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Special Topic

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Success Story

Telenor Pakistan

Harnessing the Power of AI

Reporter: Liu Yang

Awais Vohra

CTO at Telenor Pakistan

"There will be a multifaced impact of AI on our business; the strategic direction is to harness the potential of the innovations to benefit business and customers alike," said Awais Vohra, CTO at Telenor Pakistan, highlighting the pivotal role of AI in their current operations and future development in an interview with ZTE Technologies. He also discussed what makes them unique in the market, as well as their approaches to 5G, energy consumption, and OPEX. Telenor Pakistan is the country's third largest mobile operator, offering voice and data services primarily to prepaid customers.

Could you walk us through your journey, including when your career first began and how you became CTO at a brand like Telenor?

I started my professional career in 2000 with Siemens as an engineer. I joined my current employer, Telenor Pakistan, before the commercial launch in 2004, where I worked in different areas within the company. At the beginning of 2013, I went to Telenor Denmark, where I headed the core network. At the end of 2014, I came back to Telenor Pakistan and took over as Director Operations. That was the start of the working relationship with ZTE as ZTE was the supplier of network equipment and Managed Service partner. In 2018 I left Telenor Pakistan and joined Jazz as Vice President Operations, before coming back and joining Telenor again in 2020. In October 2021, I was appointed as the CTO.

What makes Telenor Pakistan truly unique as an operator in the highly-competitive market?

Pakistan is a very competitive market. The average revenue per user is around one dollar. At Telenor Pakistan, we run a very lean and efficient organization. For a network of over 13,000 cell sites spread over a vast geography, there are less than 1,000 employees. In terms of network operations, we also take a lot of pride in having the most efficient operations within the country and in Telenor group.

Pakistan is prepared to roll out 5G, which promises significant changes. How will Telenor Pakistan leverage this paradigm shift?

Pakistan is a country which is going through the digitalization journey. We have seen a big shift, especially in urban areas, that was accelerated post COVID. There is a need to have high-speed internet access across the country beyond urban centers to accelerate this journey. The new spectrum and technological evolution to high-speed, high-capacity networks will be a step forward in accelerating the digitalization. In this era, access to broadband and high-speed networks is fundamental for socio-economic development. We hope that government and regulator see the potential of high-speed networks in accelerating the socio-economic development of the country and the terms and conditions offered for new spectrum are reflective of government's ambitions of socio-economic development.

AI and large language models (LLMs) are transforming every aspect of life. Could you give us some insights how how they will impact the telecom sector? And what's your strategy towards AI?

AI is not only going to transform telecoms but all spheres of life. It's very important that we start taking AI as an enabler and take early positions that will help establish a strong foundation for the time to come. AI is poised to change customer interaction, customer offerings, customer communications and how the networks are operated—these are some of the examples. And all this is on the back of LLMs, human-like reasoning and decision-making. It is of paramount importance we remain at the cutting edge and not lag.

How would you utilize AI specifically?

Telenor Pakistan is using multiple AI use cases in Networks and IT to enhance operational aspects and efficiency. We are developing new use cases to automate tasks, improve customer interactions and optimize network through advanced data analytics. Additionally, AI use cases in finance will help with fraud control, prevention, and management.

Power is a major challenge in Pakistan. What actions are you taking to improve energy efficiency, and which solutions have caught your attention?

Telenor Pakistan is one of the most efficient operators in the country. We have invested heavily in solar power, with 23% of our network already solar powered. Energy prices are quite high, and energy efficiency is one of the criteria for any new

> For over a decade, ZTE has been a trusted partner. ZTE has good technology roadmaps, providing opportunities for strategic partnership in future.

purchase of equipment. Telenor Pakistan has invested in AI to help us get the maximum efficiency in energy.

Telenor is also a signatory of COP29. We have the target to reduce our power consumption to half of the 2019 level. There are programs we are running for energy efficiency that are contributing towards achieving this goal.

Telenor Pakistan and ZTE have cooperated for over 10 years in diverse areas. How is this partnership progressing, and what's next for it?

The partnership began in 2012 and since then it has been progressing well. ZTE is the major supplier of Telenor Pakistan's radio network, CORE VNFs, IP and transmission networks. For over a decade, ZTE has been a trusted partner. ZTE has good technology roadmaps, providing opportunities for strategic partnership in future.

As CTO, balancing network performance and operational costs is a significant challenge. What approaches are you implementing to create an OPEX-efficient operating model?

That is very important. As I said earlier, we rely on partners like ZTE to come up with solutions that are customer-centric and efficient. And future product roadmaps are well aligned. ZTE TECHNOLOGIES

Orange Liberia

Empowering Rural Liberia Through Digital Inclusion

Reporter: Yang Yan

Jean Marius Yao, CEO of Orange Liberia, highlights the critical need for reliable communication services and discusses the company's ambitious initiative to bridge the digital divide in rural Liberia. Orange Liberia, in partnership with ZTE, has successfully deployed 128 communication sites in rural areas, significantly enhancing network coverage and accessibility for the underserved populations, benefiting over 580,000 rural subscribers.

Jean Marius Yao
CEO of Orange Liberia

Can you elaborate on the initial motivation behind Orange Liberia's decision to undertake this ambitious rural network deployment project?

The demand for the development of mobile telecommunication service infrastructure in Liberia is significant. Previously, our network coverage was mainly concentrated in the capital and some major towns, leaving a significant portion of the rural population disconnected from the digital world.

Orange Liberia recognized the critical needs for reliable communication services in the rural areas, where access to information and opportunities is limited. Our goal is to empower these communities, to "Include Digital in Every Liberian Life", by providing them with the tools necessary to participate fully in the digital economy and improve their socio-economic well-being. This is also in line with our vision to be the preferred Liberian multi-service operator and partner of choice for digital, financial, and energy inclusion while respecting ethics and the environment.

What is the biggest challenge in enhancing network coverage in rural areas?

Building networks in rural Liberia comes with significant challenges—poor infrastructure, limited road access, and electricity are major hurdles. With only around 28% of the population having access to electricity and a long rainy season, construction and

One of the communication sites deployed by Orange and ZTE.

maintenance are costly and slow.

Traditional networking solutions yield low returns on investment, hindering the establishment of a positive cycle.

Establishing a network is crucial for residents in remote areas, as it can significantly improve their lives. Finding an effective way to connect the unconnected population is a shared goal.

What's your solution for the rural network coverage in Liberia?

Our rural network project covers numerous rural areas across Liberia, offering an innovative solution, which is called Rural EcoSite, to provide effective, green, and affordable mobile communication, significantly enhancing network coverage in rural areas. This enables remote populations to access information and knowledge in a timely and barrier-free manner through open and free channels, benefiting from knowledge and information acquisition and achieving information literacy. We have successfully deployed all sites and are continuously optimizing network performance.

Despite the challenges, collaborative efforts have led to the deployment of 128 sites in just three months. Over 580,000 subscribers in rural areas now benefit from enhanced digital and financial services with our Orange Money, and energy inclusion, as all the sites support 2G and 4G network services.

How has your partnership with ZTE been instrumental in the success of this rural network deployment project?

Our partnership with ZTE has been pivotal. Their expertise in telecommunications, combined with a shared commitment to digital inclusion, made this project possible. Together, we've tackled unique challenges with innovative solutions, ensuring efficient execution.

By leveraging each other's strengths, we've been able to not only deliver on our commitment to "Enhance Rural Area" but also pave the way for future collaborations that can further drive digital development in Liberia and beyond.

What value does Orange Liberia see in enhancing digital inclusion in rural areas, and what are the future plans for this initiative?

We view this as a long-term partnership for local sustainable development. Our work is not just about improving connectivity, but about creating it where there was none before. As we expand our rural network, our focus will remain on user services—ensuring the network supports the daily lives and productivity of locals, from farmers to students.

We're dedicated to making sure that every corner of Liberia is connected, empowering all citizens to participate fully in the global digital economy. ZTE TECHNOLOGIES

New Industrial Networks: Driving High-Quality Growth

Shu Yu

Chief Expert on Wireless Industry Solution Planning, ZTE

Sheng Feng

RAN Solution Manager, ZTE

At the intersection of technological revolution and industrial transformation, the industrial sector is undergoing a rapid transition from digitalization toward intelligentization. As the paradigm evolves from Industry 4.0 to Industry 5.0, the deep integration of digitalization, networking, and intelligence has emerged as a pivotal driver of new industrialization.

Industrial networks are experiencing a fundamental transformation—from traditional "connectivity infrastructure" to intelligent "central systems" equipped with sensing, computing, and decision-making capabilities—emerging as the key infrastructure underpinning enterprises' digital and intelligent transformation.

This article will explore how new industrial networks are redefining their capability boundaries under the trends of multi-technology convergence and network-service integration, and how they drive the industrial ecosystem toward greater openness, collaboration, and intelligent decision-making.

New Industrial Network Momentum

Coordinated Development of Information Technology (IT), Operational Technology (OT), Communication Technology (CT), and Data Technology (DT)

From the automation of Industry 3.0 to a new era of industrialization marked by Industry 4.0 and even Industry 5.0, the central theme has always been the deep integration of digitalization, networking, and intelligence. As a core pillar of new industrialization, intelligent manufacturing is powered by intelligent equipment, industrial software, and industrial networks. Compared with the fragmented development of intelligent equipment and industrial software, industrial networks offer more replicable and systematic pathways to significantly improve overall efficiency, becoming the key lever to break through this fragmented pattern.

By linking production elements—people, machines, materials, methods, and environments—new industrial networks enable data-driven precision decision-making and foster cross-layer, cross-domain industrial ecosystems through the coordinated integration of IT, OT, CT and DT.

In terms of technological synergy, the deep integration between industrial Internet platforms (IT) and production line automation systems (OT)

enables efficient data flow from the production floor to management layers, accelerating the digital and intelligent transformation of OT systems. For example, real-time data collection and analysis via industrial networks allows for dynamic optimization of production parameters, enabling predictive maintenance and iterative process improvement. Meanwhile, the deep involvement of CT—such as 5G and time-sensitive networking (TSN)—provides deterministic network assurance for low-latency scenarios, while DT—including big data and AI—drives innovation in production models through data modeling.

Transition from Network-Service Separation to Integration

The development of China's 5G networks has been driven by operators. It has progressed from the large-scale deployment of virtual private networks to the continuous exploration of independent private networks, forming a critical part of the new industrial network landscape.

5G virtual private networks exemplify the concept of the sharing economy by offering enterprises efficient access to public network and cloud resources, thereby accelerating the convergence and upgrade of IT informatization and OT automation. In this model, enterprises can deploy non-sensitive services in mature cloud service environments provided by operators, enabling flexible access and unified management similar to that of "external network services." This approach not only reduces network construction costs but also presents operators with a high-value entry point into the government and enterprise market.

In contrast, independent private 5G networks focus more on enterprises' core requirements for data sovereignty, flexible network scheduling, and service security and reliability. By integrating innovative technologies such as digital twin, artificial intelligence, and computing-network convergence, they serve not only as dedicated communication channels but also as key enablers of enterprises' digital and intelligent transformation.

These two network models fulfill distinct yet complementary roles, collectively driving a paradigm shift in industrial network construction—from the traditional "network-service separation" toward the emerging "network-service integration." This evolution not only enhances the agility and adaptability of enterprise networks, but also fosters deeper collaboration between

enterprises and network operators, laying the foundation for a more intelligent and service-oriented industrial ecosystem.

Digital and Intelligent Pathways for New Industrial Networks

As digitalization and intelligentization rapidly converge, industrial networks are evolving from providing mere "connectivity" to "service." The introduction of new technologies such as 5G and edge computing has not only enhanced network capabilities, but also driven the industrial Internet ecosystem from isolation toward openness, and from fragmentation toward collaboration, laying a solid foundation for building a smart, flexible, and sustainable next-generation industrial system.

Beyond Connectivity: Unleashing 5G for Enterprise Digital Transformation

5G networks originate from the mobile cellular architecture and were designed from the outset to meet widespread, ubiquitous mobile communication needs. With features such as unified planning, centralized management, and a service-oriented architecture, 5G networks align well with the trends of new industrialization. They demonstrate greater adaptability and enhanced support, especially as enterprises evolve from single production lines to multi-site collaboration and from closed internal manufacturing to socially distributed production.

Moreover, 5G networks offer robust support for virtualization and can be deeply integrated with multi-access edge computing (MEC), enabling coordinated use of edge computing resources and network capabilities. Through network slicing and SLA assurance mechanisms, 5G can flexibly construct a variety of specialized communication services—such as voice communication, cluster dispatching, broadcasting, high-precision positioning, and sensing and detection—tailored to the specific requirements of different industries and scenarios. This provides enterprises with richer network functionality options and greater customization space.

Therefore, in supporting enterprise digital transformation, equipment vendors and operators should not only provide standardized connectivity, but also leverage their accumulated expertise in network planning, system integration, and service assurance. By gaining insights into industry-specific needs, they can drive continuous innovation in products, solutions, and services, and jointly build an open, collaborative, and mutually beneficial industrial ecosystem.

From Connectivity to Services: Building the New Industrial Network Ecosystem

In the era of booming digital and Internet services, leading OT automation manufacturers have launched open architectures and product systems similar to application stores. In addition, operators and Internet enterprises are actively exploring cloud-native service models, aiming to provide comprehensive industrial Internet application services. From traditional CNC machines to modern AGVs and robots, a growing range of devices are evolving into intelligent equipment. This trend of technological convergence is blurring industry boundaries and creating a more symbiotic ecosystem.

