifts to a downlink-heavy structure for content consumption. In the industrial manufacturing sector, fully connected factories may experience varying demands depending on the area and time, requiring rapid adjustments to the uplink/downlink frame structure based on the specific needs of 5G industrial applications.

Manually adjusting network planning and allocating time-frequency resources based on user and application demands would require significant human and material resources. Additionally, resource allocation strategies must be fine-tuned to avoid performance degradation, and adjusting frame structures may introduce interference due to the coexistence of differing frame structures.

To address these challenges, ZTE has introduced the cluster dynamic frame sharing (Cluster DFS) solution, which optimizes resource allocation strategies to enhance resource utilization while ensuring a high-quality user experience.

Key Technologies of Cluster DFS

Cluster DFS enables a single 5G network to deliver diversified services, meeting both business (ToB) and consumer (ToC) demands (Fig. 1). The key technologies of Cluster DFS include intelligent traffic prediction, cluster formation, frame structure self-adaptation, and cross-cluster interference coordination.

Intelligent Traffic Prediction

Cluster DFS leverages intelligent uplink/downlink traffic prediction to assess and forecast service demands. Different methods are applied based on the application scenario. For typical commercial scenarios, future traffic demands can be predicted using historical data. When traffic demand exceeds a preset threshold, timeslot resources are adjusted accordingly. This method requires dynamic detection of traffic changes and is better suited for scenarios with gradual

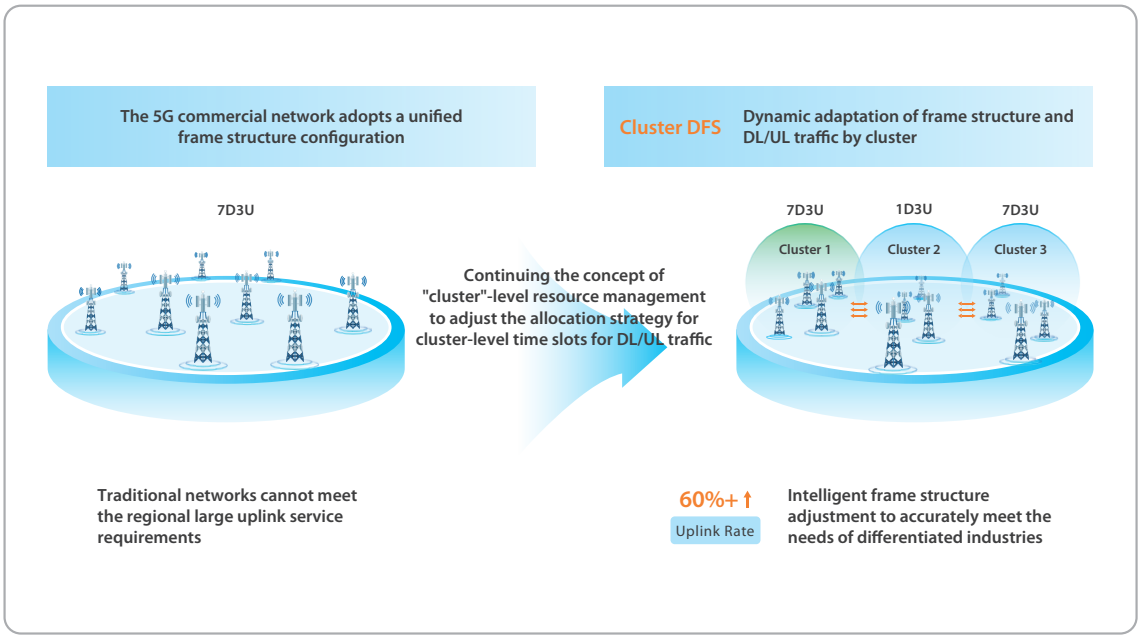


Fig. 1 Cluster-level dynamic frame structure based on traffic prediction.

changes in traffic demand. In scenarios where uplink and downlink traffic follows a predictable pattern, frame timeslot resources can be adjusted based on specific time periods to align with the expected demand.

Cluster Formation

Based on traffic prediction results, sites with similar service demand models are grouped into clusters. The clustering process also considers the geographical distribution of base stations, forming logical clusters that can be continuously updated and refined based on actual performance.

Frame Structure Self-Adaption

Within a cluster, service demands are aligned, allowing for unified frame structure adjustments to meet user needs and ensure a consistent experience. Adjustments are triggered by traffic prediction outputs, which recommend corresponding frame structure changes.

Cross-Cluster Interference Coordination

A critical challenge is addressing cross-cluster interference caused by differing frame structures. Cross-link interference between clusters with different frame configurations can severely impact performance. This issue has been acknowledged in 3GPP's 5G-A study on TDD flexible frame structures. To mitigate this, effective interference suppression and elimination techniques are required to maintain user experience in both interfered and interfering stations. Key technologies we propose include:

- **Slot adaptive modulation and coding (AMC):** This technology allows different slots to use different modulation and coding schemes, dynamically adjusting to interference levels. Base stations can adapt transmission rates based on slot position, interference strength, and channel quality, lowering the bitrate in interfered slots to minimize the impact on the air interface.
- **Enhanced interference rejection combining (eIRC):** This technique uses SuperMIMO technology to combine signals from multiple distributed antennas, improving interference rejection through enhanced diversity gain. By leveraging the strong correlation between inter-cell interference, eIRC improves channel estimation accuracy and combines received signals to suppress interference, optimizing system performance.
- **Coordinated beamforming (CBF):** Using the spatial freedom of the interfering base station's antenna

array, CBF dynamically adjusts the transmission beam to create spatial nulls in the direction of interference, effectively suppressing interference.

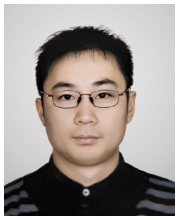
Cluster DFS in Practice

Cluster DFS has been successfully applied in several scenarios, achieving the expected pre-commercial results.

- **Live event streaming:** Cluster DFS played a key role in ensuring communication during the Asian Games, supporting high-bandwidth uplink services required for live streaming and video surveillance. Single-user uplink speeds exceeded 500 Mbps, and overall uplink throughput increased by more than 60% within the venue.
- **Smart manufacturing:** Cluster DFS has been applied in 5G fully connected factories, particularly within production line areas, increasing uplink capacity by more than 70%. It has met the high uplink traffic demands of industrial environments while also providing flexible uplink/downlink capacity for warehouses and handling burst traffic during emergencies.
- **Commercial square validation:** In a commercial test at Kaide Square in Chengdu, Cluster DFS demonstrated an average uplink speed improvement of 67.78%, with peak speeds reaching 556 Mbps. CBF achieved a noise reduction of approximately 8 dB. Cluster DFS is now being deployed in more high-value scenarios, such as concerts and the Chinese Super League.

As ToB and ToC services continue to integrate and industries undergo digital transformation, the demand for spectrum flexibility and resource efficiency is growing. Cluster DFS has proven to be a viable commercial solution, and ZTE will continue to expand its commercial deployment while optimizing performance to enhance support for commercial networks. ZTE TECHNOLOGIES

Dynamic Breathing Networks with RRU Power Pooling



Li Sijun

Planning Manager of Wireless Products, ZTE

In the early stage of 2G and 3G wireless communication development, the carrier bandwidth was narrow, and the number of carrier systems and carriers transmitted by base stations was small, with relatively low requirements for RRU cabinet-top output power. With the development of 4G and 5G services, carrier bandwidth has become larger and larger, while 2G and 3G still have certain service requirements. RRU needs to support 2G, 3G, 4G, and 5G simultaneously, increasing the demand for cabinet-top output power. Moreover, as network sharing between operators becomes more common, the need for high RRU output power has further increased. This higher RRU cabinet-top output power complicates the design and increases RRU costs, which conflicts with operators' efforts to reduce equipment costs.

ZTE's Three-Sector Power Pooling

In a traditional mobile cellular network, a communication site usually consists of three or more sectors. Due to differences in coverage, user groups, and the number of users, the load between sectors is not exactly the same at any given time and varies over time. As a result, the inter-sector RRU cabinet-top output power is unbalanced: some RRUs operate below their maximum power, while some operate at their maximum. However, RRU resources in different sectors are independent of each other and have no physical connection. Even if an RRU resource has redundant power, it cannot be transferred to the sector in need of more power, preventing power sharing.

In recent years, ZTE has launched a series of simplified site solutions, among which the three-sector integrated solution is especially favored by operators. For the first time in the industry, this solution combines multiple frequency bands, three sectors, and 4T MIMO to form an all-around product, which has been deployed or will be deployed in many regions worldwide. In addition to these traditional highlights, this solution achieves power sharing between RRU power sectors for the first time, solving the long-standing issue of power sharing failure between sectors.

How Power Pooling Works

A single RRU supports three sectors, creating physical channels for power sharing between sectors and preliminarily meeting the conditions for sharing. The total output power of the RRU across three sectors can considered a resource pool. Each sector draws power from this resource pool on demand, enabling power sharing among the three sectors. This power sharing mechanism saves RRU hardware resources by about 20%, effectively lowering operators' equipment investment costs.

