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VIP Voices

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Special Topic:

Full-Band OTN

Next-Generation Optical Communication Architecture: 400G/800G Full-Band OTN

Cover Figure | ***Jonathan Villacis, CTO of Netlife***

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Full-Band OTN Leader: Ushering in a New Chapter for Optical Networks

Wang Qiang
Deputy General Manager of Transport Network Products, ZTE

The digital wave is surging forward, with technologies like AI, big data, and intelligent manufacturing advancing rapidly. This explosive growth in network traffic is driving optical networks—the "invisible arteries" of digital civilization—toward three trends: ultra-high bandwidth transport demands pushing the transition from 400G to Tbit-level systems, deep integration of large AI models enabling higher autonomy, and exploration of hollow-core fiber transport systems for ultra-high bandwidth, ultra-long distance, and ultra-low latency transmission.

In this transformation, enhancing system capacity is key. To achieve faster speeds without reducing wavelengths, optical networks have expanded their operational spectrum to both C and L bands. Current C/L segregated systems still face challenges in wavelength scheduling, integration, and low-carbon operation. To address these, ZTE has introduced a full-band OTN solution that offers ultra-large capacity, full-band scheduling, and a minimalist architecture for an improved customer experience.

The solution combines 12 THz integration with flexible shaping algorithms to achieve a single-fiber hundred-terabit transport system, boosting capacity by 25% and supporting massive data transport. With a tunable spectral width twice that of the industry standard, it enables C+L full-band non-blocking scheduling, increasing resource utilization by 100%, eliminating wavelength waste, and enhancing network O&M. The full-band integrated architecture reduces the number of optical boards by 20% and spare-part types by 50%, saving space, lowering CAPEX, and enabling a leaner, greener operational model.

Together with operators, ZTE has conducted a series of C+L full-band OTN lab and live network tests, setting multiple records and providing crucial references for future network deployment and optimization. Looking ahead, ZTE will continue open cooperation and innovation with industry partners to drive standardization and scenario development, building a more efficient, flexible, and reliable optical network ecosystem as a solid "optical foundation" for the global digital economy.

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Netlife: Redefining the Business Model with AI in Ecuador

Reporter: Radhika Devi

Jonathan Villacis
CTO of Netlife

AI-assisted background image

"We view AI as a structural capability that redefines how we operate and how we compete in the market," says Jonathan Villacis, CTO of Netlife. In an interview with ZTE Technologies at MWC 2026, he shared how the company has grown into a leading ISP in Ecuador and how AI is reshaping the ISP business model. Netlife is the largest fixed-network operator and most technologically advanced broadband provider in Ecuador.

What's your take on the fixed broadband trends, gaps and opportunities in Ecuador?

In Ecuador, internet users have come to highly value the overall services experience, which encompasses, for example, stability, speed, timely support, and the additional digital services their provider can offer. There's still a significant connectivity gap between urban and rural areas, which we must address by creating tailored services, especially aligned with a population that can purchase these kind of products, while meeting the needs of different socioeconomic segments. Additionally, there's a digital divide that we are committed to reducing through a social responsibility program aimed at reaching the most underserved communities. That's the overall approach.

Netlife has grown into a leading fixed broadband operator since its founding in 2010. What do you consider are the key drivers behind your success?

We consider that the main factor is a strong customer-centric approach. We are truly a customer-focused ISP and the biggest ISP in Ecuador. Behind this approach, there are some key drivers that shape the experience we deliver to our customers.

One of the most important is a passionate team, committed to improving our customer's quality of life. A passionate team is the number one driver.

We are the number one ISP in Ecuador, not just because we are the biggest one, but also because we have the best experience and words about its service quality and experience.

Additionally, we have a solid and reliable infrastructure with continuous investment in technology, including AI upgrades. The adoption and internal integration of AI into our processes is now important, and we are a pioneer in Ecuador in internalizing this kind of technology. Service stability, security, digital protection, agile customer support, omnichannel service, and highly satisfactory interactions are very important for us because customers now want to interact with you and need easy communication between the ISP and themselves.

Finally, a commercial offering based on cutting-edge technology and competitive market pricing.

What is your philosophy regarding the role of AI in communication? How is it reshaping your operating model and network?

AI is definitely transforming the ISP business model. It's enabling extremely high operational efficiency through tools and solutions that deliver significant value to users. Service providers that successfully internalize AI into their processes and services will be able to lead and sustain their position in the market.

We view AI as a structural capability that redefines how we operate and how we compete in the market. With AI, we are transitioning to an anticipation-driven approach. By analyzing large volumes of real-time network data, we can identify patterns, prevent incidents, and

optimize performance before customers perceive any impact.

We first get all this information from customers and from devices, and we anticipate any claim. From a customer experience perspective, AI allows us to personalize interactions and build a more agile service model supported by conversational assistance and behavioral analytics.

The other important point is that AI is not to replace human interaction, but to enhance it and make it more effective. We have developed our own tools that enable better and more satisfying interactions with our customers. We believe that we need to develop our own AI tools and solutions to be more competitive in the market. So we are fully in it.

How has ZTE contributed to your growth, and how do you see the value of this partnership?

ZTE is a strategic partner in our nationwide deployment. We have many PON ports, GPON/XGS-PON boards, and of course, CPEs and Wi-Fi extenders, all of which have contributed to our growth and the digital experience we deliver to our customers. ZTE has been a great partner. A large portion of our network has been deployed together with ZTE, and we have maintained a successful commercial relationship for about eight years.

How do you plan to differentiate your offerings to stay ahead of the highly competitive fixed broadband market?

Our differentiator remains consistent: continuing to strengthen our customers' digital quality of life, delivering the best service experience. The vision is held by our employees, technology partners, executives, and shareholders. We have developed a robust ecosystem of platforms and processed extensive data, and built a data lake integrated with intelligent tools, allowing us to make decisions, anticipate needs, and improve service quality, performance, and stability. It enables us to provide our customers with a range of digital solutions, transforming our approach from a traditional telco to a digital company.

How would you define your technology priorities for the coming years and what role does Netlife play in the evolving landscape?

Our technology priorities for the coming years are structured around strategic pillars: network intelligence, customer experience, and transformation and evolution toward a platform-based model. We are no longer a traditional connectivity provider—definitely we are transforming into an intelligent, data-driven provider. ZTE TECHNOLOGIES

Launching an Ultra-Fast 5G FWA Network

EOLO CEO on Driving Inclusive Digital Growth Across Italy

Reporter: Marta Scateni

Guido Garrone

CEO of EOLO

As Italy accelerates its digital transformation, EOLO is playing a strategic role in shaping widespread connectivity nationwide. At the end of 2025, EOLO launched its new ultra-fast 5G fixed wireless broadband (FWA) network, capable of delivering speeds of up to 1 Gbps. EOLO's CEO Guido Garrone talked about the key factors behind a successful launch and the plans going forward. He also shared how EOLO is taking advantage of AI opportunities.