Amid this trend of convergence, technology suppliers that have traditionally focused on a specific domain or a certain link of the industry chain can not only continue offering standardized products and services, but also, in a more open and collaborative manner, deliver innovative and intelligent solutions centered on customer value. These solutions, while retaining traditional automation technologies, integrate technologies such as big data, AI and edge computing to meet customers' growing and diversified requirements. For example, the application of a digital twin cockpit in an automatic screw-fastening machine boosts production efficiency and elevates equipment intelligence, providing new directions for the future of the manufacturing industry.

To generate greater value in this transformation, it is necessary to look at the communications industry, whose success has been built on standardization, industry chain coordination, and the ability to provide standardized and customized user services. In the context of new industrialization, it is essential to fully leverage the mature mobile smart terminals and mobile Internet service models developed in the public network and extend them to enterprise-level industrial Internet applications. The key pathway to achieving this goal is the evolution from the traditional seven-layer ISO/OSI model to today's cloud-edge-end architecture. This evolution is essentially a process of streamlining layers and restructuring functions, which helps reduce the complexity and costs of system coordination, data flow, and business integration for enterprises.

However, the industrial sector still faces a number of structural challenges. Traditional OT automation integrators tend to address specific problems with customized solutions. While such an approach can maximize benefits at a single point, it may not be optimal from a broader social efficiency perspective. Drawing on the experience of the mobile Internet, a centralized IT service model for enterprises—featuring standardized IT services and smartphone-like terminals—can effectively improve both social efficiency and the operational efficiency of large-scale enterprises. To support this shift, equipment vendors and operators should transform from being mere connectivity providers into service enablers, building a future-ready industrial Internet ecosystem together.

Towards Proactive Services: AI Agents Reshaping Capabilities of Industrial Networks

With breakthroughs in large AI models and AI agent technologies, industrial networks are transitioning from passive connectivity to proactive services. Traditional networks merely enable signal transmission at the physical layer, whereas intelligent networks, empowered by AI agents, enable perception, coordination, and autonomous decision-making across key production elements.

In complex manufacturing environments, intelligent agents can digitally represent devices, systems, and personnel, enabling cross-layer and cross-domain collaboration through distributed intelligence. For instance, when a production line fails, an intelligent network can respond automatically: isolating the faulty device at the physical layer, adjusting network resources at the network layer, and pushing repair instructions to terminals at the application layer. This creates a closed-loop system for fault management, improving both system resilience and efficiency.

In the future, industrial networks will go beyond their traditional role as communication pipelines. By leveraging AI agents and digital twin, they will offer value-added services such as proactive sensing, predictive maintenance, and energy efficiency optimization. New industrial network providers will not only be responsible for connecting physical infrastructure but must also embrace open innovation and architectural evolution—paving the way for a new paradigm of "intelligent connectivity + proactive services".

As a key driver of high-quality industrial development, new industrial networks are providing enterprises with unprecedented momentum. ZTE remains committed to continuous innovation and the development of replicable models to unlock customer value and accelerate industrial development. We believe that through continuous technological innovation and real-world applications, the new industrial networks will enable enterprises to grow faster and smarter in the digital and intelligent era. ZTE TECHNOLOGIES

5G-A and AI as Dual Engines: Building a Future-Oriented Foundation for Industrial Digital Intelligence

Wang Jingfei

Director of 5G ToB Business, ZTE

He Jiqing

Director of 5G ToB Industrial Solution, ZTE

AI is leading a new round of technological revolution and industrial transformation, injecting strong momentum for innovation across industries, reshaping production methods, restructuring productivity, and accelerating the industry's transformation towards a more digitalized, connected, intelligent, and sustainable future. With the deep penetration of AI applications such as industry-specific large models, AI agents, and embodied robots into the entire production process, real-time information exchange, data processing, and decision-making increasingly require a robust digital intelligence foundation.

Challenges Faced by Industrial Digital Transformation

Due to industry differences, diverse application scenarios, and varying stakeholder interests, the infrastructure of vertical industries has long been characterized by a coexistence of multiple technologies and uneven levels of development, facing the following challenges:

- **Closed architecture:** Traditional industrial networks are based on the closed ISA-95 architecture, forming vertically segmented hierarchies and data silos where resources and data cannot be fully shared or circulated.
- **Limited flexibility:** Most production networks rely on wired fieldbus and industrial Ethernet. The resulting complex cabling creates challenges for enterprise network deployment, maintenance, and transformation.
- **Difficulty in intelligent upgrading:** Legacy equipment with high value and long life cycles, coupled with insufficient computing resources and low intelligence levels, hinders the industry’s digital and intelligent transformation.

To effectively empower this transformation, it is necessary to utilize emerging technologies such as 5G-A and AI to build a new type of industrial digital intelligence foundation.

Towards a New Industrial Digital Intelligence Foundation with 5G-A and AI

5G-A and AI, as two of the most representative technological innovations, are mutually reinforcing each other, emerging as dual engines driving the development of industrial digital intelligence (Fig. 1). On one hand, the introduction of AI unlocks the full potential of 5G-A networks by improving 5G-A transmission efficiency and enabling network intelligence, allowing 5G-A to better serve vertical industries. On the other hand, 5G-A, with its proximity to production operations, delivers enhanced mobility, real-time performance, security, and cloud-edge-end collaboration, thereby providing stronger infrastructure support for AI applications.

As 5G-A, AI, cloud computing, and other emerging technologies become increasingly integrated into industries, industrial digital transformation is giving rise to a wide range of new scenarios and applications, while the restructuring of the industrial ecosystem is accelerating. There is an urgent need for upgrading the underlying computing and network infrastructure.

To address this, the new industrial digital intelligence foundation should adopt a flat three-tier architecture consisting of on-site, edge, and center layers, integrating cloud, network, computing, and applications to enable deep convergence of operational technology (OT), information technology (IT), communication technology (CT), and data technology (DT).

It is characterized by ubiquitous interconnection, deterministic capabilities, computing-network-application integration, openness and intelligence, as well as security and controllability.

- **Ubiquitous interconnection**

Based on various wired and wireless network technologies such as 5G-A, industrial optical networks, industrial Ethernet, and time-sensitive networking (TSN), a ubiquitous interconnected converged network can be constructed. It will meet the diversified networking requirements of different devices and application scenarios, achieving full connectivity among all key production elements, including man, machine, material, method, environment and measurement, and enabling data connectivity, integration, and interoperability across devices, systems, and vendors.

- **Deterministic capabilities**

As an enhanced evolution of 5G technology, 5G-A provides commercial-grade deterministic capabilities, including 4 ms low latency with 99.99% reliability, millisecond-level jitter, 24/7 high

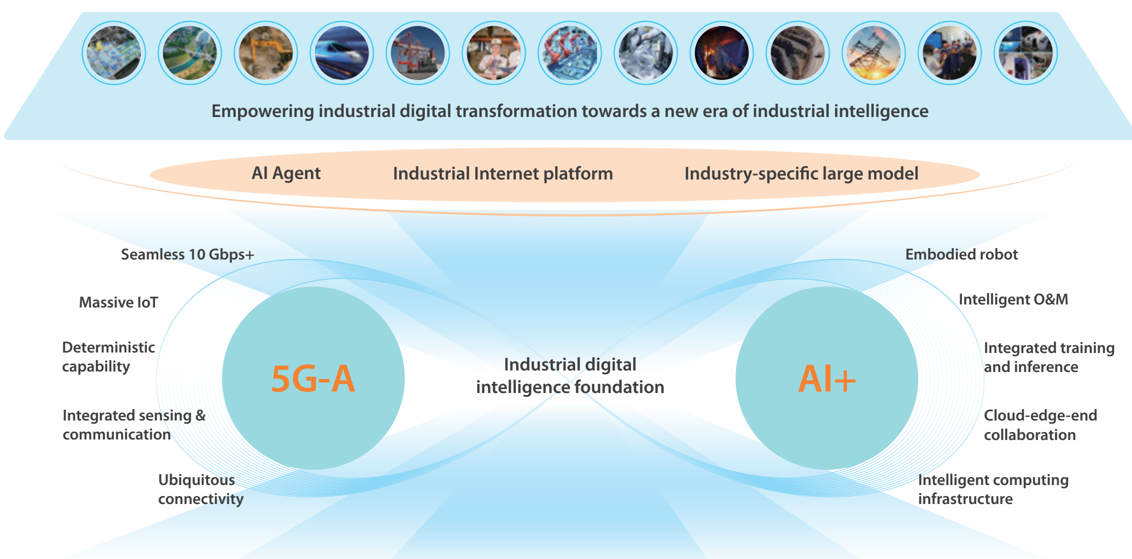


Fig.1 5G-A and AI serve as the foundation of industrial digital intelligence.

availability, 1 Gbps uplink bandwidth, on-campus data retention, and 5G LAN support. It also supports lightweight, low-cost RedCap terminals, integrated sensing and communication, and Ambient IoT, better meeting the requirements of industrial production control, flexible production, large-scale equipment access, warehousing management, the Internet of Vehicles, and the low-altitude economy.

- **Computing-network-application integration**

The intelligent digital foundation enables collaborative computing across cloud, edge, and device. The development of platforms like DeepSeek and Manus is driving a shift in the structure of computing power demand from training-centric to inference-centric. The demand for edge computing power closer to applications has exceeded that of centralized computing power, gradually forming a distributed computing power system with centralized training, diversified inference and edge-oriented deployment. Computing power collaboration relies on a cloud-edge-end computing network to perceive, measure, schedule, and control distributed computing resources, achieving unified access, management, and dynamic scheduling to better meet application needs and improve resource utilization.

Based on 5G-A all-in-one equipment, the integrated deployment of computing, network and applications enables dynamic resource sharing, allocation, orchestration and scheduling. This facilitates the deep convergence of IT, OT, CT and DT, while ensuring that SLAs are met. For example, in production control applications involving PLCs, uncertainties in delay and jitter may cause service interruption. Based on TSN clock synchronization, the 5G-A network globally orchestrates the control data, aligning data transmission timing with 5G scheduling cycles, thus ensuring the continuity of production processes.

- **Openness and intelligence**

Based on open standards, technologies, and interfaces, a full-stack open architecture enables the decoupling of network protocol layers, device software and hardware, applications and networks, models, as well as training and inference, fostering an open industrial ecosystem.

AI deeply empowers 5G-A networks and comprehensively enhances their connectivity, computing, and O&M capabilities. In connectivity, AI optimizes resource allocation and utilization, enables precise service perception and assurance, and enhances end-to-end deterministic capabilities. In computing, AI accurately predicts demands and schedules resources, achieving coordination and optimization across cloud, edge, and end computing resources. In O&M, AI agents enable networks to be self-aware, self-diagnosing, and self-repairing, while also assisting in fault delimitation and localization through interactive intelligent O&M.

- **Security and controllability**

Through enhanced capabilities in proactive defense, intelligent perception, and collaborative handling, endogenous security ensures stable, reliable, secure, and trustworthy network infrastructure and data.

Data controllability is achieved by building a computing-network system in which data flow, usage, and security risks are all effectively controlled, thus meeting the industry's stringent security requirements for data.

The Industrial Digital Intelligence Foundation Facilitating Innovation in Intelligent Applications

AI is driving innovation and transformation in various industries. The digital intelligence foundation, deeply integrated with the industrial Internet, has been successfully applied to R&D, production manufacturing, business management, and O&M, empowering enterprises to optimize resource allocation, improve quality, reduce costs, and increase efficiency.

- **Industrial Internet platform**

The industrial Internet platform connects devices vertically and the enterprise horizontally, establishing data links throughout the product lifecycle. It forms an intelligent closed-loop system for optimized decision-making covering R&D, manufacturing, marketing, service, and the supply chain by integrating technologies, consolidating resources, and accumulating mechanisms. The industrial digital

> **5G-A and AI are still developing and evolving rapidly. They will continue to deeply integrate with the industrial Internet, complementing and empowering each other to build a future-oriented industrial digital intelligence foundation that enables new industrialization.**

intelligence foundation provides data, scenarios, and computing power for industrial Internet platforms, offering comprehensive support from data collection to highly reliable data transmission and edge-cloud computing power assurance.

- **Industrial large models and AI agents**

DeepSeek greatly reduces computing power requirements and lowers the application threshold for large models, accelerating their application and implementation in industry. Manus drives the transition of AI from a tool to an autonomous decision-making entity, achieving breakthroughs in the industrial application of AI agents. Large models and AI agents have been widely used in intelligent production scheduling, intelligent production resource allocation, production plan monitoring and execution, and process document generation, greatly improving industrial intelligence. Through the multi-agent collaboration architecture based on the model context protocol (MCP), enterprise-developed agents can be integrated into the system via external plug-ins, replacing traditional customized enterprise application development with AIGC-based approaches, and significantly improving the efficiency of enterprise application development and delivery.

- **Embodied robot**

In recent years, embodied robots have developed rapidly and shown broad prospects in industries such as manufacturing, home services, and education. They are well-suited for scenarios that require physical interaction, strong environmental adaptability, and tasks that are difficult to complete efficiently by manpower, such as flexible assembly, sorting, and packaging. They effectively solve the automation challenges of the "last meter" in production and logistics. The industrial digital intelligence foundation provides both cloud and edge computing power for embodied robots, ensuring smooth, high-bandwidth, and low-latency communication between the "brain" (cloud), the "cerebellum" (edge), and the motion control system.