The power sharing architecture is shown in Fig. 1. The network consists of the RRU, EMS, and baseband controller. The sharing switch and the sharable power for each sector are set on the EMS. The baseband controller calculates the remaining power for each carrier based on the service load of each sector and flexibly allocates the remaining power to one or more sectors as needed. As the transmit power of the borrowing sector increases, the signal-to-noise ratio (SNR) of the users within the sector is enhanced, boosting the throughput of a single user and the total sector capacity by 10% to 20%. Inter-sector power allocation can adjust at transmission time interval (TTI) levels as needed, ensuring that power can be borrowed and returned with no impact on the power requirements of burst services in the sector.

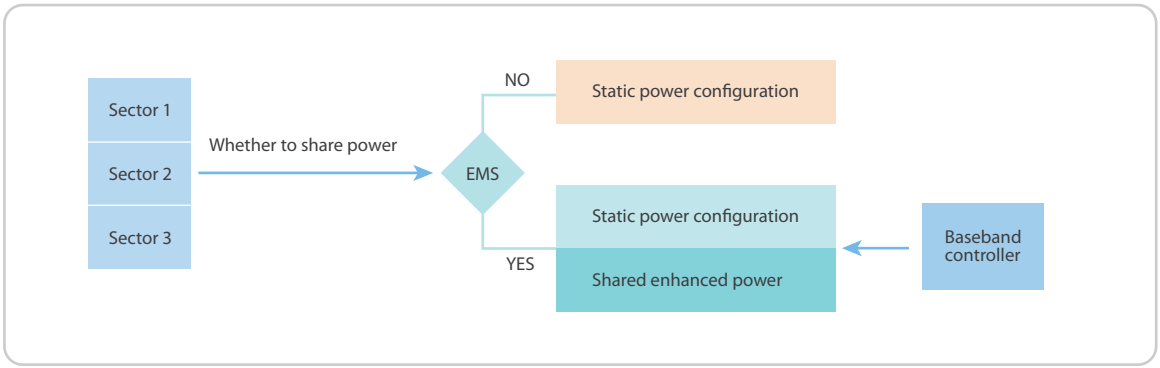


Fig. 1 Power sharing architecture.

Extreme Function: Over-Provisioning of Power

We have conducted data research in several provinces and cities with high domestic load, as well as in countries with high international load. It was found that multiple sectors of the same site rarely reaches the maximum service load simultaneously. For sites with less than 80% load, the maximum load at any given time is only about 60% to 70% of the site's theoretical maximum load.

Based on this survey data, another extreme function of inter-sector power sharing is the over-provisioning of the sector's maximum rated power. The total power of the three-sector RRU resource pool remains unchanged. The maximum rated power of one or all sectors can be configured to the maximum hardware power of a single sector. Although the total configured power for the three sectors exceeds the total power of the resource pool, as long as the service load of the entire site is not high, even if one sector reaches its maximum power output due to a high service load, the actual total output power of the three-sector RRU does not exceed the resource pool limit. This function is especially applicable to general urban and rural areas with low service loads. Base station coverage and services can be implemented in accordance with the maximum power of each sector, effectively improving coverage and cell capacity.

Use Cases for Power Pooling

Three-sector power pooling is especially applicable to scenarios where three-sector coverage is unbalanced. For example, in a coastal site, the sectors covering land are usually tourist attractions with a small cell radius, and the power required for coverage is far less than the RRU's maximum rated value. In contrast, the sectors covering the sea should be as far as possible, and the required power should be as large as possible. Traditional solutions usually use RRU with different power levels to deal with the problem, resulting in several RRU models in a single site, which makes configuration and commissioning inconvenient.

The three-sector RRU using a power pool can easily handle this problem. For example, if the total power of the RRU resource pool is 100W, the power can be divided as 20W+20W+60W, meeting the unbalanced power requirements of the three sectors without the need for dynamic adjustments by the baseband scheduler.

The urban-rural fringe is another typical scenario with uneven power requirements where the power pool can perfectly adapt. Even with future economic development and urban expansion, which may require adjustments to base station deployment, cell radius, and increased cell capacity, the power ratio between sectors can also be adjusted through software without the need for hardware changes. This truly enables smooth upgrade, saving operators' reconstruction costs and time.

The power pooling function uses the unbalanced service load across sectors and the RRU hardware that integrates the three sectors, and considers the output power of the entire device as a resource pool. Through flexible TTI-level scheduling by the baseband scheduler, the power can be shared and utilized to its maximum extent. Each watt of power is converted into bit traffic, helping operators enhance network benefits. ZTE TECHNOLOGIES

Power-Following Solution for Seamless User Experience

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Lye Pei

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The 5G network has entered a phase of refined construction and operation, focusing on enhancing service quality and network efficiency. 5G network devices offer large bandwidth and high power, and in a user-centric network, inter-device coordination allows for efficient power sharing and distribution, ensuring an optimal user experience.

High-speed railway coverage is a high-value scenario for 5G network coverage. As high-speed trains become a symbol for China, telecom operators are committed to providing a high-quality service experience for passengers. ZTE is actively engaged in the construction of high-speed railway network coverage, continuously innovating in network construction practices.

The 5G network for high-speed railway must track users travelling at speeds up to 350 km/h in real-time, providing a continuous service experience. ZTE has introduced the RRU power-following solution to build an efficient high-speed railway communication network.

Innovative RRU Power-Sharing Design

In conventional RRU design, all RRU channels have independent power amplifiers and output channels, and the power cannot be shared between different RRU channels.

However, if the power from idle RRU channels could be shared with other channels, inter-channel power and carrier configurations could be performed more efficiently, and the maximum effective downlink transmit power of some channels can be increased to improve cell coverage.

With the innovative concept of internal power sharing in RRUs, ZTE breaks through the restriction of power sharing between common RRU channels through a new RRU hardware design, enabling greater flexibility in the use of RRU power.

In this design, two RRU channels are grouped, and coupling bridges are added between channels. Through system software control, the power of the two RRU channels can be converged or output through either channel.

Take an eight-channel RRU as an example. A conventional eight-channel RRU has a total power of 400W, with each channel supporting a maximum power output of 50W. In the hardware design for RRU internal power sharing, the maximum output power per channel is increased to 100W. Power can be converged into four channels, doubling the downlink transmit power to 4 × 100W. Through system design, two eight-channel RRUs can be configured to form a dual-sector network with a dynamic output of up to 8 × 100W.

RRU Power Sharing for High-Speed Railway Scenarios

The high-speed railway 5G network typically adopts a single-site, two-RRU sector networking mode. Given the linear movement of trains, only some RRUs provide coverage for high-speed trains within a certain period of time.

Based on the operational characteristics of high-speed trains, the power from RRUs with few or no users can be shared with the RRU covering high-speed trains at the same site. In high-speed railway line coverage, multiple RRU cells are combined, and power coordination between RRUs needs to be implemented in a large logical cell.

As the high-speed railway moves linearly, the two co-sited RRUs can dynamically adjust power allocation based on the UE's position to implement

power sharing and convergence across different coverage directions, enhancing downlink performance for high-speed train users.

ZTE has innovatively proposed the RRU power-sharing solution that utilizes the RRU internal power-sharing design (as shown in Fig. 1). In accordance with the UE's position in the train's incoming direction, the algorithm and hardware work in real-time precise coordination to ensure that the focus of the RRU's transmit power follows the service direction, doubling the transmit power of a single-side antenna and meeting the 350 km/h high-speed movement requirement.

The ZTE RRU power-sharing solution ensures more reasonable energy utilization. Through real-time UE location identification and base station software control, UE-level and subframe-level RRU power sharing adjustments are implemented to maximize device energy efficiency.

Test results from the commercial high-speed railway network show that ZTE's RRU power-sharing solution can achieve a coverage gain of 3 dB and increase the downlink user-perceived rate by 10% to 20%.

The ZTE high-speed railway RRU power-sharing solution uses the RRU internal power-sharing design, decouples from the antenna system, and can be connected to the conventional smart antennas of different antenna manufacturers, making network deployment easier for operators. Different types of antennas can be selected for different sites.

RRU Power Sharing for Multiple Scenarios

In traditional cellular networking solutions, the RRU for each sector is configured independently. While power can be shared between RRU carriers, RRU power cannot be shared between different sectors.

In a typical three-sector network, the service duration and load of each sector differ, creating opportunities for power sharing between sectors. When there is remaining RRU power in a low-load sector, it can be shared by a high-load sector. This increases the downlink transmit power and spectrum efficiency of the high-load sector, improving user experience and enhancing the downlink capacity of the cell.