Looking back on 2025, what achievements would you highlight for EOLO, and how have they contributed to the company's growth?

Looking back on 2025, one of the most significant milestones for EOLO has been the launch of our new ultra-fast 5G FWA network, capable of delivering speeds of up to 1 Gbps. This new infrastructure was developed in Italy together with ZTE and other leading international technology partners. The network has been activated in more than 300 municipalities across Italy, bringing high-speed connectivity to thousands of families and businesses. Over the coming months, we will continue to progressively extend coverage to smaller towns and rural communities, further strengthening our mission to bridge both the digital divide and the digital speed divide.

What are the key success factors behind the successful launch of your 5G standalone mmWave network, and what are the next steps?

The successful launch of our new 5G standalone mmWave network was driven by a solid ecosystem of leading international technology partners and a clear strategic focus on innovation and execution. EOLO fully leverages the inherently virtualized nature of 5G CNFs by distributing the User Plane Function (UPF) as close as possible to customers, resulting in one UPF per 5G radio tower and thereby ensuring very low latencies. In particular, the UPF has been implemented within EOLO's proprietary BLU Router, which is installed in each 5G radio tower, making the UPF highly distributed. This approach has made it possible to integrate the 5G infrastructure into EOLO's existing proprietary Automated Traffic Engineering systems, which can dynamically re-route 5G traffic based on transport network load. The success of this project has also been achieved by implementing an intent-driven, TM Forum standards-based automation fabric using network orchestrator, ensuring a flawless experience at every touchpoint of the customer journey. EOLO believes that, in order to convey the quality of the service, it is equally necessary to invest effort and innovation in customers' Wi-Fi networks. For example, we are providing customers with Wi-Fi 7 HAG devices, including the ZTE H6700 router.

As for the next steps, our priority is the continued expansion of the 5G standalone mmWave network across Italy, progressively extending coverage to additional municipalities and further accelerating digital inclusion, particularly in smaller towns and underserved areas, by delivering a true fiber-like service experience in territories that are not and will not be served by Fiber FTTH. Moreover, we are focusing on optimizing the Wi-Fi signal inside the house or building. In parallel, we plan to extend the reach of the new technology from the current 6 kilometers to 11 kilometers in the short term and to 15 kilometers in the medium term.

How would you describe EOLO's role in Italy's digitalization process?

EOLO's mission is to enable people and businesses to enjoy the best possible digital experience every day, by delivering excellent connectivity "wherever there is a town" ("ovunque ci sia un paese"). By focusing on small towns and rural communities, EOLO actively contributes to bridging the digital divide and ensuring that families, professionals and SMEs can fully participate in the country's digital transformation. Through continuous investment in advanced FWA and 5G technologies, EOLO supports local economic development and digitalization, acting as a strategic enabler of more inclusive and widespread digital growth across Italy.

In your previous interview, you mentioned cultural barriers in connecting underserved communities. How are you addressing these barriers to push FWA forward?

EOLO works closely with local administrations, schools, and local businesses to demonstrate how high-speed connectivity can improve daily life and boost local businesses and the digitalization of public administrations. By tailoring our communication and support to the specific needs of each community, we foster trust in digitalization. At the same time, our user-friendly installation processes and dedicated local customer support make the technology accessible, minimizing technical barriers and encouraging adoption. In this way, EOLO ensures that FWA is not just available, but effectively embraced, giving a strong push to the country's digitalization, in line with the objectives of the European Digital Agenda 2030.

In FWA, AI's biggest opportunity is to improve service quality and customer's experience while keeping human experts firmly in control.

What opportunities does AI bring to the FWA sector, and what impact does it have on EOLO?

In FWA, AI's biggest opportunity is to improve service quality and customer's experience while keeping human experts firmly in control.

At EOLO, we've built this on long-term data foundations. Our new 5G standalone network was designed from day one to continuously stream telemetry. These feeds support both real-time closed-loop actions and the creation of rich historical datasets. We consolidate these network data with customer and external data into a single, geospatially anchored enterprise data platform so AI agents can correlate what happens across domains, act with the right context and learn over time.

Our AI strategy is designed to augment human capabilities and scale EOLO's unique know-how. We have introduced RAG and are progressively adopting multi-agent autonomous patterns, where AI agents operate within a structured, standards-based and controlled decision-making framework that ensures explainability, safe reversibility and tight human oversight. We assess AI's impact through tangible operational outcomes: cost reduction, higher first-call resolution, faster time to repair and an improved customer experience. In parallel, we are initiating the adoption of a Small Language Model to strengthen data security and keep sensitive operational knowledge protected, while still making it usable at scale. ZTE TECHNOLOGIES

From Concept to Implementation: Current Status and Future Trends of Integrated C+L Technology

Shang Wendong

Engineer, Optical System Planning, ZTE

Wu Nishan

Senior Engineer, Optical System Technology Research, ZTE

In 2025, the widespread adoption of AI-enhanced and AI-native applications has triggered a surge in global network traffic. This shift is driving network infrastructure upgrades toward ultra-high bandwidth and ultra-low latency, while accelerating the deployment of intelligent traffic scheduling systems. Simultaneously, the large-scale development of computing power networks has posed new challenges to the capacity of underlying backbone optical transmission networks.

Currently, there are two primary approaches to increasing single-fiber transmission capacity in optical transport networks: improving single-wavelength rates and expanding spectrum. Improving single-wavelength rates relies primarily on optical digital signal processing (oDSP) and forward error correction (FEC) algorithms to enhance the reception performance of higher-order modulation formats. Meanwhile, C+L band expansion can double the number of channels compared to the original C-band, thereby doubling system capacity. As a result, single-wavelength 400G/800G/1.6T C+L systems are being deployed at scale in computing power network scenarios.

Current Status of C+L Integration

In addition to ensuring Tbit-level ultra-large bandwidth, computing power networks also need to support flexible scheduling and ultra-high reliability. The introduction of C+L integrated solutions enables operators to efficiently manage data floods while ensuring high speed and large capacity. Such solutions achieve full-band, non-blocking scheduling across the extended C+L spectrum, support wavelength independence on the optical branch side, and facilitate the construction of more agile and flexible optical network facilities.