The 5G-A+AI-powered industrial digital intelligence foundation serves as a key infrastructure for new industrialization and as a platform for the deep integration between the digital and real economies. Leveraging policies such as intelligent manufacturing, 5G + Industrial Internet, and AI Plus, it is being fully integrated into industrial intelligent transformation and 5G factory development. Through ongoing practice, it continuously improves and iterates on capabilities across networks, computing power, platforms, security, and other components, achieving innovative integration of technologies and applications and driving symbiotic advancement.

5G-A and AI are still developing and evolving rapidly. They will continue to deeply integrate with the industrial Internet, complementing and empowering each other to build a future-oriented industrial digital intelligence foundation that enables new industrialization. With the vision of becoming a leader in network connectivity and intelligent computing, ZTE is committed to driving the digital economy and working hand in hand with industry partners to usher in a new era of industrial intelligence. ZTE TECHNOLOGIES

From Shared to Dedicated

Exploration and Practice of Independent Private 5G Networks

Ni Yanzi

Director of RAN Solution, ZTE

Wang Hongxin

Senior Engineer of RAN Planning, ZTE

As 5G technology matures and costs decrease, 5G private networks are gaining broader adoption across industries. The 5G private network market size is expected to reach US$3.06 billion in 2025 and grow at a CAGR of 43.60%, reaching US$18.68 billion by 2030. China has been proactive in this space, using 5G private networks to drive the digital transformation of its real economy.

Independent Private 5G Networks Enter a New Phase with Three Key Advantages

Six years after the commercial launch of 5G, China has deployed over 4.39 million 5G base stations and initiated over 40,000 industry-specific 5G private network projects across 41 sectors. Operators have utilized technologies like network slicing and edge computing to create virtual private networks, which

have achieved large-scale application in fields like smart manufacturing and intelligent port operations. In 2024, the three major operators reported over 60% year-on-year growth in 5G private network revenues.

While virtual private networks offer rapid deployment and cost efficiency by utilizing operators' public network resources, they fall short of meeting the demands of numerous vertical industries and the fragmented B2B market. Industrial giants require strict control over networks and data isolation; sectors such as manufacturing, power, and railways need to ensure ultra-high reliability in extreme environments; meanwhile, small and medium-sized enterprises are seeking a balance between affordability and technical capability. The industry is actively exploring innovative models for independent private 5G networks.

Chinese policy has consistently supported the development of independent private networks. The Action Plan for the Innovative Development of the Industrial Internet (2021-2023) called for "exploring construction and operation models for 5G networks." The upgraded "5G + Industrial Internet" 512 Project Action Plan, released by the Ministry of Industry and Information Technology (MIIT) in 2024, proposed promoting the orderly pilot deployments of industrial independent private 5G networks. Furthermore, the national industrial and informatization work conference identified "advancing the construction of industrial independent private 5G networks" as a key task for 2025.

Compared to widely used virtual private networks, independent private 5G networks rely on dedicated resources and operate separately from public networks. All 5G network elements (NEs) and management systems are specifically built for enterprise use. What makes independent private 5G networks unique? Their features and advantages can be highlighted across three key dimensions:

- **From shared to dedicated resources**

Virtual private networks rely on public network slicing or local offloading from operators to achieve resource sharing and logical isolation. In essence, they still use dynamically allocated resources from a shared pool. In contrast, independent private networks are physically isolated through dedicated infrastructure, giving enterprises full control over resources and completely avoiding public network traffic interference.

- **Architecture autonomy: from "restricted by public networks" to "deep customization"**

Virtual private networks are constrained by public network architectures, making industry adaptation challenging, especially for in-depth industrial protocol integration and customized industry solutions. In contrast, independent private networks can be deeply customized to meet industry-specific requirements—for example, supporting seamless integration of time-sensitive networking (TSN) with industrial Ethernet protocols, and incorporating edge computing and digital twin modules to achieve OT/IT convergence. In addition, they allow enterprises to independently manage and optimize network resources.

- **Data and security control: from "logical isolation" to "physical independence"**

A virtual private network relies on network slicing or local offloading to achieve logical isolation. Data is transmitted over local or public networks according to predefined rules. In some scenarios, data falls outside the enterprise's direct control. Moreover, as the underlying infrastructure is shared, its security protection follows the existing design.

Independent private networks establish data and security boundaries through physical isolation, and all data can be independently controlled. Enterprises can set strict security policies from air interface encryption to data transfer, enabling true autonomy over both data and security.

ZTE Enriching Its Independent Private 5G Network Solutions

ZTE continues to enrich its private network solutions to meet the customized, fragmented, and diverse demands of various industries. By upgrading 5G networks across multiple dimensions—including expanding depth and breadth, enhancing quality, and reducing costs—ZTE strengthens both its network technologies and product offerings to deliver tailored independent private 5G network solutions.

In terms of network technologies, ZTE provides flexible and customizable 5G private network

High Concurrency 1000 connections/cell	Large Bandwidth Gbps	High Availability No interruption	Low Latency 4ms@99.999%	Low Jitter us	Precise Positioning cm
RedCap/A-IoT	1D3U SuperMIMO	Board/link backup FRER	URLLC guarantee	TSN	UTDOA/AOA 5G hybrid positioning

Local interconnection	Local computing	Security	Isolation
5G LAN/VxLAN	Gateway/edge computing resources	Multi-level protection scheme	Slicing

Fig. 1 Independent private 5G network technology.

solutions through a multi-tiered architecture: virtual private networks (using 5G slicing for basic isolation), hybrid private networks (leveraging UPF/NodeEngine for efficient local data offloading), and independent private networks (featuring end-to-end dedicated deployment). These diverse private network options cater to various needs of different industries. Moreover, ZTE is advancing its 5G-A technology, offering ultra-high bandwidth (up to 10 Gbps), millisecond-level latency, microsecond-level jitter, and high reliability to support core production operations. By integrating reduced capability (RedCap) technology, ZTE reduces terminal costs and power consumption, meeting the demands of large-scale industrial connectivity (see Fig. 1).

In terms of product offerings, ZTE introduces a series of industry-specific products (see Fig. 2), with enhancements in functionality, coverage, and positioning. Functional capabilities have evolved from communication to integrated computing and communication, enabling hyper-converged, lightweight independent private 5G network products. Coverage has been extended to support diverse, high-risk production environments through the provision of explosion-proof, movable campsite base stations. Moreover, the solution positioning has shifted from network-oriented to service-oriented, offering IT-driven operational platforms (e.g., ToBeEasy), portable 5G testers, and 5G TSN industrial gateways to enable rapid deployment and IT-based operations.

Independent Private 5G Network Deployment Delivers Value Through Precise Demand Matching

With its innovative network technologies and customized products, ZTE has developed a wide range of independent private 5G networks solutions. By accurately understanding the unique requirements of different industries, ZTE customizes network architectures accordingly, and delivers independent private 5G networks that precisely meet industry-specific demands, demonstrating powerful potential and broad prospects.

Industrial Sector

- **In the steel industry,** ZTE has established a private 5G industrial control network to support unmanned cranes and unmanned transportation. For example, at WISCO (Wuhan Iron and Steel Corporation), the private 5G industrial control network has been applied to core production areas, supporting the widespread use of unmanned cranes in hot rolling, cold rolling, and silicon steel workshops. More than 50 cranes have been upgraded, helping the iron and steel industry reduce costs and improve efficiency.
- **In the mining industry,** 5G explosion-proof base stations have been deployed to build underground 5G private networks, supporting applications such as voice communication in coal mine tunnels and intelligent inspection robots. For instance, at China Energy Group's Qipanjing

project, 5G mid-low hybrid-frequency networking is used to provide full coverage in both ground factory areas and underground environments, facilitating the transition from "fewer people" to "no people", and from "automation" to "intelligence."

- **In the industrial manufacturing sector,** the independent private 5G network offers a low-latency, high-reliability on-site network. It supports intelligent AGV scheduling and collaborative PLC control, enhancing equipment connectivity and production efficiency. For example, an automobile company has deployed a 5G private network as the digital and intelligent foundation of its factory. It ensures stable access for production equipment and, through the full integration of OT, IT, and CT (OICT), enables upgrades to core automotive production processes.

Energy Sector

- **In the power grid industry,** the dedicated private 5G network, by integrating technologies like IoT, big data, AI, cloud computing, and edge computing, provides a digital and intelligent infrastructure for building smart power plants. It supports typical services such as production control, intelligent inspection, operation and maintenance, and emergency response. For example, at the Hanchuan power plant, a 5G private network has been deployed to enable high-precision personnel positioning for enhanced security management, UAV-based inspections for improved efficiency, and remote-assisted maintenance for faster response times.
- **In the oil and gas industry,** the private 5G network for offshore production enables the upload of production data from unmanned drilling platform operations, ensures high-reliability remote control, and separates the internal production and office networks from the public network, guaranteeing intelligent oilfield production.

Transportation Sector

- **In the port industry,** ZTE provides independent 5G private networks to support unmanned horizontal and vertical transportation from storage yards to ships, accelerating the automation of port operations. For example, the independent private 5G network at Longgong Port in Shandong has created China's first automated multi-lane transport

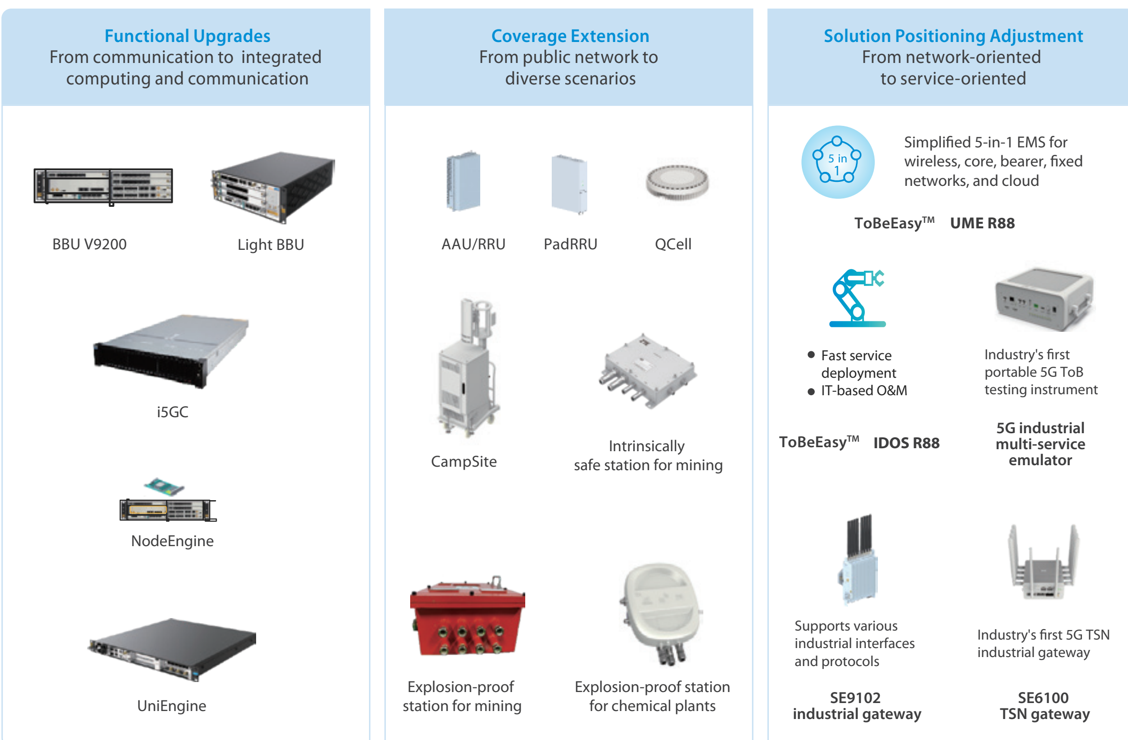


Fig. 2 A series of ZTE's 5G private network products.

> **Driven by robust technological innovation, expanding application scenarios, and industry-wide collaboration, independent private 5G networks are emerging as a key driver of industrial development.**

park, integrating 5G technology, low-carbon operations, and canal-specific advantages.

- **In the rail transit industry,** the 5G private network supports the in-train CCTV video surveillance system, onboard PIS system, and intelligent O&M system for both trains and the rail network, promoting multi-network integration in metro systems. On Tianjin Metro Line 3, leasing private 5G networks from operators instead of building self-owned infrastructure enables more professional services and higher network efficiency, achieving both cost reduction and performance enhancement.

Entertainment Sector

- **In the wireless live broadcasting industry,** the transition toward high definition and wireless connectivity is ongoing. ZTE's 5G/5G-A simplified private network solution supports this transition, enabling two consecutive years of live Spring Festival Gala broadcasts and becoming the first to introduce vertical-screen streaming and 5G-A 4K wireless live broadcasting. The solution has also been applied to events such as Malaysia Games (SUKMA) 2024, enhancing production and broadcasting experiences.
- **In the location-based entertainment virtual reality (LBE VR) industry,** the independent private 5G network, with its 10 Gbps high throughput and low latency, overcomes the bottlenecks of traditional LBE VR, such as backpack-based rendering, insufficient headset computing power, and Wi-Fi streaming interference, enabling a high-definition experience without the need for a backpack. It supports over 100 concurrent users, and promotes the efficient, large-scale deployment of LBE VR projects.