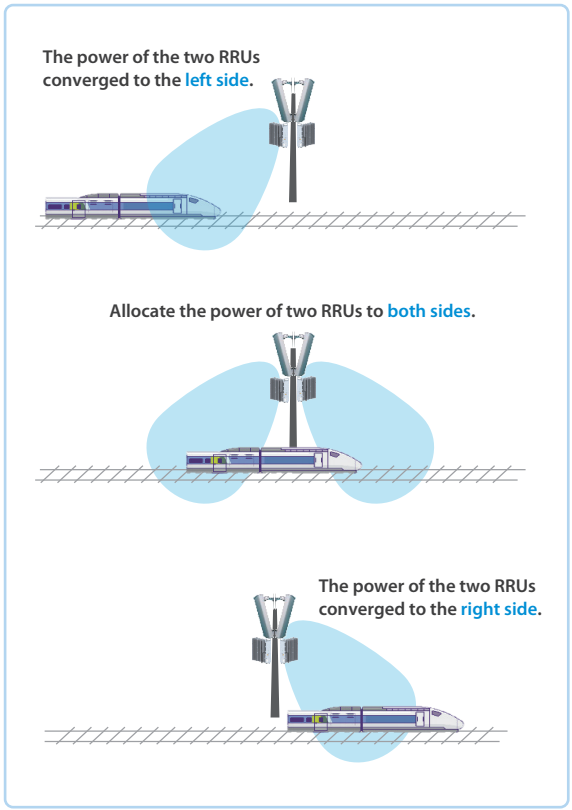

Fig. 1 The RRU power-sharing solution based on the train's incoming direction in high-speed railway scenarios.

In scenarios such as residential area coverage, subway coverage, and low-cost coverage, four-channel devices are commonly used. In these cases, it is possible to either use only some channels of the power-sharing RRU or split the eight-channel RRU into two 4TR cells. When only four RRU channels are used, the power from the four idle channels can be converged into the four working channels, doubling the power of the four transmit channels and improving the coverage and spectrum efficiency. In scenarios where an eight-channel RRU is split into two 4TR cells, the RRU power can be shared between the two groups of four channels based on the load and coverage of the two 4TR cells.

The ZTE power-following solution adopts an RRU internal power-sharing design, and has implemented innovative practices in both RF and base station software and hardware. Embracing the green network concept and expanding product compatibility, ZTE has made valuable explorations in improving overall network performance in the future. ZTE TECHNOLOGIES

Scenario-Based Intelligent Assurance Helps Users Upgrade Their 5G Experience

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Xin Shengli

Deputy Director of Network Research Institute, ZTE

With 5G's popularization, users' network demands are diversifying, especially in short videos, cloud games and extended reality (XR), which places higher requirements for speed, latency, bandwidth and reliability. Operators must effectively manage and optimize network resources. The introduction of intelligent computing boards in base stations enhances AI computing power, meets the computing needs of endogenous intelligent applications, and optimizes wireless access network performance in traffic processing, user experience, energy efficiency, spectrum efficiency and perception. Through precise resource allocation, intelligent scheduling, and personalized user experience guarantees, operators can ensure a stable, high-quality network experience, even in complex scenarios.

Enhancing Wireless Access Networks with Intelligent Computing Boards

Improve Experience and Enhance Connection Value

Traditionally, operators rely on the 5G QoS Identifier (5QI) hierarchical guarantee mechanism to differentiate the guarantee levels of different service types. However, this approach is often insufficient in meeting complex network requirements. Intelligent computing boards in base stations use deep recognition and analysis to identify over 16,000 protocols and applications, enabling customized assurance strategies for each application and thereby achieving differentiated services. By mapping services to specific types, operators can adjust scheduling priority levels or guaranteed rates to better meet diverse needs. For delay-sensitive services, optimal scheduling paths are extracted to reduce delays, ensuring stable network connections under high load. By sensing user behavior and traffic needs, base stations intelligently direct user traffic to avoid network congestion and improve the overall user experience. Assurance strategies based on intelligent in-depth identification and analysis enhance user experience, boost network connection value, and strengthen operators' competitive advantage.

Improve Energy Efficiency and Reduce Carbon Emissions

As global sustainability efforts grow, improving energy efficiency and reducing carbon emissions have become key tasks for operators. Differentiated centralized scheduling, based on service identification, not only saves energy but also reduces packet delays caused by subframe silence and packet accumulation. Through precise service filtering, operators can effectively avoid unnecessary increases in delay.

The intelligent computing board introduces refined service identification, enabling service-level experience and energy-saving collaboration and applying differentiated energy-saving strategies to balance energy savings and performance. For example, the packet accumulation scheduling function is deployed based on service characteristics, with thresholds for function enablement and packet

accumulation delays set accordingly. When the network is under low load, it automatically exits unschedulable time slots based on the delay information and shuts down invalid resources, optimizing resource utilization efficiency and reducing energy consumption. With AI technology, the board analyzes user behavior, service demands and network status in real time, predicting network load and dynamically adjusting resource allocation to support green development.

Optimize Maintenance Efficiency, Improve Network Quality, and Reduce Costs

The intelligent computing board in base stations enables wireless perception operation and maintenance (O&M) through an innovative wireless single-domain lightweight perception system, driving network optimization and cost reduction.

- Real-time association of service key quality indicators (KQI) and network KPIs ensures 100% data accuracy.
- Second-level QoE evaluations for each user service call help operators quickly identify and solve user experience issues.
- Perception data, summarized by raster and grid dimensions, combined with the geographical environment, allow comprehensive analysis of the root causes of poor quality to improve O&M accuracy and effectiveness.
- Multi-level VIP protection and major protection solutions ensure network stability during critical moments.

The application value of the intelligent computing board is shown in Fig. 1.

Scenario-Based Application of Intelligent Computing Boards

Different application scenarios have diverse network service demands. Short video and cloud game users require extremely low latency and high bandwidth, while smart manufacturing and Internet of Vehicles prioritize network reliability and stability. The intelligent computing board uses AI technology to accurately identify over 16,000 segmented applications, providing customized protection strategies for each and ensuring stable network services for both 2B and 2C users, even under high load conditions. It also integrates a wireless-side perception evaluation system that links network KPIs with service experience to optimize user experience issues.

Government Affairs Center Scenarios

In government affairs centers, ensuring the stable operation of key applications (e.g., government affairs apps, WeChat, and Alipay) is crucial. The intelligent computing board uses AI technology to identify application traffic in real-time and prioritize scheduling, ensuring that these applications receive resources first under high load for smooth service delivery. Through indoor and outdoor inter-frequency collaboration and a dynamic breathing network, the board optimizes traffic gains and overall network efficiency. Its AI-based dynamic resource adjustment mechanism maximizes traffic gains and intelligently triggers coverage rollback when KPIs deteriorate to ensure network stability. This intelligent management approach significantly enhances network support capabilities, providing users

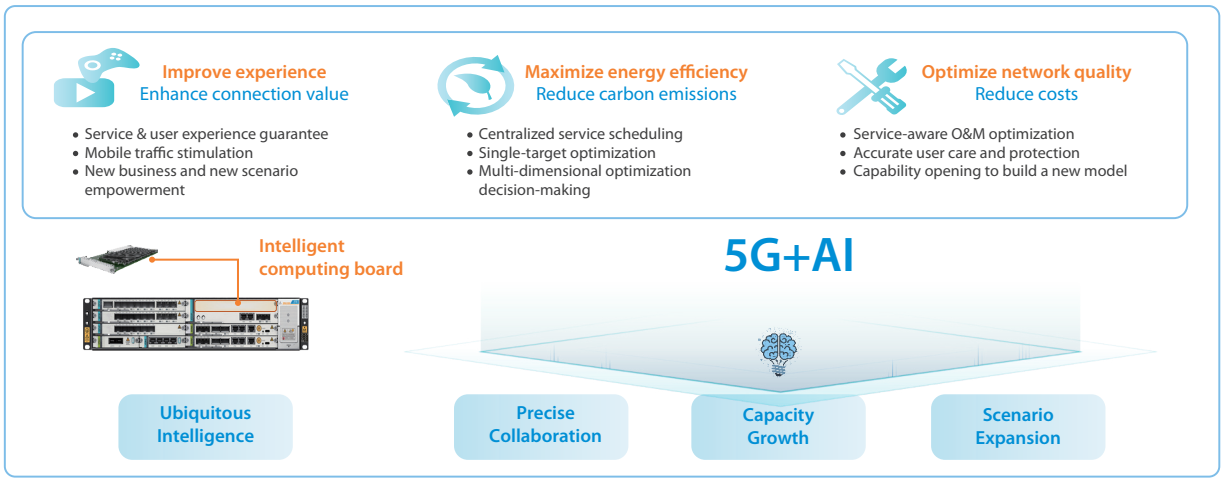

Fig. 1 Scenario-based value of the intelligent computing board.

with a smoother and more reliable network experience.

University Scenarios

In university settings, traditional macro coverage networks often face congestion in dormitory areas. The intelligent computing board automatically identifies and prioritizes key applications, such as online learning and scientific research applications, while limiting low-value traffic to optimize network resource utilization. It also optimizes resource allocation dynamically based on user IDs in new packages, improving spectrum efficiency and meeting students' varied needs. Through cell portrait analysis, the system evaluates traffic suppression in real time and adjusts the scheduling algorithm to improve spectrum efficiency and delay the network load inflection point during high traffic periods. This intelligent network management strategy helps operators better manage peak network demand in universities and provide a more stable service.

Medical Scenarios

In medical environments, user numbers vary significantly between holidays and weekdays, with peak usage from 8 a.m. to 3 p.m., often causing network congestion for services such as QR code payment, instant messaging, and medical insurance apps. The intelligent computing board utilizes AI technology to ensure the network stability for key medical applications and seamless operation of services such as payments, diagnosis, and treatment. The system provides multi-dimensional visual analysis, real-time network monitoring, and optimization for commonly used applications such as WeChat, helping operators quickly identify and resolve potential issues. Through intelligent management, the board enhances network decision-making, enabling operators to handle peak network pressures and ensure smooth and stable medical services and an optimized user experience.