The evolution path of C+L integrated systems

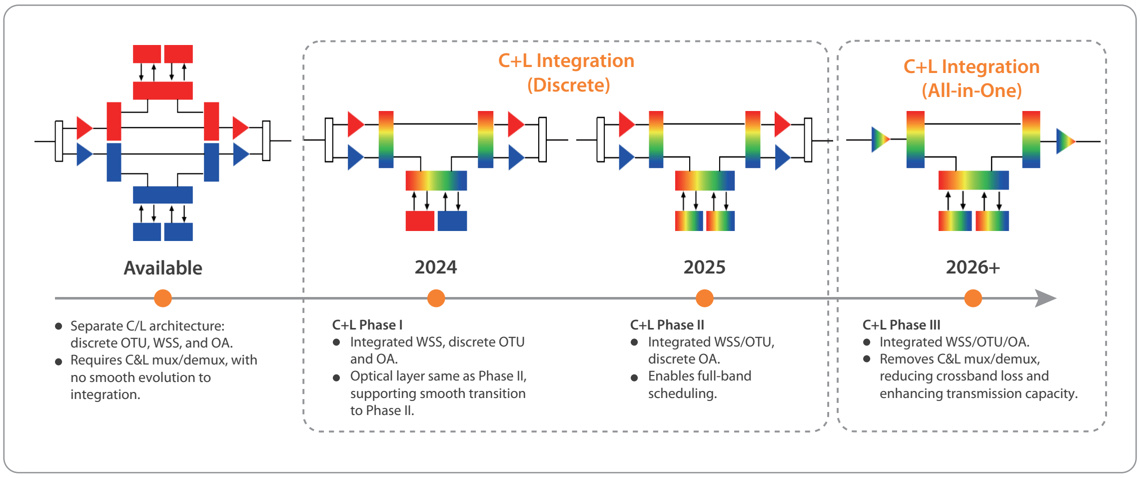

Fig. 1 Evolution path of the C+L integrated system.

starts from separate C/L band architectures and progresses through three stages: wavelength selective switch (WSS) integration, WSS/optical transponder unit (OTU) integration, and WSS/OTU/erbium-doped fiber amplifier (EDFA) integration (Fig. 1). Their ultimate form structurally resembles existing C-band systems, with device costs expected to be reduced by 30% compared to separated C+L architectures, board integration doubled, and equipment footprint significantly reduced. Once C- and L-band EDFAs are integrated, the need for protective guard bands between them is eliminated, enabling full-frequency availability. OTU and WSS can evolve toward full-frequency switching across the 12 THz C+L range, further improving spectral utilization. A unified EDFA/WSS can balance power between the C and L bands, enhancing system performance tuning and operational efficiency. Moreover, integrated C+L systems no longer require C/L-band multiplexing/demultiplexing devices, reducing cross-band loss and further enhancing transmission capacity.

In C+L integrated optical network solutions, the OTU and WSS support arbitrary tuning and scheduling across the full 12 THz C+L spectrum, simplifying system architecture and maximizing the all-optical switching capabilities of reconfigurable optical add-drop multiplexer (ROADM). In wavelength switched optical network (WSON)-based relay recovery scenarios, C+L integration allows the relay boards in the recovery resource pool to be allocated across the entire network, enhancing resilience against multiple failures.

The ultimate form of C+L integration, achieved through the comprehensive adoption of integrated WSS, OTU, and EDFA devices, eliminates the need for C/L band multiplexing/demultiplexing components, simplifying optical-layer networking. However, integrated EDFA technology and mass production remain uncertain, as integrated erbium fiber is still under research. Specific strategies will depend on future technological breakthroughs.

C+L Integration Technologies and Products

The core technologies driving C+L integration are liquid crystal on silicon (LCoS), integrated tunable laser assembly (ITLA), and erbium fiber. While integrated LCoS and ITLA have already achieved breakthroughs and are widely deployed in 400G networks, integrated erbium fiber technology still faces significant challenges. Integrated EDFA is not yet ready for commercial use.

C+L Integrated WSS

Fig. 2 shows the C+L band LCoS in the integrated WSS. Compared with discrete WSS, integrated WSS compresses the pixel size for single-channel spacing, leading to channel bandwidth narrowing. This issue can be addressed both optically and algorithmically. On the optical path side, increasing grating lines enhances dispersion and splitting; and adjusting lens position or focal length, or adding auxiliary lenses, can compress the 12 THz divergence angle and the LCoS spot size. On the algorithmic side, optimizing LCoS shaping algorithms and improving resolution (2.4k/2.9k/3.3k) can further enhance bandwidth.

Currently, 12 THz C+L integrated WSS products are being introduced, and WSS-centered optical cross-connect (OXC) devices are already in large-scale commercial use in 400G networks. As the basic unit of intelligent all-optical networks, the C+L integrated OXC—combined with coordinated control scheduling, global intelligent power management, and optical labeling—enables one-stop intelligent deployment, simplified power adjustment, service tracking, and automatic scheduling, driving computing power networks toward greater intelligence.

C+L Integrated OTU

The C+L integrated OTU consists of oDSP, ITLA, modulators/demodulators, and optical amplifiers (Fig. 3).

- **Analog and DSP chips**

The core technologies for integrated OTUs align closely with existing C-band solutions, necessitating only marginal DSP-level compensation. The 400G/800G modulation/demodulation and DSP recovery algorithms are already mature.

- **Integrated ITLA**

The integrated ITLA adopts either a dual-chip integration scheme (C/L dual chips + low-loss optical switch) or a monolithic external cavity scheme (a single gain chip based on an optimized quantum well structure + a multi-ring resonator based on SiN waveguides). Among these, the commercially mature solution is the monolithic external cavity integrated ITLA, as shown in the schematic diagram in Fig. 4.

ZTE has achieved industry-leading performance with a 30 kHz narrow linewidth, C+L integrated 240-channel tunable laser, supporting 400G/800G/1.6T coherent transmission systems and meeting operators' CL240 evolution needs.

- **Integrated modulators and detectors**

Mainstream approaches include silicon photonics (SiPh) and indium phosphide (InP). Silicon-based approaches support wide wavelength ranges with minimal wavelength dependence, offering performance comparable to discrete C/L band integrated coherent receiver modules (ICRMs). InP-based approaches, however, exhibit wavelength-dependent losses and responsivity differences. Integration using InP is expected to be more costly, requiring optimization in device materials, structural design, and algorithmic compensation.

- **C+L integrated amplifier**

Compared with integrated WSS and OTU, integrated EDFA technology and products remain immature. As the critical device for the ultimate form of C+L integration, the integrated EDFA is a major focus for future development. Challenges include erbium fiber design and fabrication, as well as amplifier system design. Greater industry-wide collaboration is needed to advance integrated EDFA research and commercialization.