More Sectors

- **In the education and training sector,** leveraging the advantages of 5G networks and in-depth industry research, ZTE has built a collaborative innovation system integrating industry, academia and research to speed up talent cultivation. For example, in Luoyang, ZTE partnered with a well-known laboratory that collaborates with research institutes, national key laboratories, and leading enterprises on a 5G-A deterministic network. The partnership has led to joint technological breakthroughs and the cultivation of industry talent.
- **In the emergency private network sector,** 5G emergency private networks integrate both public and private network base stations to ensure smooth voice, SMS, and video communications, improving rescue efficiency. For instance, the UAV rescue network in Mentougou, Beijing combines public network base stations, PDT trunking systems, Mesh ad hoc networks, and satellite relay devices. In "three-break" scenarios, it offers end-to-end communication support for the public and rescue teams.

Driven by robust technological innovation, expanding application scenarios, and industry-wide collaboration, independent private 5G networks are emerging as a key driver of industrial development. They are expected to become a cornerstone of the industrial Internet, accelerate new industrialization, and usher in a new era of industrial networking. ZTE TECHNOLOGIES

Independent Industrial Private Networks: Digital Cornerstone Driving Growth of Leading Enterprises

Sheng Feng

RAN Solution Manager, ZTE

With the advent of Industry 4.0, intelligent manufacturing and fully-connected factories have become new trends in industrial development. Leading industrial enterprises face many challenges in their digital transformation process, such as cross-campus communication bottlenecks, issues with cloud-based digital management, and difficulties in expanding industrial control subnetworks. Industrial private networks have become an inevitable choice for the digital transformation of leading industrial enterprises due to their technical features and business value.

Digital Transformation Challenges for Leading Industrial Enterprises

With the rise of concepts such as Industry 4.0 and intelligent manufacturing, industrial leaders are facing unprecedented challenges in digital transformation. With the expansion of enterprise scale, information exchange between headquarters and branches becomes more frequent and crucial. However, the existing network architecture cannot support efficient and stable cross-regional communication, resulting in data transmission delays and high packet loss rates, affecting real-time and accurate service decision-making.

Enterprises also face challenges in cloud-based digital management. Without effective OT-IT integration, the efficiency of data processing and business process management will be seriously affected.

Furthermore, the difficulties in expanding industrial control subnetworks cannot be ignored. The rapid expansion of production line networks and the demand for flexible allocation of computing resources are hindered by high costs and long deployment cycles, which fail to meet the production department's requirements for efficient and agile IT systems. In addition, the large number of internal device nodes, complex operations and maintenance (O&M) configurations, and long service deployment cycles require a dedicated O&M team, increasing overall operational costs.

The independent industrial private network has emerged as a key infrastructure oriented to the core production scenarios of enterprises. Based on an end-to-end dedicated network architecture, it provides integrated capabilities including cross-campus communication, centralized security management and control, deterministic network guarantee, elastic expansion of production lines, and efficient O&M, fully supporting the digital transformation requirements of enterprises from production to management.

Core Advantages of Independent Industrial Private Networks

Cross-Campus Communication and Centralized Security Control

By building a dedicated cross-domain communication network, the industrial private network offers system interconnection solutions for enterprises and their branch offices (see Fig. 1). This solution is based on dedicated lightweight 5G core networks, dedicated base stations, and dedicated spectrum resources to physically isolate enterprise service functions from external networks. This ensures that the independent operation of enterprise services is not affected by the public network while safeguarding the security and integrity of production data. It is a critical infrastructure that ensures the continuity of key services and the digital transformation of enterprises.

In terms of centralized security management and control across campus communication domains, this system meets the level-3 requirements of China's information security protection scheme, establishing a multi-layered security protection architecture spanning networks, terminals, platforms, and applications. Through an end-to-end encrypted transmission mechanism, zero-trust architecture-based access control, data integrity checks, and hierarchical management of access permissions, the system implements full-link security protection from terminals to the cloud. In addition, it supports mainstream encryption technologies, including Chinese national cryptographic algorithms, to ensure the confidentiality and integrity of data during transmission and storage, fully supporting centralized security management and control across campuses and factories.

Deterministic and Predictable Network

Performance and Elastic Capacity Expansion

During the transition from industrial production to intelligent manufacturing, network stability and reliability have become essential characteristics of industrial communication infrastructure. Through multiple innovative technologies, the independent industrial private network fully meets the strict demands of industrial scenarios for high bandwidth, low latency, and high reliability, providing robust support for intelligent manufacturing.

For high-bandwidth service support, the independent industrial private network provides high throughput and low-interference uplink transmission through the use of dedicated spectrum resources, customized frame structure optimization, and SuperMIMO technologies. It effectively supports typical uplink bandwidth-intensive services such as massive sensor data collection in the industrial Internet of things (IIoT), high-definition (HD) video backhaul, real-time AGV positioning and control, and AI-driven machine vision, ensuring seamless data acquisition and real-time transmission.

For low latency and high reliability, the network supports key technologies including ultra-reliable

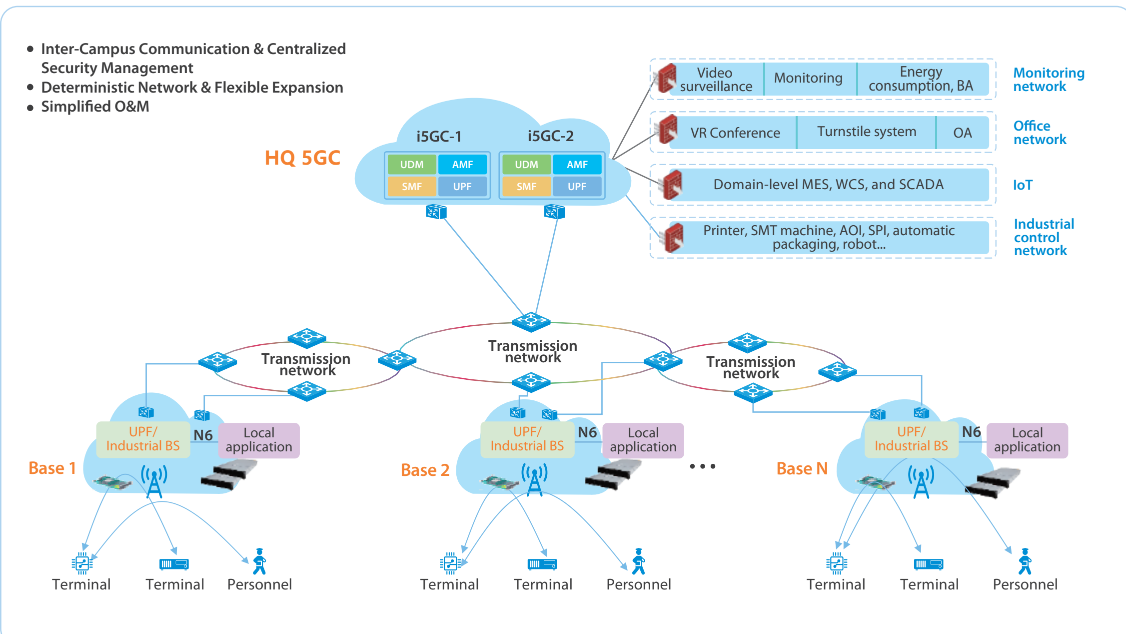


Fig. 1 The network architecture for enterprise headquarters and branches.

> **The independent industrial private network represents not only a technological upgrade, but also a strategic choice for enterprise digital transformation.**

low-latency communication (URLLC), time-sensitive networking (TSN), and frame replication and elimination for reliability (FRER). It precisely matches the data packet transmission cycle pattern of typical industrial control protocols to achieve microsecond-level latency and nanosecond-level jitter control, providing stable and reliable network assurance for real-time industrial automation scenarios such as PLC control and motion control.

In terms of network scalability and technology evolution capabilities, the independent industrial private network is both flexible and prospective. On one hand, computing-network integration equipment like UniEngine enables collaborative scheduling and elastic expansion of computing resources and network resources, precisely matching the increasing computing demands of production lines and supporting on-demand expansion of network coverage, service applications, and terminals. On the other hand, the network is compatible with cutting-edge technologies such as 5G LAN, TSN, and cloud-based PLC, offering robust technology evolution capabilities. It can continuously adapt to the service requirements of enterprises in different development phases, providing a sustainable network foundation for the digital and intelligent evolution of industrial production.

Resident O&M Platform and Simplified O&M

The independent industrial private network provides a comprehensive O&M framework, implementing efficient management through the resident O&M platform. This platform offers simplified O&M functionalities and sophisticated device monitoring capabilities, allowing enterprise O&M personnel to directly monitor local devices and perform basic routine maintenance tasks. In addition, the 5G private network provides a professional O&M platform and services, supporting core functions such as enterprise number allocation and terminal management. It also provides open APIs for deep interconnection with the enterprise management system to ensure seamless cloud resource integration. This "platform + service" model not only reduces O&M complexity and costs for enterprises, but also improves network reliability through automated monitoring and intelligent alarm functions.

The independent industrial private network represents not only a technological upgrade, but also a strategic choice for enterprise digital transformation. By integrating resources and enabling automated O&M, it helps reduce costs, improve efficiency, and avoid redundant investment and labor expenses, while ensuring security and controllability through a hard isolation architecture that safeguards core data security and avoids public network risks. Moreover, it supports agile innovation and flexible expansion, enabling enterprises to rapidly respond to market changes and seize competitive opportunities. The independent industrial private network solution, represented by ZTE, has been implemented and verified in several leading enterprises. As Industry 4.0 advances, the independent private network will become the core engine for enterprises to build fully-connected factories and achieve intelligent manufacturing, providing them with a competitive edge in global competition. ZTE TECHNOLOGIES

5G Private Networks
Enable Stable and Intelligent Urban Rail Transit

Zha Xiping

Wireless R&D Planning Manager, ZTE

According to statistics from Ministry of Transport, by the end of 2024, a total of 54 cities in China had opened 325 urban rail transit lines, with a total operational mileage of 10,945.6 kilometers. Throughout 2024, the actual number of trains operated reached 40.85 million, with a total passenger volume of 32.24 billion. The rapid expansion of urban rail transit networks has significantly enhanced urban operational efficiency and facilitated residents' travel.

However, the costs of constructing and operating urban rail transit are significant. Data shows that the average operating cost per kilometer for rail transit enterprises nationwide stands at a staggering 11.26 million yuan, rising to over 15 million yuan per kilometer in major cities like Beijing, Shanghai, Guangzhou, and Shenzhen.

With adjustments in government investment policies for municipal infrastructure, the era of extensive rail transit expansion has ended, marking the beginning of a more diversified, intelligent, and sustainable future. The deployment of 5G private networks in urban rail transit systems not only enhances operational quality and efficiency but also aids enterprises in achieving dual goals: improving both economic and social benefits.

5G Private Networks Enable Simplified System Architecture

Wireless communication networks serve as a crucial foundation for ensuring the efficient and safe operation of rail transit systems. The implementation of wireless private networks in urban rail transit has progressed through several stages:

- In the early 1990s, analog voice wireless communication networks were introduced.
- In 2005, Nanjing Metro Line 1 pioneered the use of TETRA digital trunking communication.
- In 2008, Beijing Subway Line 2 upgraded its CBTC signaling system by utilizing WLAN.
- In 2016, Wuhan Metro Line 6 achieved a milestone by implementing LTE-M-based CBTC services for the first time.

However, these wireless communication networks lack compatibility and cannot substitute for one another, resulting in a scenario where multiple networks overlap and coexist, leading to issues such as data silos and inefficient resource utilization. The 5G private network, with its high speed, low latency, large capacity, and extensive coverage, can effectively address these pain points in urban rail transit by replacing multi-network coexistence with unified network integration. The evolution of wireless private networks in urban rail transit is shown in Fig. 1.

5G Private Networks Offer Significant Technical Advantages

5G offers a range of unique features that can better adapt to the diverse application needs of the rail transit industry.

- **Flexible 5G NR air interface meets uplink capacity requirements:** Unlike the LTE network, the NR wireless frame structure offers greater flexibility in configuring uplink and downlink timeslots, allowing the number and length of uplink and downlink timeslots to be adjusted based on service needs. In

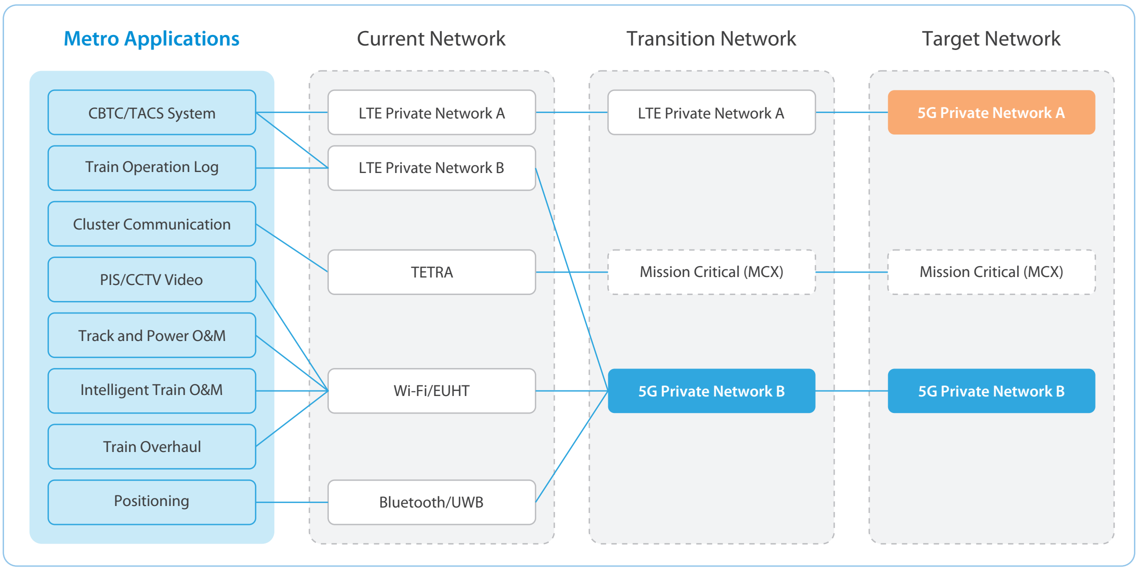


Fig. 1 The evolution of wireless private networks in urban rail transit.

addition, it supports asymmetric spectrum allocation to improve system adaptability and resource utilization. This flexibility enables NR to better adapt to the uplink-dominant data transmission model on the vehicle side in the rail transit industry.