Business Districts and Scenic Spots

In high-density scenarios such as business districts and scenic spots, heavy traffic creates tidal effects, with short video services dominating traffic demand. AI-powered real-time perception of user behavior and traffic demand allows precise network protection and quality experience for high-value users. Intelligent MIMO technology improves spectrum efficiency and network capacity by optimizing beam selection and user pairing. The exploration of AI within the intelligent computing board to enhance channel state information feedback offers new opportunities for improving network performance. These technologies help operators meet high-standard network experience demands across various services, including short videos, live broadcasts, and instant messaging.

Subway Scenarios

In subway scenarios, tidal fluctuations in passenger flow require dynamic network management, especially during peak hours. The application of AI technology effectively enhances the user experience, especially at ticket gates and security inspection areas, by improving code scanning efficiency through intelligent optimization and speeding up passage. In carriages and tunnels, the high demand for instant messaging and video playback places stringent requirements on network speed and stability. By strengthening network coordination, smooth connections can be ensured in high-demand scenarios, significantly improving overall service quality and meeting users' high expectations for network experience.

High-Speed Railway Scenarios

High-speed railway network assurance requires fast response and strong technical support. The intelligent computing board improves network quality in high-traffic and fast-moving environments. By identifying service types in real time, the intelligent computing board provides customized assurance strategies and makes timely adjustments to accommodate traffic changes. The system automatically triggers a self-healing mechanism to protect the service experience of VIP users. Additionally, varying average bit rate limits are set for video services to optimize the perceived quality of other services. Geographical raster data display enables network managers to monitor and optimize network conditions, ensuring service continuity and stability.

The application of intelligent computing boards has significantly improved the intelligence of wireless access networks. Through precise resource scheduling, real-time load prediction, and intelligent fault repair, operators can optimize network performance and provide users with a higher-quality network experience. In the future, wireless access networks will become even more intelligent, flexibly adapting to changing service demands and network environments, further promoting the application and development of 5G networks. ZTE TECHNOLOGIES

User-Centric Spectrum Integration: Optimizing Spectrum Efficiency and Enhancing User Experience

Mi Dezhong

Chief Wireless Product R&D Planner, ZTE

At the beginning of 2024, the representative technology of 5G-A, three component carrier (3CC) aggregation, was first deployed at scale in China. ZTE, in collaboration with domestic operators and industry partners, achieved a peak downlink speed exceeding 5.4 Gbps in multiple field test environments across Zhejiang, Shanghai, and other regions, laying a solid foundation for 5G-A commercialization. To meet the increasing speed demands of applications such as extended reality (XR) and ultra-high-definition (UHD) video, ZTE and domestic operators achieved a new downlink speed record of 9 Gbps. This milestone was accomplished through multi-carrier transmission combining FR1 100 MHz and FR2 800 MHz spectrum, utilizing commercial chips. Currently, over 100,000 3CC-enabled cells have been deployed across major regions in China, covering key areas such as scenic spots, central business districts (CBDs), universities, shopping malls, high-speed railways, subways, and so on.

While downlink speed continues to set new records, the widespread adoption of services like UHD live streaming has significantly increased uplink capacity demands. However, terminal limitations have rendered uplink speeds a bottleneck in further enhancing user experience. ZTE's multi-carrier integration solution overcomes this bottleneck by employing uplink multi-carrier aggregation, uplink Tx switching time-division transmission technology and a flexible frame structure configuration. In April 2024, ZTE achieved an uplink peak speed of 1.2 Gbps in a field test in Beijing. This not only significantly improved users' uplink experience but also demonstrated the enormous potential of new technologies in enhancing network uplink transmission efficiency. The solution provides strong technical support for a wide range of application scenarios, including cloud computing, big data, IoT, telemedicine, and UHD video uploads.

While existing multi-carrier technology ensures high-speed service experiences through aggregated carrier transmission, the independent scheduling of aggregated carriers limits flexibility and increases overhead as the number of carriers grows. Moreover, diverse combinations of carriers and transmission modes require an intelligent spectrum integration solution to maximize spectrum efficiency and ensure smooth user experiences. To address these challenges, ZTE has introduced a user-centric spectrum integration solution to further optimize spectrum efficiency and improve user experience.

Spectrum Pooling to Enhance Efficiency

With the re-farming of 2G/3G/4G spectrum, the release of new spectrum, and deeper network integration among operators, 5G spectrum resources have become increasingly abundant, spanning from low-band 700 MHz/800 MHz/900 MHz to ultra-high-band 26 GHz/28 GHz, with carrier bandwidths ranging from 10 MHz to 400 MHz. The aggregation of more spectrum provides a solid foundation for improving data rates, but as the number of aggregated carriers increases, overhead from independent transmission of common carrier information becomes more prominent. Redundant

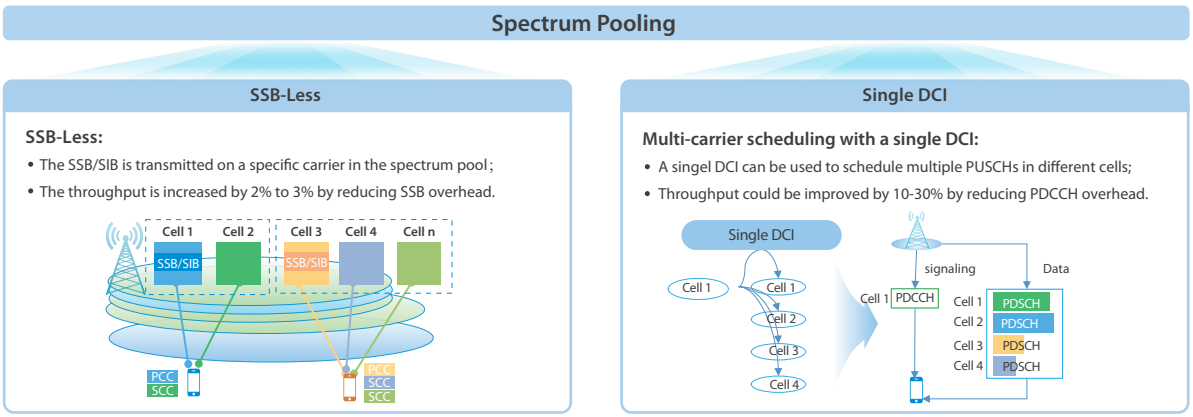

Fig. 1 Principles of spectrum pooling

control information and imbalances in control channel quality across carriers also become significant issues, highlighting the need to simplify the use of spectrum and optimize the existing multi-carrier strategy.

ZTE's user-centric spectrum integration solution introduces spectrum pooling technology, which enables the sharing of common and control channels among carriers within the same spectrum pool, thus reducing overhead and enhancing scheduling flexibility. Specifically, the solution employs a single downlink control information (Single DCI)-based multi-carrier joint scheduling mechanism, which reduces redundant overhead through the sharing of control channels and also addresses control channel imbalances across carriers, enhancing scheduling flexibility. The introduction of synchronization signal block (SSB)-less technology for multi-carrier scenarios minimizes the overhead associated with the repetitive transmission of common channels (such as SSB/SIB) by sharing these channels within the spectrum pool (Fig. 1). These innovations significantly enhance spectrum utilization and improve the user experience by 10% to 30%.

Intelligent Carrier Aggregation to Enhance User Experience

As carrier aggregation becomes more widely deployed, multi-carrier operation is becoming the primary mode for users. The traditional approach of selecting the best single carrier for users needs to evovle to meet the growing demand for optimal aggregation and higher speeds in multi-carrier scenarios. ZTE's user-centric spectrum integration solution introduces intelligent carrier combination and transmission mode optimization based on built-in intelligence, ensuring optimal user experience and maximizing cell spectral efficiency.

This solution leverages the base station's built-in capabilities to identify user and service types accurately. By considering UE capabilities, carrier configurations, carrier loads, and channel conditions, the system employs multi-dimensional data modeling to predict the potential carrier combinations and transmission modes for each user across different cells. Based on these predictions, the system selects the optimal carrier combination and transmission mode for each user, ensuring a guaranteed and consistent experience.

As networks evolve from 5G to 5G-A and eventually 6G, numerous new services, scenarios, applications, and ecosystems will emerge. At the same time, with the release of existing spectrum and the discovery of new spectrum, the diversity of spectrum resources will become increasingly evident. This will require continuous optimization of multi-carrier solutions to meet the growing user demands.

ZTE's user-centric spectrum integration solution breaks through the traditional constraints in spectrum resource allocation and scheduling. By dynamically orchestrating high-, medium-, and low-frequency resources based on user and service requirements, carrier capabilities, and channel quality, it transcends the limitations of flexibility in existing multi-band network. Through cross-layer decoupling, cross-band decoupling, and uplink/downlink decoupling, the solution unlocks spectrum flexibility, improves spectrum efficiency, and meets the diverse needs of users in the evolving 5G and 6G landscape. ZTE TECHNOLOGIES

Low-Carbon, User-Centric Networks Lead 5G Era

Guo Cheng
Director of Wireless Product Planning, ZTE

Fan Yingying
Director of Wireless Product Planning, ZTE

As global climate change accelerates and extreme weather events become more frequent, there is an expanding need across industries for sustainable, low-carbon growth. Digitization is essential to achieving carbon neutrality and is crucial to advancing global efforts to address climate change. With the widespread deployment of 5G base stations, managing energy usage goes beyond mere energy conservation—it involves striking a balance between service expansion and user experience. This means implementing energy-saving mechanisms that prioritize real user requirements and experiences, aiming to minimize energy consumption per bit while maintaining robust network performance.