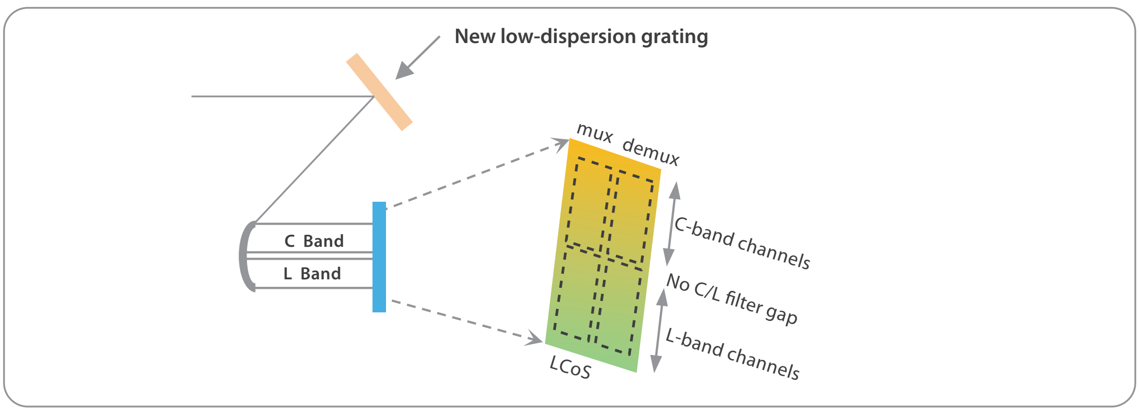

Fig. 2 Structural diagram of C+L integrated WSS.

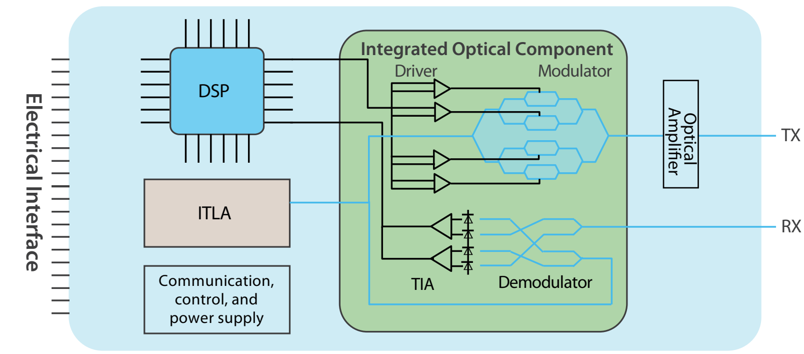

Fig. 3 The internal structure of a coherent optical module.

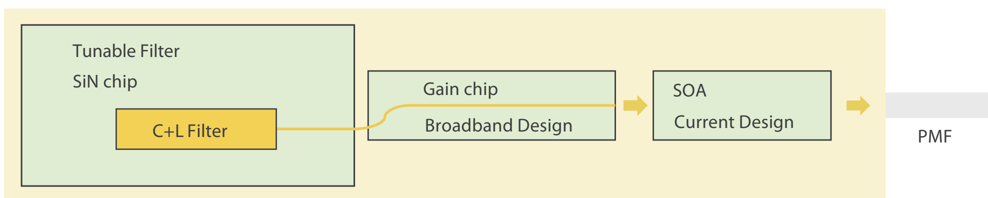

Fig. 4 Schematic diagram of the monolithic external cavity integrated ITLA solution.

Applications of C+L Integration

In 2025, ZTE continued to deepen its efforts in C+L integrated optical network technology, launching an exclusive full-band OTN solution and introducing integrated 400G/800G/1.6T C+L optical modules. These innovations increased system capacity by 25% while reducing spare part types by half, with multiple live-network validations conducted jointly with domestic and international operators.

In March 2025, ZTE and China Telecom completed the world's first C+L band integrated 80×800G WDM trial on live network. Based on China Telecom's backbone ROADM network, the trial validated the transmission capability of 800G C+L integrated OTU modules, optical-electrical scheduling within the 12 THz ultra-wide spectrum, and WSON wavelength recovery.

In May 2025, the two parties completed the world's first live-network trial of 400G/800G mixed-rate ROADM, verifying the coexistence of 800G and 400G wavelengths in computing power core regions. Combined with hybrid WSON technology, the trial confirmed the reliability of all-optical scheduling. Results showed that existing 400G networks can be smoothly upgraded to support 800G wavelengths, achieving stable coexistence and uninterrupted wavelength rerouting recovery.

Future Outlook for C+L Integration

In backbone WDM scenarios, mature integrated C+L 400G solutions will dominate in the short term, with 800G deployments limited to specific high-rate demand scenarios. For metro/DCI core high-traffic scenarios, 800G upgrades and new builds are expected to surge in 2026.

Currently, major operators and vendors are advancing C+L integrated optical networks through standards development, product R&D, and pilot deployments. Continuous iteration of high-speed coherent optical modules and new wide-spectrum optical amplifiers will inject momentum into integrated optical networks, supporting the evolution and upgrade of computing power networks. ZTE TECHNOLOGIES

Next-Generation Optical Communication Architecture:

400G/800G Full-Band OTN

Chen Yong

Chief Engineer of OTN Product Planning, ZTE

The rapid development of new-generation information technologies, such as 5G, cloud computing, big data, and AI, is driving an exponential growth in data traffic. Consequently, traditional optical networks are facing bottlenecks in bandwidth capacity, transmission latency, and intelligent O&M. To meet future demands for ultra-large capacity, high efficiency, and intelligent transport, all-optical network architecture, combining full-band OTN (C+L band) with ultra-high-speed 400G/800G, has become a key direction for next-generation optical communication networks.

400G/800G Full-Band OTN Solution

The ZTE 400G/800G full-band OTN network solution adopts a three-layer architecture—"full-band OTN +

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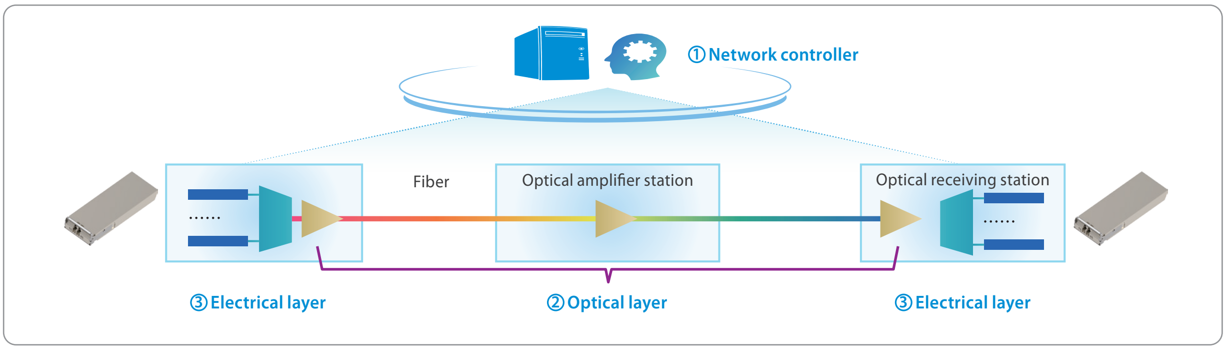

Fig. 1 Full-band OTN network architecture.

high-speed optical modules + intelligent scheduling and control"—to build a future-oriented all-optical network platform. As shown in Fig. 1, full-band OTN consists of the electrical layer, the optical layer, and the network control layer. The electrical layer primarily includes full-band OTN equipment and 400G/800G optical modules, enabling high-speed, high-reliability data transmission and encapsulation. The optical layer is characterized by the need for amplifiers and OXC system components to support C+L band integration, providing up to 12 THz bandwidth for ultra-large capacity transmission. The network control layer, composed of an SDN controller and an intelligent scheduling system, enables wavelength-level service scheduling, resource optimization, and automated O&M.