- **End-to-end (E2E) 5G network slicing for comprehensive service bearing:** Network slicing creates multiple virtual E2E networks on shared physical infrastructure. Each slice realizes logical isolation in terms of equipment, access network, transmission network and core network, better supporting secure production, internal management, and external services in the rail transit industry. With 5G, several dozen subsystems achieve comprehensive service bearing and independent operation.
- **5G time-sensitive networking (TSN) supports deterministic communication and guarantees critical services:** By integrating 5G networks with TSN technology, and leveraging clock synchronization, intelligent perception of service message types and characteristics, dual sending & selective receiving, intelligent scheduling, and precise gating, end-to-end service-level agreement (SLA) can be assured. Highly reliable deterministic network access with 10 ± 1 ms latency is provided, ensuring the safe and stable operation of train signaling systems such as CBTC/TACS.
- **5G LAN simplifies network connectivity:** 5G LAN can replace commonly used IPSec and L2TP tunnel protocols in the industry, providing flexible communication capabilities such as terminal interconnection or terminal separation. Point-to-point and multi-point communication modes based on IP or Ethernet can be applied within the same LAN group. The traditional TCP/IP network service architecture can access the 5G network without modification, making networking simpler and connection more reliable.
- **5G MEC edge computing enables AI applications:** The 5G network supports deploying computing power closer to the edge of the network, enabling a wide range of video AI application scenarios in urban rail transit, such as visual detection of key vehicle components in depots and video-based detection of catenary systems. Incorporating RFID technology, it facilitates efficient management through big data applications such as personnel positioning and passenger flow analysis.
- **5G multicast and broadcast services (MBS) improves the travel experience:** 5G MBS broadcasts multimedia content to users, ensuring a smooth viewing experience. This feature can be integrated with existing PIS services, saving air-interface transmission bandwidth and simplifying multi-screen networking on the vehicle side. It also supports a free-to-air mode, enabling

> **5G private network technology is poised to play a pivotal role in urban rail transit, driving it towards greater automation, intelligence, and sustainability.**

SIM card-free reception so that passengers can use their own mobile phones to access rich media content provided by the PIS system.

- **5G mission critical communications (MCx) broadband trunking breaks communication barriers:** 5G MCx mobile broadband trunking services meet the trunking communication needs across voice, video, data and industry-specific services. Featuring high reliability, high security and easy deployment, they support integration and interworking with systems such as TETRA, B-TrunC, and PDT, breaking traditional communication barriers, and improving the efficiency of cross-line, cross-network operations, and cross-departmental collaboration.

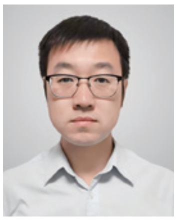
5G Private Network Deployment Modes

Frequency serves as the foundation of 5G wireless networks. Taking into account current policies, regulations, and industry standards, urban rail transit systems across China have adopted flexible and diverse business models to actively deploy 5G private networks tailored to local conditions.

- **Operator-led deployment and maintenance:** By the end of 2024, the Ministry of Industry and Information Technology had cumulatively allocated a total of 1109 MHz of radio frequency bandwidth to four major telecom operators, of which 86.5% can be used for 5G. For RAMS services (such as signaling and trunking) in the rail transit industry, operators can offer construction and maintenance of standalone private 5G networks on behalf of enterprise clients. For non-RAMS services (including passenger information systems, video surveillance systems, and intelligent maintenance systems), operators can provide logical private networks based on 5G public network slicing, ensuring business needs are met while reducing operational costs.
- **Industry-built 5G private networks:** Currently, aside from enterprises like China Railway and COMAC that have obtained trial authorization for dedicated 5G frequencies, no other industries have yet been granted such authorization. However, under national radio frequency allocation regulations, industries can deploy standalone private 5G networks using 5G New Radio Unlicensed (5G NR-U) in the 5 GHz band or millimeter-wave frequencies. These medium- to high-frequency 5G private networks can replace existing Wi-Fi-based vehicle-to-ground networks, addressing issues related to Wi-Fi security and mobility, while meeting the industry's need for self-construction and self-maintenance. The unauthorized spectrum-based 4G/5G network has been deployed and implemented in the second phase of Chengdu Metro Line 19, while millimeter-wave frequencies have been deployed on Shanghai Metro Line 4 and on Seoul Metro lines overseas.

With the adoption of 5G private networks to replace existing wireless systems in the rail transit sector in over 10 cities in China, including Guangzhou, Shanghai, Nanjing, Wuhan, Tianjin, and Suzhou, there has been a gradual shift from carrying non-core operational services to exploring the feasibility of supporting core business systems, which will ultimately lead to a comprehensive 5G-based solution for all types of operations. 5G private network technology is poised to play a pivotal role in urban rail transit, driving it towards greater automation, intelligence, and sustainability. ZTE TECHNOLOGIES

5G mmWave Dedicated Networks: Powering the Intelligent Transformation of Railway Yards



Liu Jia

Chief Wireless Product Planning Engineer, ZTE

Rail freight plays a pivotal role in China's economic development and constitutes a key revenue stream for the railway sector. In 2024, China's railways transported 3.99 billion tons of goods, representing a 1.9% year-on-year increase and marking the eighth consecutive year of growth. Notably, the daily average loading volume exceeded 180,000 vehicles for the first time. With the implementation of the Belt and Road Initiative and the upgrading of domestic consumption, there has been a surge in demand for transporting raw materials, components, and finished goods through containerized logistics.

Railway freight yards and marshalling yards are integral to the railway transportation system. However, these facilities currently face significant operational challenges. Traditional communication methods fail to meet the real-time performance and reliability requirements of railway yards, leading to delays or inaccuracies in information exchange that compromise operational efficiency and safety. Additionally, the complex operational environment and numerous devices in railway yards exceed the coverage and capacity limits of conventional networks, hindering effective connectivity and management.

In recent years, China has placed great emphasis on the development of the digital economy and introduced a series of policies to promote the digital transformation of traditional industries. The "14th Five-Year Plan for Digital Economy Development" explicitly calls for faster industrial digitalization and deeper integration of digital technologies with the real economy. Against this policy backdrop, the railway sector, as a critical national infrastructure industry, must accelerate its digital transformation.

Railway Yards Impose Stringent Requirements on Dedicated Wireless Networks

During train marshalling, real-time information such as train position, speed, and status must be acquired to enable dispatchers to conduct rational command and scheduling. During cargo loading or unloading, real-time monitoring of progress, weight, and location is essential to ensure the safety and accuracy of cargo transport. The transmission of such real-time data requires the dedicated wireless network to offer high bandwidth and low latency.

Railway yards are home to a large amount of mechanical and electrical equipment, such as loading and unloading machinery, trackside sensors, and signaling machines. Such equipment, along with numerous new applications, requires connectivity through a dedicated wireless network to support operations like autonomous driving, remote control, centralized management, and monitoring. The wireless dedicated network must feature large capacity and wide coverage to ensure massive device connectivity and maintain stable communication between devices.

Additionally, since most operations in railway yards take place in vast outdoor environments with complex wireless conditions, the dedicated wireless network must deliver high reliability and security-grade performance to prevent data leakage and interference, thereby ensuring operational integrity.

Fig 1. Satellite image of a large domestic freight yard.

A New Option for Wireless Broadband Access in Railway Yards

Railway yards are typically located on the outskirts of cities and cover large land areas (see Fig. 1). However, these regions often suffer from poor 5G public network coverage and weak signal quality, resulting in significant performance gaps compared to urban areas. Under the 5G public network sharing model, it is difficult to meet the high-capacity and low-latency requirements of railway yards, and data security risks remain unaddressed.

At present, some railway yards still rely on legacy self-built Wi-Fi networks. Different business systems within the same yard may use separate Wi-Fi networks. These networks offer relatively limited coverage and are prone to mutual interference. Terminals require re-authentication when switching between hotspots, which can lead to service disruptions, data loss, and other issues.

Furthermore, Wi-Fi networks operate in unlicensed spectrum, and the lack of unified management across multiple systems poses security risks. Existing security mechanisms are insufficient to prevent external attacks and unauthorized access.

In contrast, 5G millimeter-wave (mmWave) technology offers abundant spectral resources and enables gigabit-level transmission rates. This facilitates the rapid and precise transmission of large volumes of high-definition video, real-time data, and other critical information within railway yards, significantly enhancing operational efficiency. With its low-latency characteristics, 5G mmWave meets the stringent real-time requirements of railway yard operations, ensuring timely command transmission and response in remote control scenarios—thereby improving both operational efficiency and safety.

Beyond its communication functions, 5G mmWave provides high-precision sensing capabilities that enhance situational awareness and operational safety in railway yards. Building a dedicated, self-contained 5G mmWave network tailored to railway yards aligns with the security requirements and operational practices of rail systems. Such networks substantially enhance wireless broadband access capabilities and represent a transformative direction in the digitalization and modernization of railway yards.

Dedicated 5G mmWave Network Solution for Railway Yards

The dedicated 5G mmWave network solution for the railway yard is tailored to the yard's topography and service distribution. 5G mmWave base stations and edge UPFs are deployed as needed within the yard and are ultimately connected to the railway bureau's 5G core network.

Deploying 5G Core UPF at the Edge

According to the overall technical requirements of the railway 5G dedicated mobile communication system, the 5G core network consists of nationwide shared equipment, railway bureau's core network equipment, and edge computing nodes. The railway bureau's core network is centrally deployed in its data center using a dual-DC disaster recovery approach.

To mitigate the impact of traffic carried by 5G mmWave base stations on the railway data communication network and reduce end-to-end service latency, it is recommended to deploy edge UPFs within yard premises to enable local data offloading. The edge UPF connects to the control-plane SMF of the railway bureau's core network via the data communication network over the N4 interface, enabling user-plane data forwarding.

Business traffic carried by 5G mmWave base stations is forwarded to the edge UPF via the transmission network. The edge UPF directly interfaces with application servers within the yard premises through local transmission links, reducing bandwidth demands on long-distance transmission and ensuring that all data remains local.

Professional Wireless Network Planning and Deployment

The topography of railway yards often presents challenges such as poor signal penetration in storage areas, significant elevation differences across coverage zones, and limited wireless propagation paths (Fig. 2). ZTE proposes moderately adjusting and optimizing the wireless link budget for such scenarios, based on the 3GPP-defined outdoor line-of-sight (LOS) propagation model. When an unobstructed LOS is maintained between terminals and 5G mmWave base stations and base station coverage extends up to 1 km, uplink edge rates of over 100 Mbps can still be achieved.

The 5G mmWave base station AAU can be mounted on large lamp poles within the yard, with a recommended installation height of 25 to 30 meters. The BBU of the 5G mmWave base station can be connected to the core network equipment of the railway bureau via the transport network, enabling access authentication, session establishment, and data transmission for mmWave terminals. The 5G mmWave network deployed within the yard adopts a standalone (SA-only) architecture.

To enhance service experience, the 5G mmWave network's frame structure can be adjusted to a

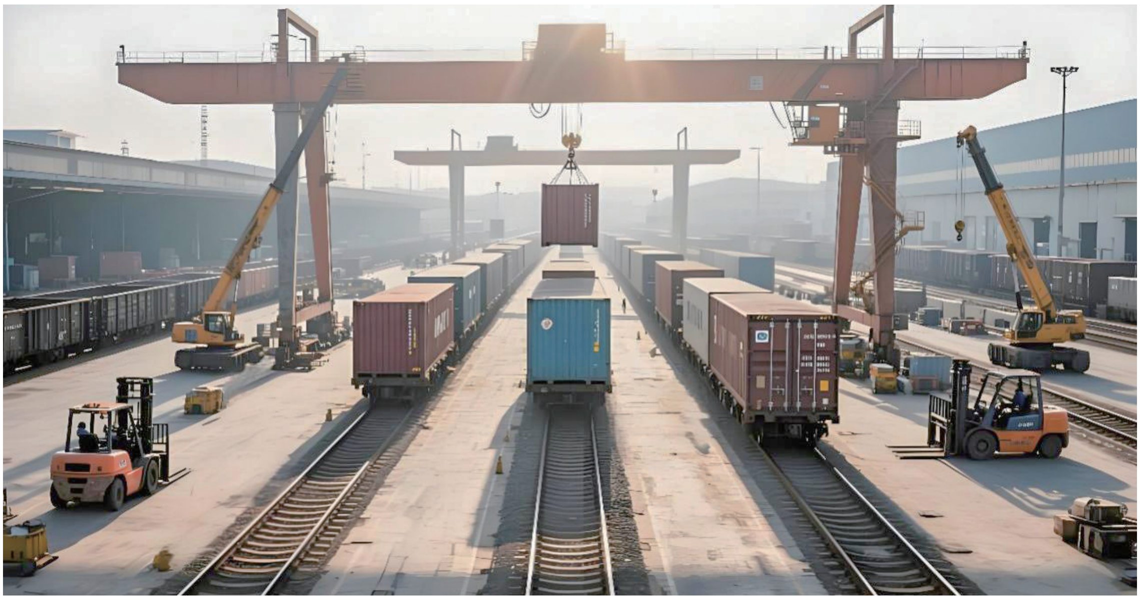


Fig. 2 Operational environment of the freight yard.