HI-RAN: Enhancing Energy Efficiency Through Intelligent Coordination with a Distributed Architecture

Energy-saving technologies for mobile network have undergone extensive innovations in time-domain symbol shutdowns, frequency-domain carrier shutdowns, spatial-domain channel shutdowns, power-domain management, and even extreme dormancy in device domains. However, factors such as multi-mode, multi-frequency networks, increasingly complex deployment scenarios, and diverse service expectations make it challenging to implement precise and efficient energy-saving solutions that are site specific and time specific.

ZTE's hybrid intelligent RAN (HI-RAN) energy-saving solution utilizes a dual-layer computational architecture that encompasses both the network management layer and the base station native layer. The distributed architecture allocates AI's three fundamental aspects—data annotation, model training, and inference execution across its layers, creating a system where model training takes place at the network management layer, while inference is executed within the base station. The solution reduces energy consumption and enhances energy efficiency without compromising network performance, employing technologies such as predictive optimization, autonomous orchestration, multi-frequency collaboration and digital twin visualization.

The solution leverages the collection of network performance and energy consumption data to enable traffic load forecasting and implement optimal energy-saving strategies in response to variations in service or network performance:

- **Traffic load forecast analysis:** Employs deep learning to predict traffic loads at the cell level, identifying low-load cells suitable for energy conservation.
- **Service offloading capability analysis:** Evaluates real-time measurement reports to identify co-coverage cells for energy conservation and forecast their load patterns to identify the optimal offloading (coverage compensation) cells.
- **Energy conservation strategy self-configuration:** Creates energy conservation strategies based on specific requirements, such as shutdown thresholds, time windows, duration, and energy-saving features.
- **Self-optimizing strategy iteration:** Evaluates comprehensive traffic scenarios, energy conservation effects, and KPI trends to enhance self-learning and continuously update strategies

online, ultimately achieving an optimal balance between energy usage and network performance.

To prevent sudden traffic surges or declines in user experience during energy-saving operations, base stations must rapidly detect network performance degradation and adjust energy-saving strategies in real time. Continuous evaluations are conducted across three phases—pre-, during, and post-energy conservation—to ensure predictable network performance indicators in energy-saving areas through a "real-time, event-driven, and periodic" performance assurance mechanism.

- **Pre-energy conservation:** Monitors control and user plane indicators of both energy-saving cell and basic coverage cells. If established targets are not met, restrictions on access are not applied.
- **During energy conservation:** Monitors control plane indicators during cell access restrictions and user relocation. If performance indicators exceed the predicted thresholds, the energy-saving mode is exited.
- **Post-energy conservation:** Monitors the control and user plane indicators of the basic coverage cell immediately after the initiation of energy-saving strategies. If performance indicators exceed the predicted thresholds, the energy-saving mode is exited.

Enhancing Energy-Saving Solutions Based on User Experience

The rapid development of mobile networks has introduced a variety of services, such as video streaming, online gaming, social media, and online shopping. Mobile networks play a crucial role in ensuring stable and reliable internet access, while delivering high-quality experiences, which increases the demand on the base stations' capacity to identify and meet service requirements. To support AI applications in wireless networks, base stations need expanded processing and storage capacities, including the installation of integrated computing and communication boards, to meet the demands of AI modeling.

Enhancements in energy-saving technologies, based on service experience, utilize base station computing capabilities to collect service data, monitor the patterns of popular applications, and promptly adapt to the changes in these patterns. This ensures a higher-quality experience for essential services and advances application-level energy-saving technologies.

- **Latency-sensitive services:** Latency-sensitive applications, such as real-time video calling, online gaming, and cloud meetings, require minimal network delay and consistent transmission of data. Even a small increase in latency may negatively impact the user experience, resulting in video freezes, audio interruptions, or gaming lags. In providing these services, base station systems adopt a minimal data joint scheduling delay threshold and, if necessary, may skip joint scheduling to ensure fast transmission of information to the user. This approach ensures seamless real-time service while keeping network stability.
- **Latency-insensitive services:** For services without real-time response requirements, such as file downloads, large data synchronization, and system upgrades, users do not need immediate feedback. This allows greater flexibility in energy-saving techniques. The network may adopt higher data joint scheduling delay thresholds, allowing a greater number of data packets to be aggregated before transmission, thus extending the symbol shutdown duration. This significantly decreases power amplifier energy usage and optimizes overall system energy efficiency.

Future mobile networks will face greater challenges due to growing demand for new services, such as holographic communication, intelligent interaction, and digital twins. The explosive growth in network traffic will raise energy consumption requirements. By integrating intelligent energy-saving technologies with user-centric improvements, 5G and future networks will substantially improve network efficiency while lowering overall energy consumption. This is going to propel the global digital society towards a low-carbon, sustainable future, offering strong support for achieving "mobile net-zero". ZTE TECHNOLOGIES

User-Centric Architecture for Cell-Free Massive MIMO Networks

Chen Dong

Wireless system architect, ZTE

Chen Jianjun

Wireless system architect, ZTE

In today's digital age, to cope with the exponential growth trend of mobile data traffic, the densification of network infrastructure has become a key strategy, mainly through ultra dense networks (UDN) and massive multi-input multi-output (mMIMO) technology. However, increased cellular density intensifies inter-cell interference, adversely affecting data transmission quality and stability. UDN also leads to fluctuating service quality, with users experiencing vastly different network performance across areas.

To tackle these challenges, a user-centric cell free-massive MIMO (CF-mMIMO) architecture has emerged. Fig. 1 shows a comparison between traditional cellular networks and user-centric CF-mMIMO networks.

Advantages of CF-mMIMO Networks

In CF-mMIMO networks, each user is treated as the center, receiving personalized services through the collaborative work of distributed antenna units, which leads to higher spectral efficiency, energy efficiency, and better user experience. CF-mMIMO networks are particularly suited for scenarios with high coverage overlap and significant uplink and downlink interference, such as small-scale dense networking, indoor-outdoor macro-micro coordination, and low-altitude coverage (Fig. 2)

- **Eliminate edge issues and expand coverage**

Traditional cellular networks often face weak signal problems at cell edges, impacting user experience. In contrast, CF-mMIMO networks dynamically allocates cooperative receiver-transmitter clusters based on user location, service requirements, and channel conditions. This approach effectively eliminates signal blind spots, ensures stable signals for users, regardless of their location, and enhances overall network availability.

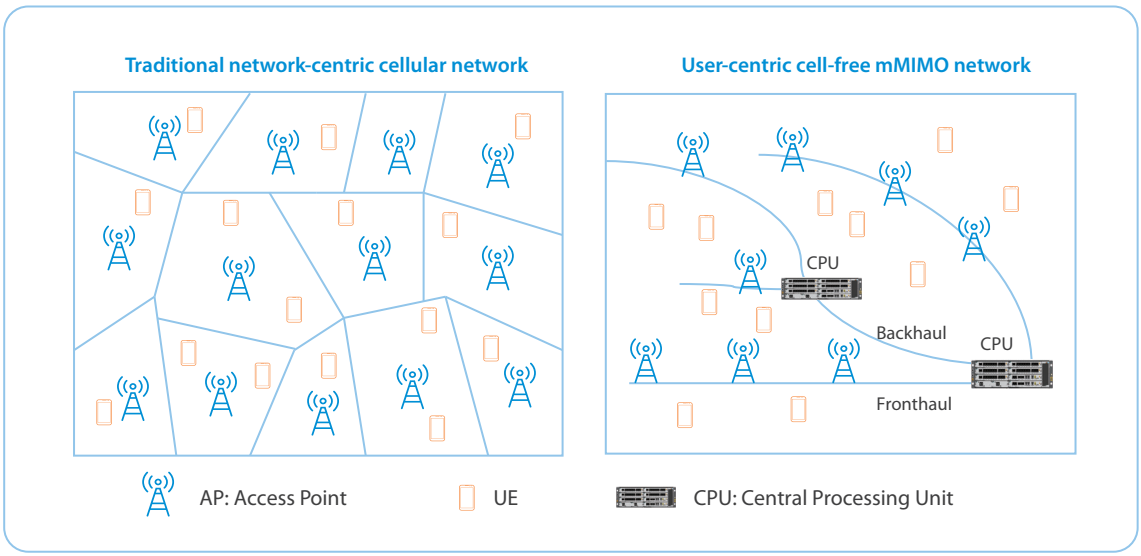

Fig. 1 Comparison between traditional cellular networks and user-centric CF-mMIMO networks.

- **Achieve interference suppression to reduce interference levels**

CF-mMIMO networks reduce signal propagation path overlap by coordinating the signal transmissions from distributed antenna nodes, lowering the probability of interference, effectively suppressing it, and improving signal quality and reliability.