The full-band OTN optical layer, based on core components such as wavelength division multiplexing (WDM), wavelength selective switches (WSS), and coherent optical modules, establishes intelligent scheduling and efficient transmission mechanisms for wavelength-level services across a full spectrum range (12 THz). It adopts dense WDM (DWDM) technology with a 150 GHz channel spacing, supporting up to 80 wavelengths (40 wavelength channels each in the C-band and L-band) with high capacity. Leveraging WSS, it achieves dynamic configuration and flexible scheduling of wavelength-level services, enhancing network intelligence and scalability. In addition, C-band/L-band erbium-doped fiber amplifiers (EDFA) or Raman amplification are used to compensate for optical signal attenuation during fiber transmission, supporting stable long-distance transmission of high-speed signals. With its large capacity, high performance, and flexible scheduling capabilities, full-band OTN lays a solid foundation for next-generation high-speed optical communication networks.

The full-band OTN electrical layer supports flexible containers such as ODUflex and OTUCn, efficiently meeting the demands of 400G/800G high-speed services. It provides multi-granularity service scheduling at both wavelength and sub-wavelength levels for precise on-demand bandwidth allocation, while supporting unified transport for multiple services including IP, Ethernet, and storage. In addition, the layer supports flexible OTN (FlexO) interfaces, enabling adaptation to optical modules of different rate levels and enhancing networking flexibility and transmission efficiency. The 400G/800G high-speed optical modules utilize coherent modulation technology to significantly improve spectral efficiency and transmission performance, meeting the growing demand for high-bandwidth services. These modules support various transmission distances, covering short-distance data center interconnection (DCI), medium-distance metro transmission, and long-distance backbone network applications. Furthermore, support for C+L full-band operation improves modular integration and facilitates flexible deployment and O&M, helping operators build high-performance and scalable next-generation optical communication networks.

The network control layer focuses on intelligent scheduling and control and adopts an SDN architecture to achieve network virtualization and automated service deployment, thereby improving the flexibility and management efficiency of network resources. By introducing AI algorithms, it enables link quality prediction, rapid fault location and self-healing, as well as dynamic optimization of network resources, significantly enhancing network reliability and operational efficiency. In addition, it supports seamless integration with business support systems (BSS) and operations support systems (OSS) to achieve unified end-to-end service management and orchestration, improving network intelligence and O&M automation capabilities, thereby helping build efficient, elastic, and adaptive networks.

Solution Evolution

The evolution for 400G/800G full-band OTN optical networks can be divided into three main stages.

- **Initial stage (2024–2026):** This stage focuses on 400G modules and C+L integrated optical path scheduling. The feasibility of C+L band transmission technology will be verified through backbone network applications, laying the technical foundation for the full-scale implementation of full-band OTN.
- **Mid-term stage (2027–2029):** During this stage, 400G full-band OTN will be deployed at scale. Optical modules, optical path scheduling, and amplifiers will all support C+L full-band integration. Unified scheduling and collaboration across C and L bands will significantly enhance network bandwidth and scheduling flexibility.
- **Mature stage (post-2030):** 800G modules will gradually be deployed across all scenarios, while AI-driven intelligent scheduling technology will mature. The network will evolve toward full intelligence, enabling converged transport and efficient scheduling of multiple services. The goal is to build a high-bandwidth, low-latency, and adaptive next-generation optical network to support the future digital economy and emerging services.

Full-band OTN networks offer several significant advantages. In terms of bandwidth capacity, a single link can support a capacity of up to 12 THz, enabling 80-wavelength 400G/800G transmission. With appropriate wavelength planning and inter-channel interference control, it can further evolve to an 80-wavelength Terabit (T-bit)-scale capacity. Regarding flexibility, the intelligent scheduling system enables precise scheduling of network services at both wavelength and sub-wavelength levels, improving resource utilization and scheduling flexibility. From a cost-efficiency perspective, modular deployment reduces network upgrade and expansion costs. As the industry chain matures and economies of scale develop, the unit cost of full-band high-speed optical modules and band extension technologies will continue to decrease. Regarding intelligent O&M, the network supports SDI and AI-driven scheduling and operations, significantly enhancing automation. Furthermore, an evolvable O&M architecture design ensures a seamless transition from existing networks toward full-band OTN.

Deployment Strategy

For future 400G/800G full-band OTN network solution deployment, ZTE recommends the following strategies:

- **Phased deployment:** Prioritize the deployment of 400G high-speed optical modules in backbone networks, combined with C-band channel expansion to enhance transmission capacity. As service demands grow, gradually introduce the L-band to achieve C+L band integration, ensuring efficient utilization of spectrum resources and reducing initial investment.
- **Modular upgrades:** Utilize pluggable optical modules (e.g., CFP2 packaging for long-haul backbone and metro networks, and QSFP-DD/OSFP packaging for short-reach DCI) together with scalable OTN equipment to support on-demand expansion. This approach significantly reduces upgrade costs and cycles while enhancing network flexibility.
- **Proactive intelligent O&M:** Prioritize the deployment of SDN controllers and AI-driven O&M platforms to enable real-time network perception, automatic fault recovery, and intelligent traffic scheduling, thereby enhancing network automation and operational efficiency.
- **Multiservice unified transport:** Establish a unified transmission platform that supports the flexible scheduling and transport of various services, including IP, Ethernet, OTN, and SDH, within a single network, increasing resource utilization and reducing network complexity and operational costs.

The combination of full-band OTN (C+L band) and 400G/800G/1.6T+ high-speed optical modules is a key enabler for next-generation all-optical networks. This solution provides high bandwidth, high flexibility, and enhanced intelligence, supporting various scenarios such as large-capacity backbone networks, metro networks, DCI, and enterprise private lines. In the future, as the cost of coherent optical modules decreases, AI scheduling algorithms mature, and standard protocols improve, full-band OTN is expected to accelerate adoption across industries, laying a solid foundation for the rapid growth of the digital economy. ZTE TECHNOLOGIES

Ultra-High-Speed Optical Transceivers and Core Components

Shen Bailin

System Architect of
ZTE Photonics

Ultra-high-speed coherent optical transceivers are core components of full-band OTN networks, and their rates, transmission distances, power consumption, and costs directly affect the evolution of the optical transport network infrastructure. At present, long-haul 400G and metro 800G are in commercial deployment phase, and long-haul 800G and metro 1.6T are in technical development phase. When the single-wavelength rate increases, the working band needs to be extended to support the upgrade of the single-fiber transmission capacity. For example, the working band of the 400G long-haul coherent optical transceiver extends from the C band to the C+L band, and the T-bit long-haul coherent optical transceiver may evolve to the S+C+L band in the future. With the advancements in coherent optical transceivers, core components are facing challenges in bandwidth, integration, power consumption, and cost, and are driving innovation in new materials, new architectures, and new packaging processes.