> **By leveraging the high-speed, low-latency characteristics of the 5G mmWave dedicated network, railway yards can achieve higher levels of automation and intelligence.**

1D3U configuration to provide enhanced uplink capacity. Beam parameters for individual logical cells can be flexibly adjusted and optimized based on the spatial relationships between site locations and terminal positions.

Access of Terminal Equipment

For various large-scale mechanical equipment within the yard, such as gantry cranes and reachstacker, mmWave CPEs can be deployed on their exterior rooftops. Application terminals connect to these CPEs via Ethernet ports to access the 5G mmWave network. For equipment located in dispersed positions, traffic can first be aggregated through switches before being connected to a CPE for external communication.

mmWave signals have shorter wavelengths, weaker penetration, and limited diffraction capabilities, making them highly susceptible to obstruction. To achieve optimal transmission performance, LOS connectivity between mmWave CPEs and AAUs should be maintained. Additionally, mmWave CPEs can be configured to convert signals into Wi-Fi, enabling hybrid network architectures that expand access modes and coverage.

Network Evolution and Service Expansion

Railway yards are large in area and have a variety of services types. Therefore, a model of overall planning, phased implementation, on-demand access, and gradual improvement can be adopted to advance the digital transformation and upgrade of railway yard operations.

In the first stage, network coverage is completed for key operational areas and high-priority services—such as remote control of gantry cranes, container and vehicle number recognition by reachstackers, and intelligent cargo handling are granted early access.

In the second stage, full indoor and outdoor coverage is achieved across the railway yards. Additional intelligent services, such as ground patrol by machine dogs, unmanned container trucks, low-altitude drone inspections can be connected to the 5G mmWave network.

If there is a demand for push-to-talk (PTT) services, considering network and service evolution, it is recommended to utilize the subsequent construction of 5G-R networks. 5G-R base stations can be reserved based on the specific conditions of each yard. At some sites, co-siting with 5G mmWave base stations may be considered, with both connected to the railway bureau's 5G core network. Users only need to install the MCX application on the existing 5G handheld devices to realize the PTT functionality.

By leveraging the high-speed, low-latency characteristics of the 5G mmWave dedicated network, railway yards can achieve higher levels of automation and intelligence, significantly enhancing operational efficiency and safety while reducing personnel labor intensity. This opens up unprecedented development opportunities for railway freight yards and marshalling yards. Additionally, the 5G mmWave dedicated network will play a significant role in scenarios such as massive data transfer between trains and ground facilities and monitoring of railway infrastructure along the route. ZTE is committed to providing a robust digital foundation for a broader range of railway applications, accelerating the digital transformation and upgrade of the railway sector. ZTE TECHNOLOGIES

Exploring New Paradigms in Cultivating Multi-Skilled Talent

Wang Hongxin

Senior Engineer of RAN Planning, ZTE

The new wave of industrialization is reshaping the core of industry through digital technologies. At its heart lies the creation of an intelligent ecosystem that spans all elements, the entire value chain, and the full lifecycle. As a key enabling technology, the independent private 5G network plays a crucial role in driving industrial transformation toward digitalization, connectivity, and intelligence. It offers three core advantages—on-demand capacity expansion, on-demand flexible deployment, and on-demand dynamic scheduling—enhancing the flexibility and scalability of industrial networks while providing secure, reliable, and efficient communication for the industry. This lays a solid foundation for building a new-type industrial network integrating IT and OT.

Demand for Digital and Intelligent Talent Under New Industrialization

The upgrade of the technical architecture of new industrial networks requires the deep integration of independent private 5G network technologies—including planning, deployment, and O&M—with industrial systems, thereby placing higher requirements on talent. Professionals must not only be proficient in core technologies such as 5G network slicing, edge computing, 5G LAN, and time-sensitive networking (TSN), but also have a deep understanding of industry-specific processes and equipment protocols (such as OPC UA and Profinet). They must be capable of designing low-latency wireless control systems and ensuring seamless integration with the existing factory systems such as PLC and SCADA. Only in this way can the performance advantages of the independent private 5G networks be accurately translated into substantive improvements in production efficiency, quality control capability, and security level. This calls for multi-skilled talent well-versed in both the industrial and digital technologies.

Institutions of higher learning take on significant responsibilities for talent training. Higher vocational colleges focus on developing highly skilled, application-oriented talents that meet the immediate needs of the industry. Undergraduate colleges focus on theoretical innovation and scientific research capability training. However, most of the institutions of higher learning adopt a single-track approach and cannot meet the requirements for interdisciplinary, multi-skilled talent.

Jointly Shaping New Models for Talent Training

As a leader in the ICT field, ZTE collaborates with partners and educational institutions to promote the integration of end-to-end 5G applications into school training. It seeks to establish a closed-loop talent development model under the new wave of industrialization, covering curriculum design, practical training, competitions and certifications, and employment alignment. The ultimate goal is to build a technology-to-talent ecosystem and create an industry–education collaborative innovation system (Fig. 1).

Facing the demand for talent in new industrial networks, ZTE collaborates with ecological partners and universities to explore new paradigms of industry-education integration in multiple technical directions, including 5G-A deterministic networks, minimalist independent private 5G networks for new industrial scenarios, and the emerging low-altitude economy.

- As a key technology for industrial digital transformation, the independent private 5G network meets the diverse requirements of industrial networks by providing connectivity as well as data collection and transmission capabilities. It incorporates core private network technologies, such as deterministic communication, large bandwidth, low latency, slicing isolation, and 5G LAN. To support talent development, dedicated courses are designed to teach students how to build private 5G networks tailored to diversified industrial application environments and how to integrate key 5G technologies with industrial applications.

- Deterministic networking is a core capability of independent private 5G networks, addressing the rigid requirements of core industrial control scenarios and enabling flexible production design and orchestration. For universities, we plan to open capabilities related to service network computation under protocols such as IEEE 802.1Qcc, including air interface resource configuration and slice isolation configuration. This will provide teachers and students with a physical operational environment for deterministic network research, as well as a collaborative platform for technological innovation. Together, we aim to tackle key challenges in 5G-A deterministic network technologies, complement each other in professional expertise and talent structure, jointly cultivate urgently needed industry professionals, and empower intelligent manufacturing.
- The approach to building new industrial networks has shifted significantly with the advent of independent private 5G network. Featuring deterministic connections, independent private 5G network uses the CT technology to connect the IT and OT domains. It enables real-time data collection from on-site equipment and, when integrated with low-code-based open automation systems, meets the demands of intelligent manufacturing such as higher efficiency, personalization, and green, low-carbon development. To align education with this trend, we propose providing students with practical training in building new industrial networks. This includes the deep integration of IT and OT technologies, the flexible orchestration of production lines through open automation systems, and the use of digital twin visualization to invoke real-time data of production lines. Thus, students can learn the processes and concepts of applying IT technologies in OT-driven production environments.
- The production line digital twin simulation system based on an independent private 5G network

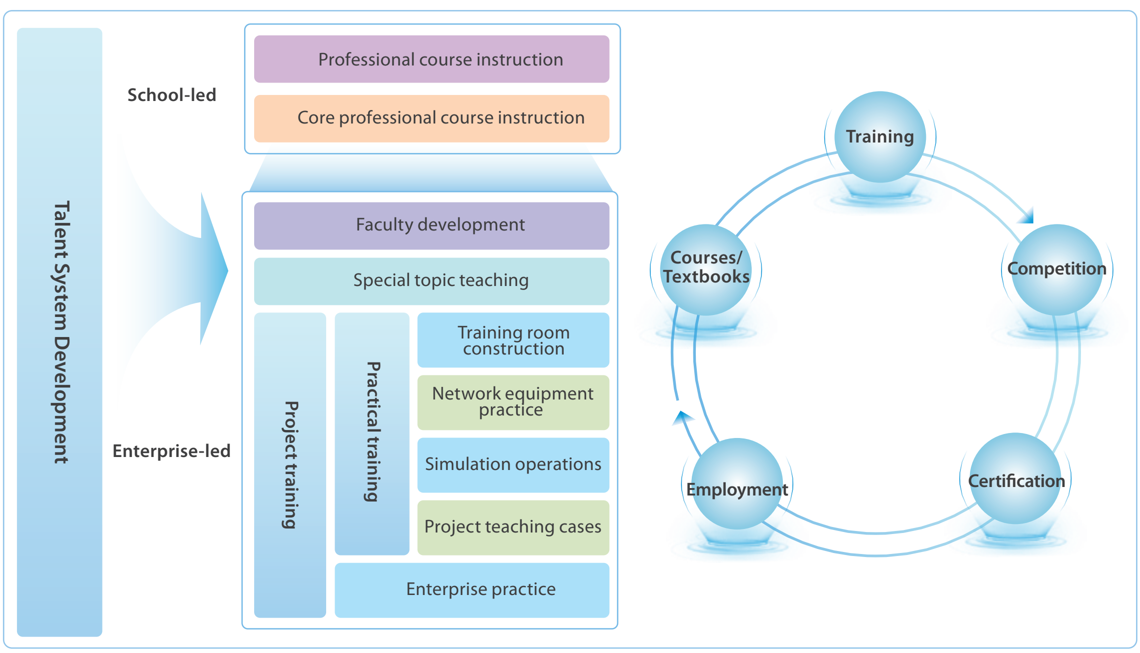


Fig. 1 Cultivating multi-skilled digital talent through industry-education integration.

obtains sensing data through the private network channel to achieve virtual mapping of the physical environment. In addition, the collected data can be used for reverse modeling, enabling simulation and verification in the early stages of industrial design. This allows for a comprehensive and accurate reproduction of equipment structures, process flows, and environmental conditions. We work with partners to provide universities with digital twin simulation systems for intelligent manufacturing production lines, along with innovative applications such as online courses, virtual training, and new forms of instructional materials. These offerings help students master core competencies in intelligent manufacturing processes, production efficiency improvement, and quality control. They also reduce dependence on physical hardware and related costs, and support a new model for virtual simulation–based intelligent manufacturing design.

- Oriented to the continuous evolution of 5G networks and 5G-A technologies, and with a focus on the low-altitude economy, we collaborate with partners in the low-altitude industry chain to provide universities with research environments and practical training. Drawing on our own practical experience, we leverage the sensing capabilities of the 5G-A integrated sensing and communication (ISAC) networks to support areas such as intelligent perception and identification of drones, drone applications, and drone equipment.

In the ongoing digital and intelligent industry transformation, new industrialization serves as the strategic goal, independent private 5G networks provide the cornerstone of security, and multi-skilled talent acts as the key value enabler. ZTE continues to leverage its strengths to actively promote the integration of vocational and general education, as well as the synergy between industry and education. In collaboration with partners, ZTE is building an educational ecosystem that continuously optimizes training models for cultivating multi-skilled talent capable of integrating OT and IT. By exploring new approaches aligned with the development of the digital economy, we aim to unlock the true value of data elements and drive the transformation from traditional to intelligent manufacturing. ZTE TECHNOLOGIES

5G Private Networks Empower Cobots for Smarter Industry

Chen Dong
Wireless System Architect, ZTE

Chen Jianjun
Wireless System Architect, ZTE

As the global manufacturing industry moves toward greater intelligence and flexibility, Industry 4.0 is reshaping the industrial landscape with an irreversible momentum. In this process, the deep integration of 5G private networks and autonomous collaborative robots (cobots) has emerged as a key driver in addressing traditional industrial pain points and unlocking the potential of digital and intelligent transformation.

Cobots, as intelligent agents with environmental perception, autonomous decision-making, and collaborative operation capabilities, overcome the limitations of traditional industrial robots, which have been constrained by rigid programming and isolated operation. They not only work safely with humans but also collaborate through wireless networks to complete complex tasks that a single robot cannot handle.

However, in industrial manufacturing scenarios, cobots face three core challenges: reliable millisecond-level real-time control, complex, dynamic communication among multiple cobots, and sufficient edge computing power for big data processing. Traditional industrial networks often fall short in meeting these demands, especially in latency, reliability, and connection density.

5G private networks address these challenges through several key technologies: First, the ultra-reliable low-latency communication (URLLC) stabilizes end-to-end latency to the millisecond level, meeting the synchronous control requirements of high-precision assembly scenarios. Second, network slicing enables allocation of dedicated channels for tasks with varying priorities, ensuring interference-free transmission of quality inspection video streams and robotic arm control instructions. Finally, the deployment of edge computing nodes brings computing power closer to the production floor, enabling AI applications such as image recognition and path planning, and significantly improving the response speed of data processing.

Multi-Scenario Deployment Reshaping the Industrial Value Chain

The integration of 5G private networks and cobots is transforming production methods and reshaping value chains across a wide range of industries—from flexible manufacturing on factory floors and autonomous operations at construction sites, to precision tasks in smart agriculture and human-machine interaction in intelligent services (see Fig. 1).

- **Smart manufacturing**

In the industrial manufacturing sector, the combination of 5G private networks and cobots is enabling a new production paradigm. Taking a car welding workshop as an example, when 20 cobots work together, a traditional Wi-Fi network may experience latency fluctuations of up to 50 ms, leading to significant welding path deviations and reduced production accuracy. After deploying a 5G private network, the multi-cobot collaborative positioning accuracy can reach ±0.02 mm, significantly reducing product defect rates.