- **Improve energy efficiency**

By concentrating signals in the direction of the user and reducing transmission power, CF-mMIMO networks minimize interference with other users while improving energy efficiency. In addition, the distributed antenna deployment in the CF-mMIMO architecture reduces signal propagation loss and lowers received power. Together, these approaches significantly improve energy efficiency and advance the goal of green communication.

- **Enhance service for high-mobility users**

For high-mobility users, maintaining a stable communication connection is crucial. CF-mMIMO networks utilize distributed antennas to reduce signal propagation loss and interference, while enhancing signal reception strength. Even during high-speed movement, users can consistently receive strong signals, ensuring a stable connection. Meanwhile, collaborative communication enables rapid tracking and service handoffs for highly mobile users. As users move across areas, the network quickly adjusts the cooperation mode of antenna nodes, providing seamless service handoff and enhancing the user experience.

Challenges for CF-mMIMO Networks

Although CF-mMIMO technology has great potential in improving communication system performance, several challenges remain.

- **Fronthaul link capacity**

The fronthaul link in CF-mMIMO networks is required to transmit a large amount of signal data and control information. As a result, the fronthaul capacity has become one of the key factors limiting system performance. How to improve fronthaul capacity and reduce fronthaul latency is an important challenge faced by CF-mMIMO networks.

- **Coherent cooperative transmission accuracy**

In CF-mMIMO systems, coherent cooperative transmission is crucial to ensure that signals sent by multiple APs can be correctly combined and received at the user end. Only when the signals maintain a certain phase correlation can the signal energy of multiple APs be effectively utilized to improve system performance. If the phase relationship between signals is inaccurate, it may cause them to cancel each other out, reducing system performance.

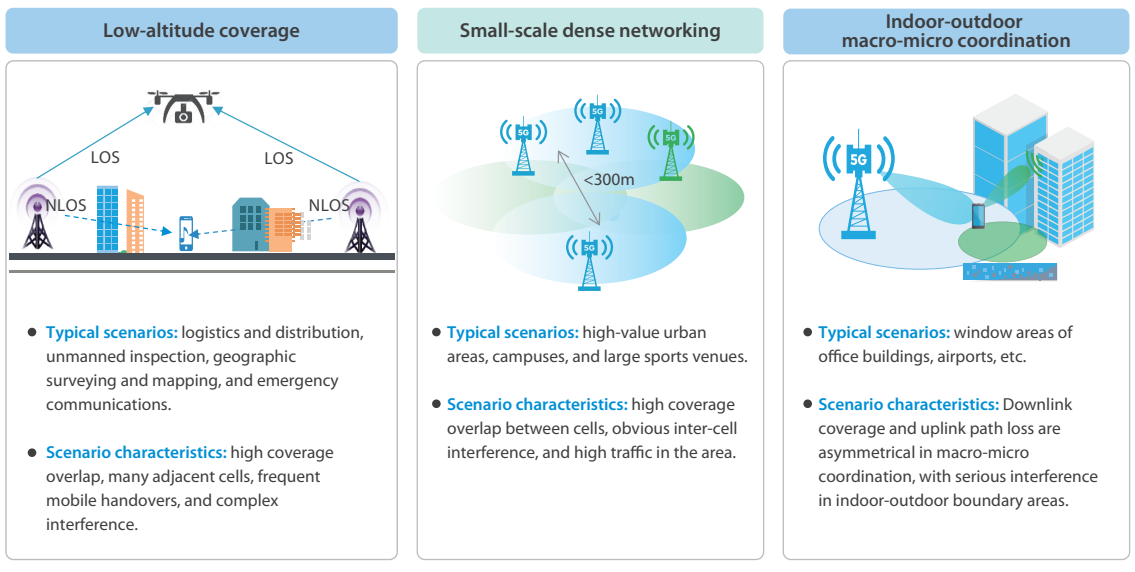

Fig. 2 User-centric CF-mMIMO network application scenarios.

> The user-centric CF-mMIMO network architecture is an innovative and forward-looking wireless communication technology.

- **Accuracy of channel state information estimation**

Accurate estimation of channel state information (CSI) is key to achieving high performance in CF-mMIMO networks. However, CSI estimation becomes more complex in non-cellular networks due to the distributed deployment of antenna units and user mobility. How to improve the accuracy of CSI estimation and reduce errors is a significant challenge for CF-mMIMO networks.

- **Complexity of resource allocation algorithms**

Resource allocation is a key technology in CF-mMIMO networks. Reasonable resource allocation can improve spectrum efficiency, energy efficiency, and service quality. However, in non-cellular networks, resource allocation needs to account for factors such as the distributed deployment of antenna units, user mobility, and service requirements, making the optimization of resource allocation algorithms difficult. Optimizing resource allocation algorithms to improve performance remains an important challenge.

Future Development Directions

With the development of 5G-A and future 6G communication technologies, multi-antenna technology will continue to evolve. Massive MIMO technology will further increase the number of antennas and system capacity, while new antenna technologies, such as smart antennas and reconfigurable antennas, will bring additional performance improvements to CF-mMIMO networks.

The application of AI in wireless communications is becoming increasingly widespread. In CF-mMIMO networks, AI can be used for channel state information estimation, service cluster formation, resource allocation, and other areas to improve system performance and intelligence.

CF-mMIMO can also be integrated with other emerging technologies such as intelligent reflecting surface (IRS) and millimeter wave communication to achieve higher spectral efficiency, energy efficiency, and coverage range. For example, IRS can enhance network coverage and improve signal quality by reflecting signals, while millimeter wave communication can provide higher data rates and lower latency.

At the same time, to promote the development of CF-mMIMO networks, relevant standards and specifications need to be formulated to promote the maturity and development of the industry chain. Standardization will ensure compatibility and interoperability between devices from different manufacturers, while industrial development will reduce equipment costs and enhance market competitiveness.

The user-centric CF-mMIMO network architecture is an innovative and forward-looking wireless communication technology. Although this architecture still faces many challenges, these challenges will gradually be resolved with the continuous technological development and innovation. In the future, CF-mMIMO network architecture will be widely applied in indoor wireless communications, intelligent transportation systems, industrial Internet of Things and other fields, bringing greater convenience and benefits to people's lives and work. ZTE TECHNOLOGIES

Hunan Telecom: 5G-A Intelligent Dual-Domain Collaboration Creating a New Network Experience

Tan Yonglong

RAN Product Director, ZTE

Wu Jian

Senior Technical Director of China Telecom Hunan Branch

The rapid development of 5G networks worldwide has created new opportunities and challenges for many industries. As 5G infrastructure continues to expand, operators are focused on efficiently managing and optimizing network resources to address issues such as spectrum imbalance and poor user experience across different scenarios. In response, Hunan Telecom and ZTE launched an innovative solution: "Intelligent Dual-Domain Collaboration". This technology enhances 5G signal quality, increases network resource utilization, and significantly improves user experience through intelligent collaboration across the frequency and spatial domains.

In constructing 5G networks, Hunan Telecom primarily face the following challenges:

- **Unbalanced spectrum resource allocation:** Indoor and outdoor spectrum resources are often unevenly distributed, making effective coordination in the frequency domain difficult. For example, in complex multi-scenario networks like universities, hospitals, business districts, and residential areas, coordinating and optimizing spectrum resources has become a bottleneck in enhancing network performance.
- **Poor user experience:** Indoor user experience in indoor-outdoor collaborative scenarios is often unsatisfactory, especially when network continuity and stability cannot be ensured during scenario handovers and cross-site processes, which affects the overall experience.
- **Equipment deployment falling short of expectations:** Existing network equipment fails to deliver its full performance and value. Its coverage and capacity don't meet user needs, resulting in a decline in user experience.

These challenges are common in the construction of 5G networks across the country, and innovative solutions are urgently needed to address the imbalanced allocation of indoor and outdoor spectrum resources, improve user experience, and tap the full potential of existing equipment.

To solve these pain points, the "Intelligent Dual-Domain Collaboration" solution based on 5G-Advanced (5G-A) technology was launched. This solution efficiently handles cross-site services through intelligent coordination across the frequency and spatial domains, improving both

user experience and network performance (Fig. 1). The implementation process involves three key strategies:

Strategy 1: Inter-Frequency Networking to Reduce Indoor and Outdoor Co-Channel Interference

In existing 5G networks, indoor and outdoor co-frequency networking often leads to mutual interference between macro stations and indoor cells, negatively impacting user perception. To address this, Hunan Telecom has implemented an inter-frequency networking strategy to separate indoor and outdoor coverage frequencies:

- The indoor coverage frequency band is 3.3 GHz, dedicated to indoor users, reducing reliance on outdoor spectrum.
- The outdoor coverage frequency bands are 3.4 GHz and 3.5 GHz, used to meet the wide coverage needs of outdoor macro stations.

This strategy effectively reduces conflicts between indoor and outdoor spectrum resources, minimizes interference, and ensures improved user perception in different scenarios.

Strategy 2: Airspace Integration, Flexible Handover and Capacity Enhancement in T+T and F+T Scenarios

Hunan Telecom has implemented innovative applications in multiple scenarios in airspace integration, enhancing the seamless experience for both indoor and outdoor users. By dynamically managing frequency bands and airspace resources, network capacity and coverage efficiency are significantly improved.