Development Status

Coherent optical transceivers for long-haul and metro transmission in the telecom field are mainly CFP2. Coherent optical transceivers for interconnection between data centers are available in QSFP-DD and OSFP form factors. Optical transceivers have traditionally been required to be standardized, small factor, pluggable, and easy to maintain. ZTE uses CFP2 coherent optical transceivers. Below is an overview of the technological status of coherent light sources and optical components in an optical transceiver.

Coherent light sources include integrated lasers and external-cavity lasers. The monolithically integrated InP laser does not support C+L integration. External-cavity lasers consist of two solutions: spatial optical filters and silicon photonic filters. The wavelength dependence of the high-reflection film in the etalon of the spatial optical filter solution makes it difficult to achieve C+L band integration. ZTE's coherent light source solution is a Nano-packaged external-cavity laser. It employs a silicon photonic filter design and utilizes an innovative structure combining dual micro-rings and a Mach-Zehnder interferometer, shaping the resonant notch and suppressing the competing mode peaks. The laser frequency tuning range can be extended to 12 THz, covering 240 wavelengths across the integrated C+L band. This represents a twofold increase compared with the tuning range of the current mainstream C120/L120 solution in the industry. The laser achieves a linewidth of 30 kHz, meeting the requirements for long-haul transmission systems.

Coherent optical transceiver components are mainly made of silicon photonics, InP, and thin-film lithium niobate. Silicon photonic components offer significant cost advantages. They use wavelength-independent designs such as adiabatic couplers, supporting C+L integration, but have limited modulation bandwidth. In the future, silicon photonics will evolve toward the integration of thin-film lithium niobate materials to support large-bandwidth modulation.

InP components offer large bandwidth but are costly. A key advantage is the ability to integrate semiconductor optical amplifiers (SOAs) to achieve high power output, while the wavelength-dependent loss introduced by the multi-mode interferometer in the modulator can be compensated by the SOA. For C+L integrated InP components, it is necessary to overcome the technical challenges of amplification across the C+L band in SOAs and to improve the wavelength-related phase performance of the 90° optical hybrid in the receiver.

Developed from bulk lithium niobate, thin-film lithium niobate supports C+L integration by utilizing a multimode interferometer with low wavelength sensitivity. ZTE uses a technology platform based on silicon photonic receivers and thin-film lithium niobate modulators, enabling the realization of C+L integrated 128 GBd optical transceivers through packaging integration.

Future Evolution

C+L integrated optical transceivers have become a clear market requirement. To support the evolution of optical transceivers towards ultra-high speeds, technical innovations are required in the electrical interface form factors, materials for optical transceiver components, and component packaging technologies.

In terms of optical transceivers, pluggable optical transceivers are expected to remain the mainstream until 2030. As the single-channel electrical signal rate on the board increases to 448 Gbps and beyond, the form factor evolution of optical transceivers may follow two directions: introducing flyover cables or co-packaged cables (CPC) to improve the quality of electrical signal transmission while supporting front-panel pluggable transceivers, or embedding optical transceivers within a board, where coherent optical transceivers are placed as close as possible to the digital signal processing chips, as shown in Fig. 1. The power consumption of coherent optical transceivers increases in a spiral manner, and advanced heat dissipation technologies such as cold plate liquid cooling will be gradually introduced. The driving force of optical transceiver rate evolution is to increase the baud rate and reduce the number of optical and electrical channels, lowering the transmission cost per bit. When the optical baud rate reaches 400+ GBd, the dual-wavelength parallel architecture may be used to meet higher-rate transmission requirements in consideration of cost performance.

As the demand for high bandwidth in photonic integrated chips grows, research into new optical transceiver materials is increasing. These materials, including lithium tantalate, barium titanate, and graphene, have high electro-optic coefficients. The application of these materials should offer advantages in cost or performance. Based on the silicon photonics technology, the integration of new materials to complement each other's strengths represents a crucial direction. The characteristics of optical transceiver component materials are shown in Table 1.

Heterogeneous integration of silicon photonics and thin-film lithium niobate may become the mainstream technology for coherent optical components in the future. It supports S+C+L integration and the 400+ GBd baud rate required by 2030. The silicon photonic passive components at the transmitting end support multi-band operation, while the thin-film lithium niobate waveguide is used solely for modulation, supporting a bandwidth exceeding 200 GHz. At the receiving end, thermal phase tuning is employed to achieve precise mixing with a 90° phase difference across multiple bands. The germanium photodetector supports bandwidths exceeding 200 GHz by reducing the transit time of photogenerated carriers and optimizing the series resistance.

In terms of component packaging, the

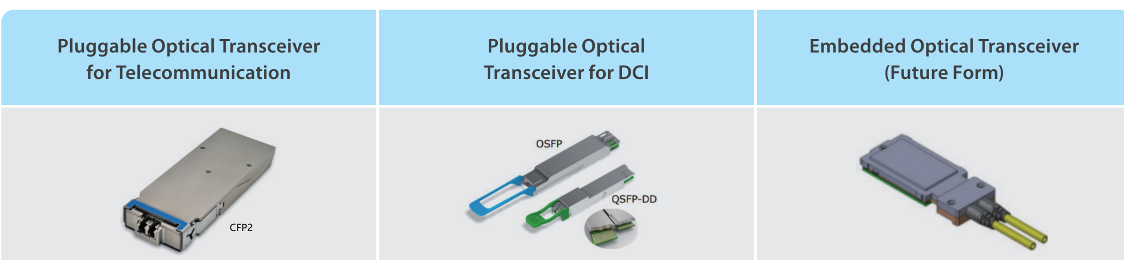

Fig. 1 Form factors of coherent optical transceivers.

Item	Silicon Photonics	InP	Thin-film Lithium Niobate	Silicon Photonics + Thin-Film Lithium Niobate
Modulation bandwidth	~60 GHz	~110 GHz	>200 GHz	>200 GHz
Detection bandwidth	>200 GHz	>200 GHz	None	>200 GHz
Working band	S+C+L Integration	S or C or L	S or C+L	S+C+L Integration
Integration	High	High	Medium	High
Cost	Low	Medium	Medium	Medium

Table 1 Comparison of optical transceiver component materials.

optimization of high-speed signal interconnection between photonic integrated chips, electrical chips, and DSP chips is the driving force behind the evolution of optical component packaging. Optoelectronic components will use the packaging technologies from the integrated circuit industry, such as copper bumps, hybrid bonding, through-silicon vias, integrated capacitors, organic substrates, substrate-like PCBs, and glass substrates. The key difference between optoelectronic packaging and integrated circuit packaging lies in the need for optical coupling in photonic integrated chips and the requirement to protect the optical coupling surfaces during the packaging process.