In collaborative handling scenarios, multiple autonomous mobile robots (AMRs) form temporary communication subnets through the 5G private network to achieve millisecond-level time synchronization and coordinated path planning. This "dynamic networking–task execution–subnet dissolution" mechanism

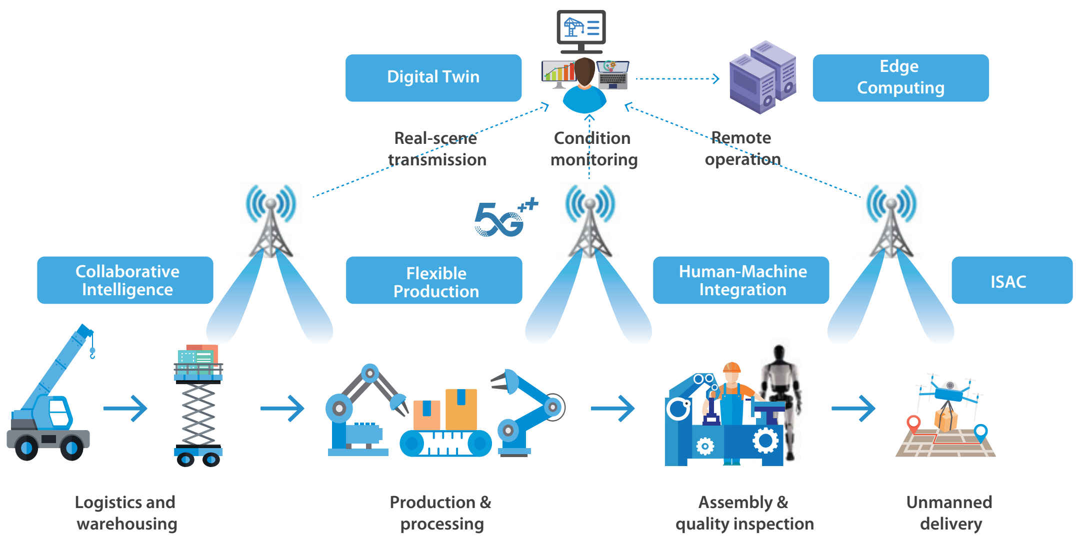


Fig. 1 5G private network empowers cobots.

enables the cobot cluster to quickly respond to unexpected tasks, such as emergency equipment handling or production line reorganization, greatly enhancing the factory's flexible production capabilities.

- **Smart construction: from labor-intensive to autonomous construction**

Construction sites are shifting from "mass labor" to "robotic armies". In autonomous construction environments, construction cobots equipped with 5G private network devices can exchange location and construction data in real time, enabling full automation of tasks such as brick handling, 3D printing, and drilling. The integrated sensing and positioning capabilities (ISAC) of 5G networks allow for accurate detection of personnel locations and obstacles, significantly reducing construction-related accident rates.

Meanwhile, the combination of digital twin technology and 5G private networks enables remote monitoring and virtual simulation. Engineers can use immersive extended reality (XR) to view construction progress in real time and adjust construction plans accordingly, avoiding rework and waste caused by design errors.

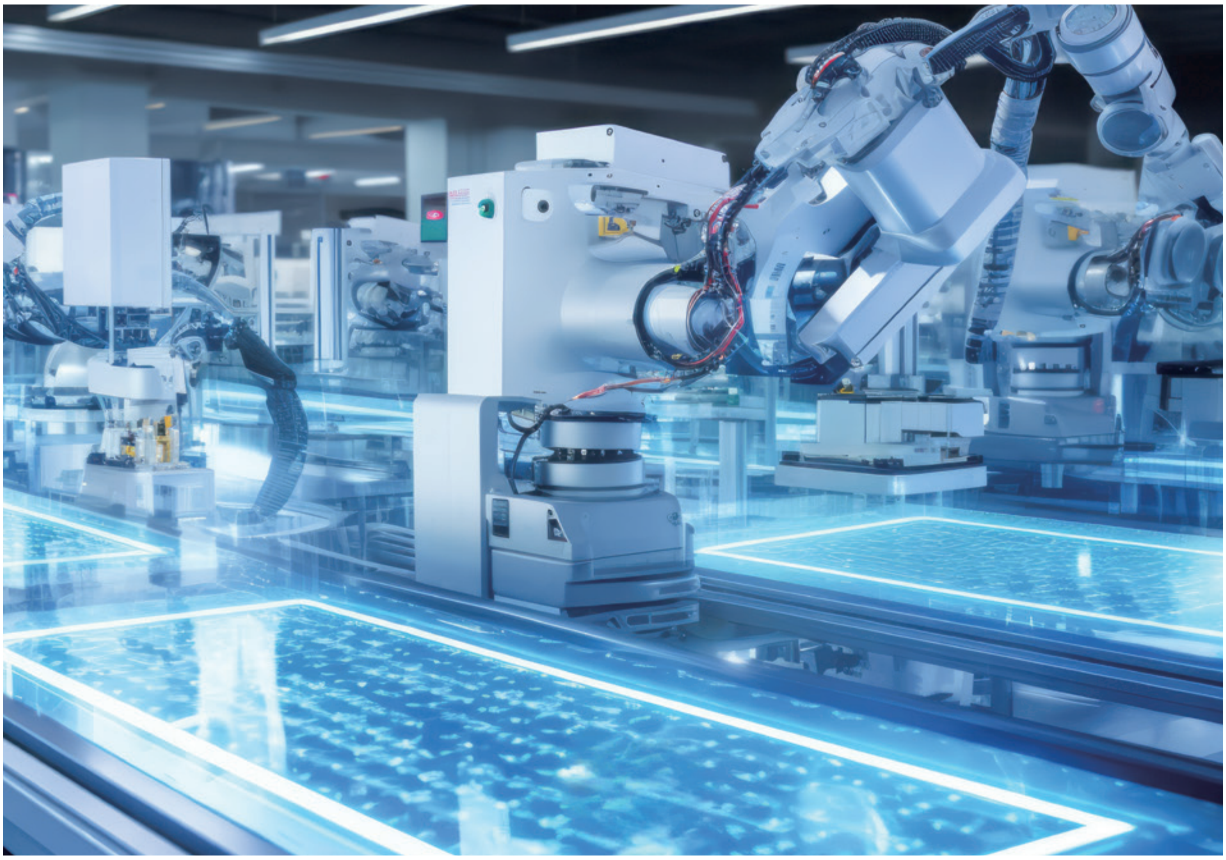
- **Smart agriculture: from experience-driven to precision farming**

In the agricultural sector, cobots supported by 5G private networks are revolutionizing traditional farming practices. To address the challenge of insufficient mobile communication coverage in agricultural environments, the mesh networking capability of 5G private networks enables the construction of self-organizing networks, ensuring stable communication for machines even in remote farmlands.

Autonomous tractors and crop-protection drones collaborate through local communication subnets, dynamically adjusting their operational routes and parameters based on real-time data such as soil moisture levels and crop growth conditions. For instance, in weed control scenarios, AI algorithms analyze high-resolution camera data to identify weeds, guiding cobots to precisely spray pesticides, thereby reducing pesticide usage.

Embrace a New Era of Dual Engines for Digital and Intelligent Transformation

Although 5G private networks have achieved significant breakthroughs in latency and reliability, continuous innovation is still needed to meet the stringent requirements of industrial cobot



applications. For example, in motion control scenarios, latency jitter of current 5G technology may still lead to inaccuracies in robotic arm operations. It is necessary to further reduce the latency to sub-millisecond levels by leveraging millimeter-wave communication, while introducing techniques such as multi-path signal processing, adaptive beamforming, and space-time coding to enhance anti-interference capabilities.

The optimization of edge-cloud collaborative architecture is another key to enhancing robot intelligence. By offloading latency-sensitive tasks (such as obstacle avoidance decision-making) to edge nodes and delegating global optimization tasks (such as production scheduling) to the cloud, an intelligent "edge-cloud collaboration" system can be established, reducing the computational load on individual machines and improving overall decision-making efficiency.

Energy efficiency of equipment is also a key challenge. Battery-powered mobile robots need to balance energy consumption between communication and operations. In the future, communication power usage can be reduced through energy harvesting technologies and lightweight protocol designs (such as streamlined IP headers), while optimizing network resource allocation to avoid waste of air interface resources.

The integration of 5G private networks and cobots is a key symbol of Industry 4.0 and a core driver of digital and intelligent transformation—serving not merely as a means to enhance efficiency, but as a catalyst reshaping industrial ecosystems and creating social value. Looking ahead, this transformation, fueled by both communication technologies and intelligent devices, will lead industries toward a more efficient, safer, and more sustainable future, turning the vision of Industry 4.0 into reality and injecting new vitality into global economic growth. ZTE TECHNOLOGIES

LLM-Based Multi-Agent System for Intelligent O&M of Independent Private 5G Networks

Wang Wei

Wireless R&D Manager, ZTE

With the rapid adoption of independent private 5G networks in industrial digital transformation, tensions between complex network O&M and increasingly refined industry demands are becoming more apparent. The traditional O&M model, which relies on manual experience, often suffers from delayed responses and high costs, making it difficult to meet the stringent requirements for network stability, low latency, and high reliability on industrial sites.

Based on the UniEngine integrated computing and network platform, ZTE proposes an intelligent O&M solution for independent private 5G networks, powered by a large language model (LLM)-based multi-agent system. By integrating endogenous intelligence with industry-specific customization capabilities, the solution offers a new approach to the construction and operation of private 5G networks.

Endogenous Intelligence: Building a Digital Brain with a ToB Agent Matrix

The core technology behind intelligent O&M for independent private networks is an endogenous intelligent architecture that enables an intelligent O&M system for industrial sites through a three-layered framework (Fig. 1).

At the bottom layer, the GPU-powered edge computing engine, based on lightweight edge servers, enables local AI inference and real-time data processing, significantly reducing the dependence on cloud computing power, ensuring that high-sensitivity data remains on site, and enhancing data security.

At the middle layer, serving as the agent's "cognition center", ZTE's Nebula large model provides natural language understanding, multimodal data integration, and decision-making and inference capabilities, enabling the agent to meet the diversified requirements of complex scenarios.

At the top layer, a ToB agent matrix, built upon the Nebula large model, forms a closed-loop O&M system:

- **The Q&A agent** responds to customer and work order queries in real time through multilingual interactions and semantic correction, replacing traditional manual customer service.
- **The monitoring agent** automatically establishes hierarchical network connections based on customer requirements, analyzes network KPI (e.g., delay, bandwidth usage), device status, and environmental sensor data in real time, and implements abnormal behavior prediction and visual early warning.
- When detecting network connectivity or delay issues, **the assurance agent** automatically checks parameters, collects service logs, and diagnoses and analyzes services and networks based on decision logic.

Through "user-network-cloud" collaborative deployment, this architecture deeply integrates network-layer and service-layer O&M, enabling an end-to-end intelligent O&M closed-loop for industrial sites. With real-time responsiveness and

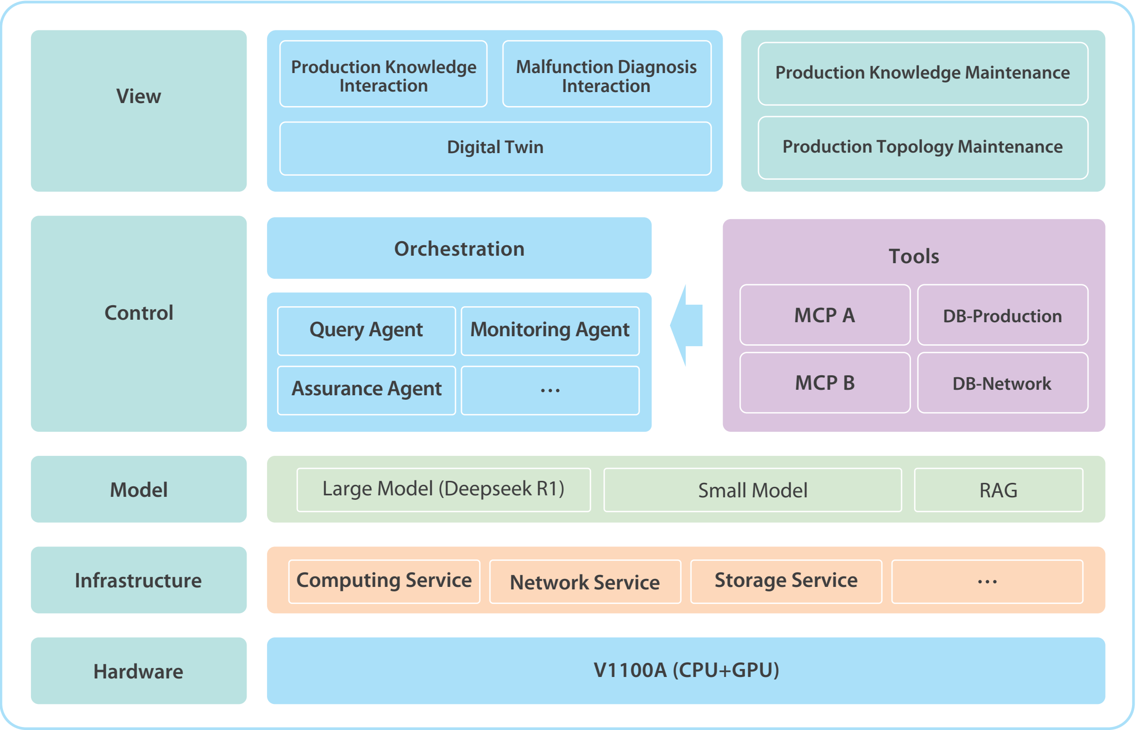


Fig. 1 Intelligent O&M architecture for independent private 5G networks.

autonomous decision-making capabilities, it provides "O&M-free" support for 5G industrial site networks, enabling vertical industries to make an intelligent leap in both network and business operations.