- **T+T handover scenario:** Through flexible integration of indoor and outdoor T-bands, cross-site carrier resources are fully utilized, improving both user download and upload rates.
- **F+T scenario capacity expansion:** In response to the insufficient capacity in the 2.1 GHz frequency band, Hunan Telecom expanded the capacity of the handover band through high-bandwidth macro stations, enhancing the user experience. The frequency integration of macro stations and spotlight antennas further maximizes the advantages of high- and low-frequency resources.
- **3CC bandwidth expansion:** In the combined scenario of 2.1 GHz, 3.4 GHz, and 3.5 GHz, indoor users gain overall perception improvement

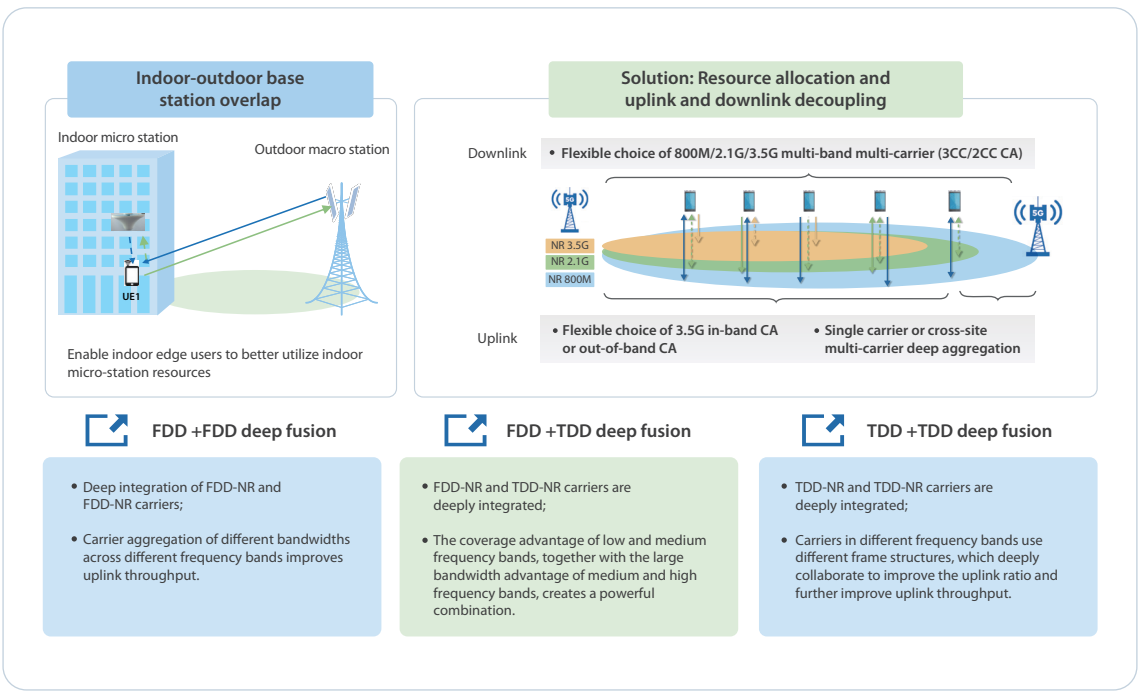

Fig. 1 Intelligent dual-domain collaborative solution.

through the uplink 2.1 GHz frequency band and downlink macro station bandwidth resources.

Through the airspace integration of these strategies, Hunan Telecom has effectively solved the capacity and coverage challenges in complex network environments, particularly in high-traffic scenarios such as universities, hospitals, and business districts, resulting in a significantly improved user experience.

Strategy 3: Intelligent Scheduling for Indoor and Outdoor Resource Coordination

Intelligent resource management strategies are employed for scheduling. By evaluating the downlink data transmission delay of each carrier, the carrier with the smallest delay is automatically selected for data offloading. This scheduling mechanism ensures that each user's data transmission experience is optimized and avoids network congestion and lag caused by uneven distribution of network resources.

In a pilot project at Changsha University of Science and Technology, intelligent scheduling nearly doubled mobile phone download speeds. Without expanding the capacity of existing sites, the average network speed of users at the edge of the base station community increased by more than 23%, while uplink speeds in nearby residential areas increased by over 36%. This achievement demonstrates the significant role of intelligent scheduling in enhancing network performance.

The "Intelligent Dual-Domain Collaboration" technology, jointly launched by Hunan Telecom and ZTE, not only underscores the importance of 5G in network evolution but also achieves efficient control over operating costs and improves investment returns in indoor and outdoor distribution systems. Through intelligent spectrum resource allocation and cross-site collaboration, 5G-A technology has increased Hunan Telecom's network traffic by more than 9% while greatly improving the user experience. It not only boosts the user's service experience but also promotes the efficient use of 5G network resources, leading to secondary traffic growth. In the Changsha Sanxiang Nanhu Building application, with the support of 5G-A, the average network speed of users increased by over 23%, fully reflecting the huge potential of 5G-A in various scenarios.

As 5G networks evolve, Hunan Telecom will further explore the application of 5G-A technology and promote the extensive deployment of 5G networks in various scenarios. Through continuous innovation and optimization, Hunan Telecom is committed to providing users with high-quality, efficient and intelligent 5G services, building a robust 5G-A commercial network, and achieving a comprehensive leap in signal enhancement, experience upgrade, and traffic growth. ZTE TECHNOLOGIES

Future Is Now: 5G-A Pioneers a New Era for Smart Parks

In Shanghai, a fast-growing and modern city, the combination of nature and technology delivers an aesthetically appealing vision of a futuristic metropolis. Century Park, located in the Pudong New Area and known as the city's "green lung," has seamlessly merged with neighboring communities after the removal of walls and landscape upgrades. Residents and visitors now have easy access to the park for relaxation and travel, benefiting from a variety of available services. The park's 24-hour accessibility fosters a deeper connection to nature, while requiring enhanced safety management and smart technological innovations. In an innovative execution of the "Citizen's City" concept, China Telecom Shanghai Branch and ZTE have partnered to integrate 5G-Advanced (5G-A) technology within the smart park, enhancing the visitor experience and upgrading park management to promote a harmonious integration of civilization and the environment .

Elevating Park Experiences with Ultra-High Capacity and Ultra-Low Latency Technologies

Millimeter wave technology, characterized by its large bandwidth, significantly larger frequency resources, and unique transmission behaviors, enables rapid data transfer, low latency, and highly-reliable communication—key to achieving the goals of 5G-A. With the implementation of millimeter wave technology, Century Park now offers optimized internet connectivity to residents. Visitors benefit from the ultra-high-speed internet connections to explore innovative entertainment options within the park, enhancing their overall experience.

Whether it's the beauty of the cherry blossom festival, the tranquility of summer night camping, or the bustling energy of weekend markets, every moment in the park is worth sharing. However, the

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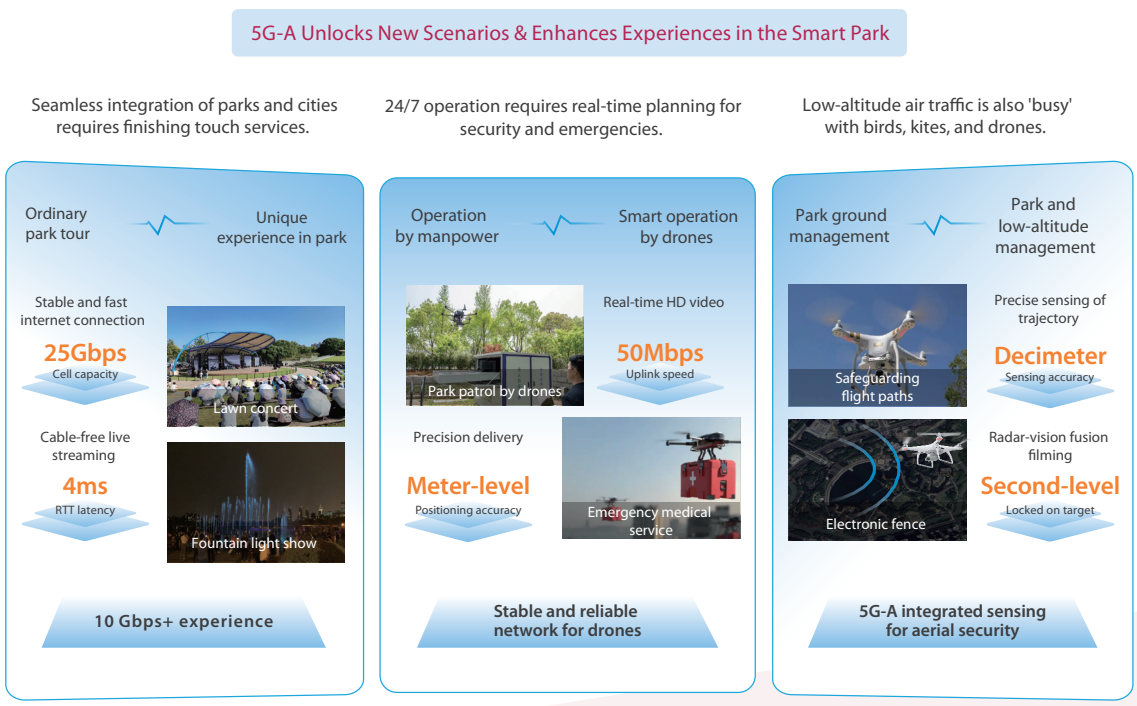
rapid sharing of these experiences was often delayed due to network congestion caused by large crowds. With network speeds exceeding 25 Gbps, 5G-A base stations enable instantaneous sharing of photographs or videos of blossoming cherry blossoms and live streaming under the starry sky, allowing users to seamlessly capture and share moments of joy.