In the near and medium term, the packaging architecture of optoelectronic components may be that the photonic integrated chip acts as the interposer, and the modulation driver and the transimpedance amplifier chip are reversely mounted on the photonic integrated chip. High-speed signals of the interface are interconnected with the electrical chip through vias of the photonic integrated chip. The photonic integrated chip and the electrical chip use copper-copper bonding or pillar soldering to achieve a short transmission path and small parasitic effects. The DSP chip and the photoelectric chip share the substrate for encapsulation. Fig. 2 illustrates a possible, highly simplified form factor for medium- to long-term coherent optical components: employing fan-out wafer-level packaging, where the coherent DSP chip integrates control and management, modulator driver/transimpedance amplifier, and capacitor functions. The coherent DSP chip is flip-chipped and interconnected with the photonic integrated chip through the redistribution layer, with the DSP mounted on top to facilitate heat dissipation.

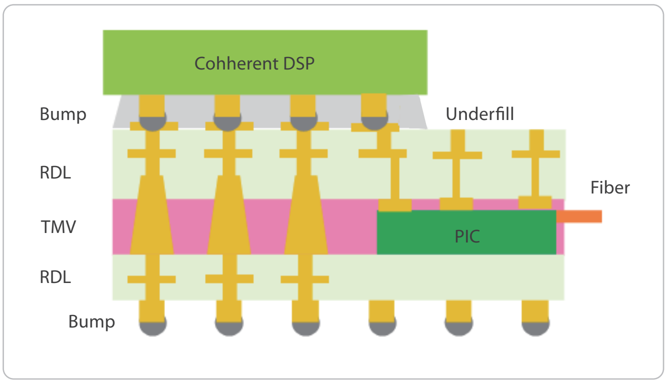

Fig. 2 Possible forms of coherent optical components.

Coherent optical transceivers are developing towards higher bandwidth, higher integration, higher reliability, lower power consumption, and lower cost, promoting continuous innovation in core components in terms of chip materials, architecture solutions, and packaging process. Currently, ZTE has successfully developed the C+L integrated coherent optical transceiver. Looking into the future, T-bit optical components are expected to use the heterogeneous integration technology combining silicon photonics and thin-film lithium niobate to achieve C+L integration or S+C+L integration and support 256 GBd/400+ GBd high baud rates. ZTE TECHNOLOGIES

Ultra-High-Speed Optical Transmission Standards

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Driven by both the AI computing revolution and the rapid growth of data centers, ultra-high-speed optical transmission continues to evolve toward higher rates and higher bandwidth. The large-scale deployment of single-wavelength 400G WDM systems in operators' backbone networks marks the beginning of commercial adoption of 400G optical transmission. At the same time, with the ongoing standardization of 400G/800G optical transmission standards both domestically and internationally, beyond 1T (B1T) optical transmission and new technologies have become key focus areas for standardization organizations.

Overview of Standardization Organizations for Ultra-High-Speed Optical Transmission

Standardization organizations involved in ultra-high-speed optical transmission include the ITU-T Study Group 15 (SG15), the Optical Internetworking Forum (OIF), IEEE 802.3, and the China Communications Standards Association (CCSA). The relevant organizations and key technologies are illustrated in Fig. 1.

As shown in Fig. 1, ultra-high-speed optical transmission standards mainly include technologies for optical systems, optical modules, B1T OTN, and Ethernet interfaces. The ITU-T SG15 standardizes optical systems and B1T OTN for high-speed optical transmission. Specifically, Question 5 (Q5) of ITU-T SG15 specifies new optical fibers, such as G.654.E and space-division multiplexing fibers. Q6 specifies 800G metro DWDM systems and optical components, while Q11 standardizes the frame structure, multiplexing, and mapping for B1T OTN. IEEE 802.3 specifies 800GE/1.6TE ultra-high-speed Ethernet interfaces, which serve as client-side interfaces for ultra-high-speed optical transmission. The OIF specifies standards for 800G/1.6T ZR/ZR+ optical systems and optical modules based on coherent modulation technology, which are used for line-side interfaces in ultra-high-speed optical transmission and data center interconnects.

Chinese standardization organizations for high-speed optical transmission include CCSA TC6 and TC12. The WDM equipment industry standards specified by the TC6 WG1 working group are widely recognized, reflecting the requirements of China’s three major operators and equipment manufacturers' capabilities. In addition, this working group is involved in standardizing new optical transmission technologies such as C+L integration and hollow-core fibers. Meanwhile, TC6 WG4 specifies optical module standards based on data rate and transmission distance.

Progress on Optical Layer Standards for 800G and Beyond

ITU-T SG15 Q6

ITU-T SG15 Q6 is standardizing 800G metro DWDM systems, with completion targeted for 2026. Committed to standardizing multi-vendor interoperability of DWDM systems, SG15 Q6 has been continuously seeking metrics to assess transmitter quality, which is challenging for coherent modulation-based DWDM systems. Q6 has decided to adopt the ETCC approach and is actively collaborating with OIF and IEEE 802.3 on further research.

At the Q6 meeting held in Paris in June 2025, ZTE proposed initiating the standardization of 1.6T systems, which received broad recognition. Meanwhile, China Mobile proposed a joint study by Q6 and Q5 on hollow-core fibers, which received preliminary approval.