Capability Expansion: Building Expert Agents by Injecting Industry Knowledge

Facing the complex and differentiated O&M challenges in vertical industries such as energy, manufacturing, and other industrial sectors, ZTE's intelligent O&M large model for independent private networks significantly enhances the domain adaptability and decision-making precision of agents through an industry knowledge injection mechanism. This mechanism leverages the intelligent digital operation service (IDOS) of the UniEngine to build three core capabilities:

- **Customized knowledge base:** Users can inject structured and unstructured data, such as device manuals, O&M SOP, and historical work orders, into the Nebula large model to create a dedicated knowledge base. For example, a steel company can upload parameters of the blast furnace cooling system, allowing the assurance agent to accurately identify the correlation between water temperature anomaly and equipment aging, improving root cause identification efficiency.
- **Self-orchestrated knowledge graph:** Through the IDOS platform, users can construct device topologies, software-hardware mapping relationships, and data service flow diagrams in the production domain. When a fault occurs, the ToB agent dynamically reasons over the self-orchestrated knowledge graph, simulates the fault propagation path, and quickly identifies the root cause.
- **Real-time enterprise database access:** With authorized access to enterprise databases (such as ERP and MES), the agent can retrieve the latest service rules and device records in scenarios such as work order processing and fault diagnosis, ensuring that decision-making and service updates are synchronized. For example, a power company can embed the latest inspection standards into the Q&A agent to enable

standardized responses.

These capabilities enable the ToB agent to evolve from a "general assistant" to a "domain expert", significantly improving the accuracy of O&M decision-making and expanding scenario coverage.

Capability Opening: Building an Agent Platform to Let Customers Act as AI Product Managers

To unlock the full innovation potential of the industry, ZTE has launched an agent construction platform centered on low-code development, breaking through the limitations of traditional O&M tools and enabling customers to flexibly construct professional agents tailored to their specific needs. The platform provides a graphical workflow orchestration function, enabling users to combine the input, processing logic, and output of an agent in a modular manner with simple drag-and-drop operations, quickly building a customized O&M process. It supports API plug-in integration, allowing users to encapsulate the API capabilities of existing systems as standard plug-ins and seamless embed them through parameter configuration for seamless interconnection with the service system. The platform also features a built-in industrial agent template library, covering preset solutions for industrial, energy, and manufacturing sectors. Users can invoke these templates with one click or further develop them, significantly lowering the threshold for innovation. This platform-based capability enables enterprises to shift from using tools passively to actively defining intelligence, accelerating the deep integration of 5G private networks and industrial scenarios.

Future Outlook: From "O&M-Free" to "Self-Evolution"

The ultimate goal of intelligent O&M for independent private networks is to build a self-evolving industrial digital intelligent agent. By continuously learning from industry data, user feedback, and network operation status, the agent will autonomously iterate model parameters and optimize O&M policies, ultimately establishing a new paradigm of network as a service (NaaS). ZTE is working with global industry partners to promote the upgrade of 5G private networks from mere connectivity infrastructure to intelligent production hubs, injecting continuous innovation momentum into Industry 4.0.

The LLM-based multi-agent system for intelligent O&M of independent private 5G networks represents not only a technological breakthrough, but also a paradigm shift in O&M. Built on endogenous intelligence and empowered by knowledge injection and agent platforms, it enables industrial 5G networks to achieve truly unattended operation and autonomous decision-making. ZTE TECHNOLOGIES

Communication Revolution in Blue Oil Fields: ZTE Helps CNOOC Set a New Benchmark in Smart Energy

In July 2023, with the official launch of the 5G private network on the Bohai Bay drilling platform, China National Offshore Oil Corporation (CNOOC) ushered in the 5G era for its offshore oil fields. The integrated private network solution—combining submarine optical cables, microwave links, and 5G technology—was jointly developed by ZTE, Liaoning Telecom, and CNOOC to address communication challenges in sea areas 40 to 300 kilometers offshore. This breakthrough in deep-sea communication technology marks a historic shift from labor-intensive to data-driven operations in China's largest offshore oil field.

Pilot Breakthrough in Bohai Bay

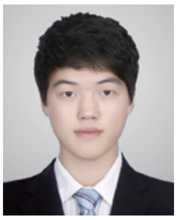
Traditional offshore oil fields relied on microwave equipment installed on main platforms for communication with land, while nearby vessels had to switch to satellite communications once they sailed away. These legacy networks were characterized by high latency, low speed, and limited mobility, and were prone to frequent interruptions during severe weather conditions like typhoons and heavy fog, which severely constrained safe and efficient maritime operations. As a result, CNOOC urgently needed a communication revolution to address these long-standing bottlenecks affecting offshore operations.

As part of this communications revolution, ZTE collaborated with Liaoning Telecom to pilot the deployment of a 5GC control plane, installing one UPF along with 5G base stations on each drilling platform. By connecting CNOOC and seven drilling platforms in Bohai Bay via submarine optical cables and utilizing the ultra-long-distance coverage of base stations, 5G communication was established across the surrounding sea areas.

With a unified 5GC control plane for all drilling platforms, seamless handovers and interoperability among surrounding operational vessels have been achieved. Data from operational vessels and platform equipment is transmitted back via 5G private network base stations to the on-platform UPF, where local data offloading is performed before being forwarded to application servers both on the platforms and at

Wang Zheng

R&D Planning Manger of Core Network Products, ZTE



Wei Li

R&D Planning Manger of Core Network Products, ZTE

headquarters for further analysis. This ensures that data remains within operational areas while meeting requirements for high bandwidth and low latency.

Scaling Success Across Maritime Areas

Building on the initial success, other branches CNOOC sought to replicate the benefits of this digital transformation. In 2024, following the deployment in Bohai Bay, drilling platforms across the East China Sea, South China Sea, and Beibu Gulf began deploying UPFs and 5G base stations, all connected to the 5GC control plane at headquarters. Thus, a preliminary cross-sea 5G private network took shape, seamlessly integrating the blue territory into the digital pulse of the nation.

In this network, ZTE tailored its solutions to the specific conditions of different maritime areas.

Wireless

At the wireless level, to meet the coverage requirements of CNOOC's offshore platforms and surrounding maritime areas, ultra-long-range base stations were deployed on offshore platforms. These base stations utilize beamforming technology, which adjusts the phase of signals emitted from each antenna to create an electromagnetic wave superposition at the terminal reception point, thereby enhancing signal strength. Offshore terminal access the 5G network via high-gain SE9102 gateways. Based on antenna characteristics, directional antennas are installed on oil extraction vessel platforms, while omnidirectional antennas are utilized on shift vessels. By modifying terminals to support external antennas, RF gain is improved, wireless links are optimized, and data transmission rates are maximized.

Transmission

At the transmission level, satellite backhaul is adopted for the Shanghai offshore platform due to its considerable distance from the mainland. Meanwhile, drilling platforms in Liaoning, Dongying, Shenzhen, and Zhanjiang are connected via submarine optical cables to Telecom A and B equipment. The equipment of various branches of CNOOC connect to the headquarters' 5GC through inter-provincial OTN dedicated lines, establishing internal CNOOC networks that transmit the control signaling of the 5G private network. This approach replaces the previous microwave solution, ensuring stable and reliable transmission.

Core Network

At the core network level, ZTE adopts a lightweight i5GC for ToB scenarios, encompassing key 5GC network elements such as AMF, SMF, UDM. The goal is to provide industry customers with a lightweight, industry-customized, and easy-to-maintain 5G core network.

- **Lightweight deployment:** i5GC occupies less space, consumes less energy, requires less hardware investment, and can be deployed on-demand in a variety of environments, including enterprises, parks, airports, and mines.
- **Extensive connectivity:** i5GC can be extended to support integrated access for 4G, 5G, eMTC, and NB-IoT, as well as future evolution to fixed-mobile convergence (FMC). It can also enable innovative features such as 5G LAN, QoS monitoring, FRER, and TSN.
- **Strong security:** Leveraging 5G's built-in confidentiality and integrity protection features, i5GC prevents terminal data leakage and ensures secure terminal access. To meet the varying security needs of different business traffic within industry clients, services can be isolated using different domain names (DN) and separate secure tunnels, ensuring that offshore operations and office traffic remain fully isolated and interference-free.

Furthermore, the integrated hardware-software design of i5GC reduces the complexity of deployment, operation, and usage, while offering simple system monitoring functions for enterprise-level autonomous maintenance. Customized service solutions, distinct from general-purpose core networks, are designed to address the diverse application scenarios of industry users.

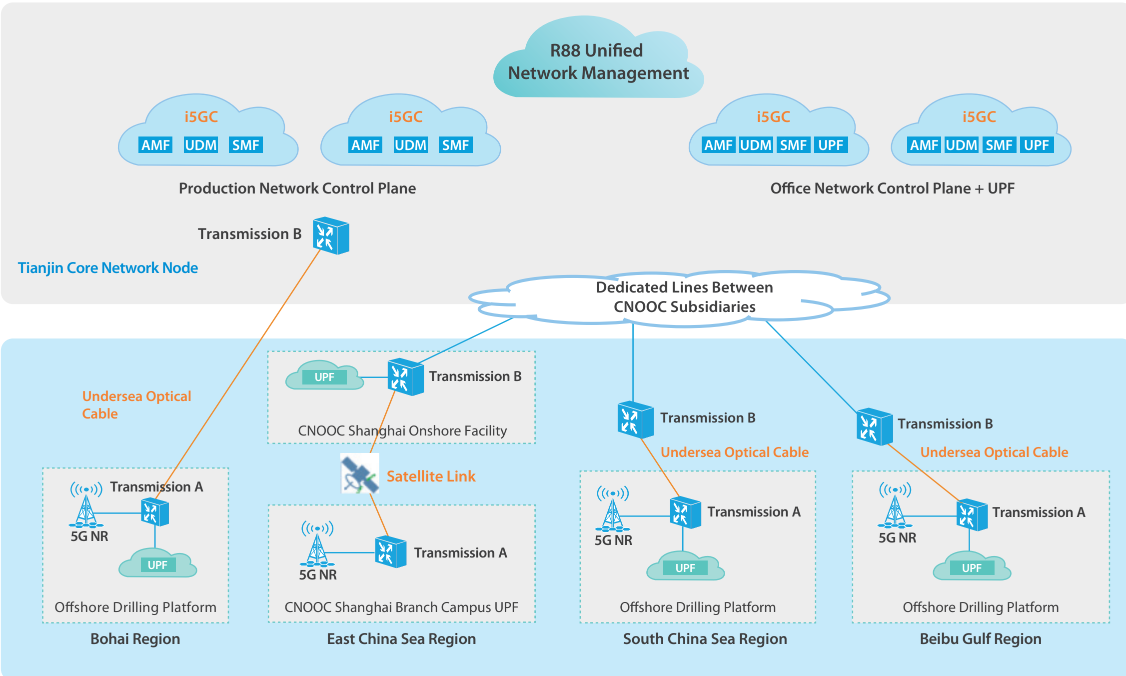


Fig. 1 Networking architecture of UPFs across maritime areas and the 5GC control plane in Tianjin.

Deployment, Operations and Delivery

At the overall architecture level (see Fig. 1), Tianjin hosts the deployment of the 5GC control plane and unified network management system, while UPFs are deployed on offshore drilling platforms across the Bohai Bay, East China Sea, South China Sea, and Beibu Gulf regions. Wireless base stations and UPFs in regions like Liaoning, Dongying, Shenzhen, and Zhanjiang are connected to land-based office networks via submarine optical cables, while the Shanghai platform is connected via satellite. All terminals are managed under unified numbering by the UDM within the headquarters' i5GC, supporting roaming scenarios for operational vessels of different branches across various maritime areas. Each branch uses distinct number segments to facilitate easier management.

Additionally, the R88 unified network management is deployed at the headquarters, enabling comprehensive O&M across wireless, transmission, and core networks. It provides robust capabilities including network configuration, fault monitoring, statistical analysis, performance tracking, version upgrades, and security management. The embedded iDOS enterprise portal offers both business and device dashboards, supporting visual operations through large-screen displays.

To accelerate the rapid deployment and commissioning of CNOOC's network, ZTE offers a "three-no" solution—no design, no on-site installation, and no debugging—with all pre-installation completed at the production line. Upon arrival at branch locations, one-click reconfiguration is performed based on the site environment. Once transported to drilling platforms, the equipment can be directly connected and powered on for immediate operation, enabling site activation in less than 24 hours and significantly shortening project timelines.

The collaboration between ZTE and CNOOC demonstrates that a 5G private network not only resolves communication bottlenecks in offshore oil fields, but also redefines the production paradigm of marine oil and gas development. It delivers replicable results and provides useful references for more remote marine scenarios in the future. As CNOOC's chief engineer remarked, "5G is not merely a technological upgrade—it is the golden key to unlocking the treasure trove of deep-sea energy." ZTE TECHNOLOGIES

ZTE

To lead in connectivity and intelligent computing, enabling communication and trust everywhere