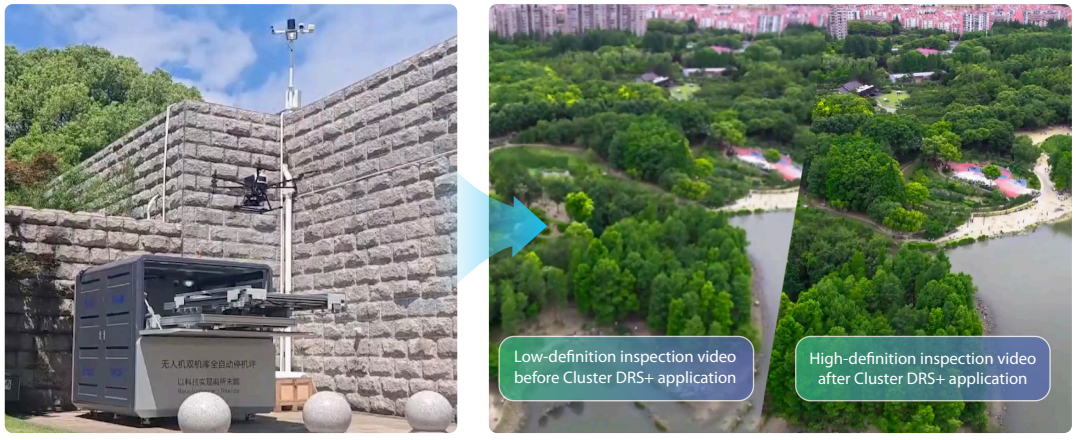
As people seek better enjoyment of life, parks have evolved from basic walking areas into desirable destinations for exploration and entertainment during holidays. Augmented reality (AR) park tours, powered by 5G-A, have transformed traditional walking experiences. Mobile devices can achieve downlink rates exceeding 6 Gbps, enabling instant access to vivid photos, videos, and 3D models. Imagine entering Century Park on a sunny day, using your phone or AR glasses to see virtual animal sprites jumping between branches or playing among the flowers. Guided by an AR tour, you can learn about various plants while searching for hidden digital treasures in every corner. These interactive experiences not only elevate the joy of park visits but also redefine family outings.

The Shanghai Nightlife Festival, themed "Tonight is the Night," showcases various citywide nightlife settings, including parks, rooftops, and waterfronts. 5G-A technology, with its ultra-low latency and great performance, enables live broadcasting without the limitations of cables, allowing photographers to move freely through crowds and capture every exciting moment. Real-time transmission of ultra-high-definition, lightly compressed video, powered by 5G-A, integrates seamlessly with video from wired cameras, allowing synchronized horizontal and vertical screen live streaming. Audiences at home can experience the vibrancy and romance of the scene as if they were right under the sparkling lights, immersing themselves in the charm of the city.

Enhancing Park Management with Cluster DRS+ and Integrated Sensing Technology

Century Park's 24/7 operation has increased the demand on its security and emergency response systems. In collaboration with China Telecom Shanghai Branch, the park has introduced drone security patrols that complement the smart surveillance system, establishing a comprehensive security mechanism for all weather conditions.





However, real-time transfer of high-definition inspection video from drones to the ground control center faces challenges due to low-altitude connectivity. The Cluster DRS+ solution effectively extends the ground 5G network coverage to 300 meters above ground level, enabling stable video feedback at 50 Mbps for drone patrols. This configuration guarantees excellent performance for drone operations through shared network resources via a virtual private network. A single 5G network, via adaptable resource allocation and synchronization, supports both ground-based users and low-altitude drones, delivering high-definition video experiences, lag-free gaming, and real-time high-definition video feedback to improve park inspection efficiency.

Beyond drone patrols, 5G-A integrated sensing and communication (ISAC) base stations have been deployed in Century Park to serve as "Air Navigation Towers" for drone operations. With their high-precision sensing capabilities and integrated computing power, these stations enable route planning for drone inspections and deliveries and offer continuous trajectory tracking and navigation assistance. At the Mobile World Congress Shanghai 2024, ZTE and China Telecom Shanghai Branch, in partnership with Antwork Technology, presented innovative services including on-demand drone delivery, meter-level positioning, and precise drop-offs inside the park, highlighting significant potential for various smart park services.

Furthermore, the increasing use of personal drones for flight testing and aerial photographs in Century Park presents new challenges for low-altitude management. Bird Island, the bird reserve in the park, often faces disturbances from drones. Low-altitude aerial photography during major events also requires strict control, with electronic no-fly zones established as needed. The implementation of 5G-A integrated sensing technology for real-time tracking of such areas significantly enhances park management. Unauthorized drone entry into no-fly zones triggers real-time alarms, with "radar-vision filming" providing video recognition and target locking within three seconds, providing adaptable and precise low-altitude security control for the park.

In the future, smart parks will integrate the natural world with human creativity, creating a harmonious environment that merges aesthetics with advanced technology for an accessible and inspiring experience. Century Park's implementation of 5G-A technology sets a benchmark for the parks of tomorrow. ZTE TECHNOLOGIES

TIM Brasil Tests ZTE's Solution that Saves up to 35% Energy

Source: Light Reading November 27, 2024

Marco Di Costanzo, CTO at TIM Brasil

The technology, which recently won "Most Innovative RAN Product or Solution" at the 2024 Leading Lights Awards, dramatically reduces the amount of radio units needed on cell towers while maintaining the same network coverage. ZTE's solution can reduce up to 57% of space on the tower and 35% of power consumption.

"This solution promises to fit well in the dimension of sustainability, lowering consumption and improving productivity and efficiency. With 5-band UBR solution we can reduce up to 57% of space on the tower and 35% of energy consumption", said Marco Di Costanzo, CTO at TIM Brasil, speaking at the ZTE 5G Summit and User Congress in Istanbul last week.

The technology works by integrating multiple pieces of equipment into a single box. ZTE can provide industry unique 5-band UBR with customized spectrum combination, so to

> **This solution promises to fit well in the dimension of sustainability, lowering consumption and improving productivity and efficiency. With 5-band UBR solution we can reduce up to 57% of space on the tower and 35% of energy consumption**

dramatically reduce the number of modules needed on cell towers, replacing up to 15 separate units with just 3.

The solution also features the industry's first hibernation technology, which can reduce power consumption to as low as 3W during periods of low traffic, combined with two-layer AI solutions that optimize energy usage. This simplification cuts both tower rental costs by over 60% and energy use by more than 30%, according to ZTE.

"We started by providing coverage in the major areas and big cities, and now we are leading Brazil's 5G landscape. We are number one in terms of sites and cities covered. We have already covered more than 500 cities with 5G, some of them with 100% coverage", Di Costanzo said.

However, despite this leadership position, TIM still faces significant challenges in expanding its network further.

"Brazil is a vast country—it's more like a continent than a country, so we cope with challenges covering such a large territory within a low-income environment," Di Costanzo explained. "We need to balance growth—that is, network development—with sustainability and profitability."

The UBR solution can help us to addresses these challenges, Di Costanzo said.

The new design makes sites easier to maintain and faster to install—important benefits in a country where technical teams must cover large territories.

TIM believes that the potential adoption of the UBR solution can leverage the expansion of 5G in underserved areas. "5G will help to reduce the digital divide", said Di Costanzo.

ZTE's new generation UBR series has already gained significant traction, with deployment underway by over 30 mobile operators worldwide. The technology was recognized as a market leader in 2023 by industry analysts Omdia and GlobalData, validating its position at the forefront of radio access network innovation.

"The commercial results demonstrate that the UBR series has successfully addressed the crowded conditions in the existing installation space of towers and poles, and remarkably reduced site power consumption," said Li Xiaotong, vice president of ZTE.

"We want access to products that are easy to buy, deploy, and maintain. That's why we rely on partners who provide us with the right services and products," Di Costanzo added. "All of this is aimed at maintaining our leadership, not just in coverage and connectivity, but also in providing new services for both individuals and industries".

TIM's market strength continues to grow, with its mobile customer base reaching 62 million. "Staying competitive is our key mission", said Di Costanzo. TIM Brasil and ZTE's collaboration dates back to 2012, when they first partnered to implement ultra broadband projects in São Paulo and Rio de Janeiro. The partnership expanded significantly in 2017 when ZTE won the largest share of TIM's GPON project, and by 2020, their joint efforts had helped grow TIM's fixed broadband users. In 2024, the partnership extended to the wireless part to foster network expansion and modernization. ZTE TECHNOLOGIES

ZTE

To enable connectivity and trust everywhere