Q6 attaches great importance to standards that

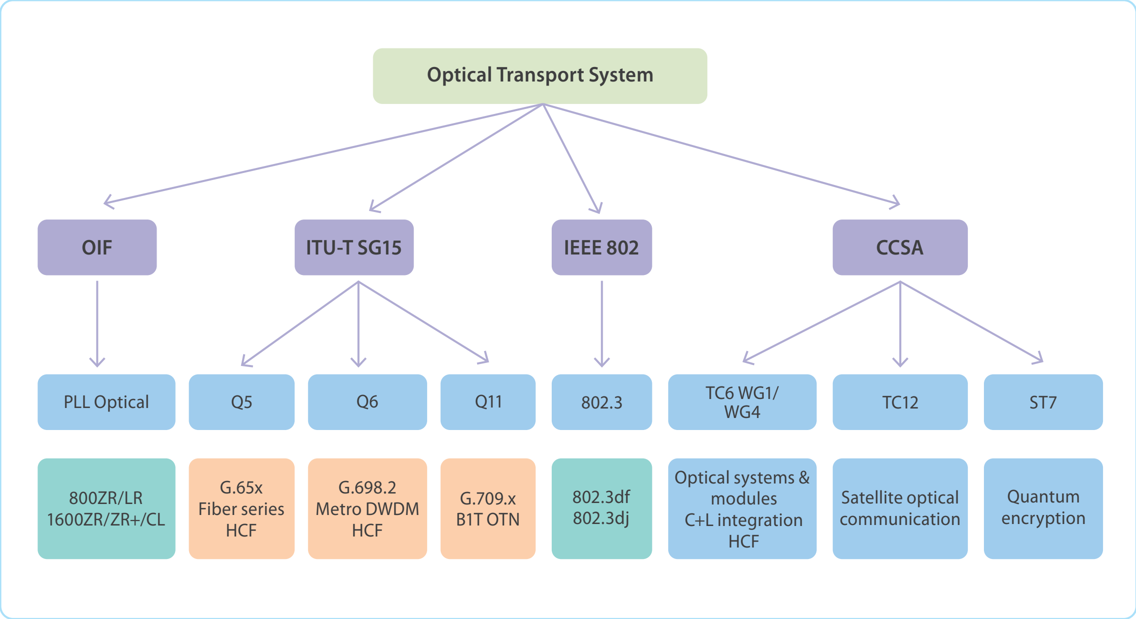

Fig. 1 Standardization organizations and key standard technologies for ultra-high-speed optical transmission.

reflect its unique value. Technologies such as C+L-band extension and S-band extension, as well as hollow-core fibers and space optical communications, are expected to be considered in future standardization work. The role of Q6 in the standardization of high-speed optical transmission is highly anticipated.

OIF

OIF has been leading the standardization of coherent optical systems and optical modules in recent years, maintaining a strong position among various standardization organizations. OIF released the 800G ZR standard in October 2024, and the 800G LR standard in April 2025, marking the completion of the standardization of 800G coherent optical modules. The 800G ZR interoperability was further demonstrated at OFC 2025.

Since 2024, OIF has successively initiated the 1.6T ZR, 1.6T ZR+ and 1.6T CL projects, signaling the formal entry of OIF into the 1.6T standardization era. The 1.6T ZR project, targeted for completion in Q3 2026, utilizes single-wavelength 1.6T with PM-16QAM modulation for a transmission distance of 80-120 km. The 1.6T ZR+ project adopts dual digital subcarrier modulation, targeting transmission distances of 2000 km (1.2T) and 1000 km (1.6T), using the C+L band. The project is expected to be completed by the end of 2026. In parallel, OIF has launched the 1.6T coherent light (CL) project to standardize and simplify coherent technologies and expand their application scope.

It is worth mentioning that the 1.6T ZR+ project is the first OIF standard to specify multiple spans. This is expected to further enhance the influence of OIF and have a significant impact on the technical direction of 1.6T standardization and ITU-T and IEEE 802.3.

IEEE 802.3

IEEE 802.3 plays a leading role in the specification of Ethernet interfaces and has been standardizing 800G/1.6T Ethernet interfaces. It released the IEEE 802.3df standard based on 100G-per-lane technology, in 2024. At present, IEEE 802.3 is working on the 802.3dj project based on 200G-per-lane technology, with solutions for different distances already determined and draft D2.0 published. This project is expected to be completed in September 2026.

Meanwhile, IEEE 802.3 has started the research on 400G-per-lane technology. With the maturation of this technology, IEEE 802.3 is expected to advance the standardization of 1.6T Ethernet interfaces.

CCSA

In 2024, CCSA TC6 WG1 completed the *Technical*

Requirements for N×400G Ultra-Long-Haul WDM. This standard specifies DWDM optical systems using QPSK modulation above 120 GBd. It meets the ultra-long-haul 400G transmission requirements of China's three major operators and promotes large-scale commercial deployment of 400G DWDM.

In 2025, the working group started to standardize the *Technical Requirements for Metro N×800G Optical WDM Systems* and launched research on long-haul 800G optical transmission system technologies, S+C+L band WDM transmission technologies, and 1.6T WDM system technologies. These efforts position China at the forefront of long-haul and high-speed DWDM standardization.

In addition, CCSA TC6 WG4 has basically completed a series of standards for 800G intensity modulation and phase modulation technologies. It has also initiated research and standardization on 1.6T optical modules and C+L integrated key optical components to better support the application requirements of optical system standards.

B1T OTN Standards

ITU-T SG15/Q11 is standardizing B1T OTN, a large-bandwidth OTN interface technology for optimized Ethernet service transport. B1T OTN follows a design philosophy of simplified architecture and industry-wide sharing.

Simplified Architecture

OTUk-based OTN interface technology for 100G and below defines the tributary slot granularity of 1.25G and 2.5G for efficient transport of customer services. For the OTUk interface, the mapping and multiplexing hierarchy adds one additional level with each generation of rate evolution, and the rate evolution itself is not always an integer multiple. For example, the OTU4 bit rate is more than, not exactly 10 times the OTU2 bit rate. As a result, there are multiple mapping and multiplexing levels for 100G and below OTN interfaces, and the interface bit rate continues to increase.

The FlexO-based B100G OTN introduces the OTUCn and FlexO technologies. OTUCn supports 5G tributary slots for customer service transport. FlexO, as an interface technology, introduces the better-performing RS (544, 514) FEC. FlexO also introduces the concept of 100G instance. FlexO interfaces at different rates are all integer multiples of the 100G instance. This approach solves the problem of continuously evolving interface bit rates, but does not address the multi-level multiplexing in traditional OTN.

The B1T OTN interface technology is an extension of the FlexO interface and introduces a FlexO path layer with a 100G tributary slot granularity. To reduce the number of mapping and multiplexing levels, no more than three path layers are designed from the outset. That is, regardless of how the bit rate evolves, B1T OTN supports at most three path layers. While inheriting the advantage of FlexO in avoiding additional bit rate increases when the interface evolves, it solves the multi-level multiplexing issue in traditional OTN, highly simplifying the entire OTN architecture. In addition, in terms of OAM monitoring, it reduces the six-level tandem connection monitoring (TCM) architecture of traditional OTN to a maximum of four levels.

Industry-Wide Sharing

ZR, defined by OIF, is a point-to-point interface technology that uses the FlexO frame structure defined by ITU-T. ZR supports Ethernet as the customer service. B1T OTN is an end-to-end network technology, with Ethernet comprising about 90% of the customer services.

To maintain the advantage of the shared industry chain, a major technical focus in the standardization discussion is to keep the mapping mechanism from Ethernet services to FlexO frames in ZR the same as that from Ethernet services to the new FlexO path layer in B1T OTN. That is, Ethernet clients are first distributed with a 257b granularity and then mapped to the payload area of the service layer using the generic mapping procedure (GMP). The new FlexO path layer in B1T OTN maintains the same payload area and bit rate as the FlexO frame in ZR, while its overhead area is extended to support path monitoring (PM) and TCM monitoring capabilities

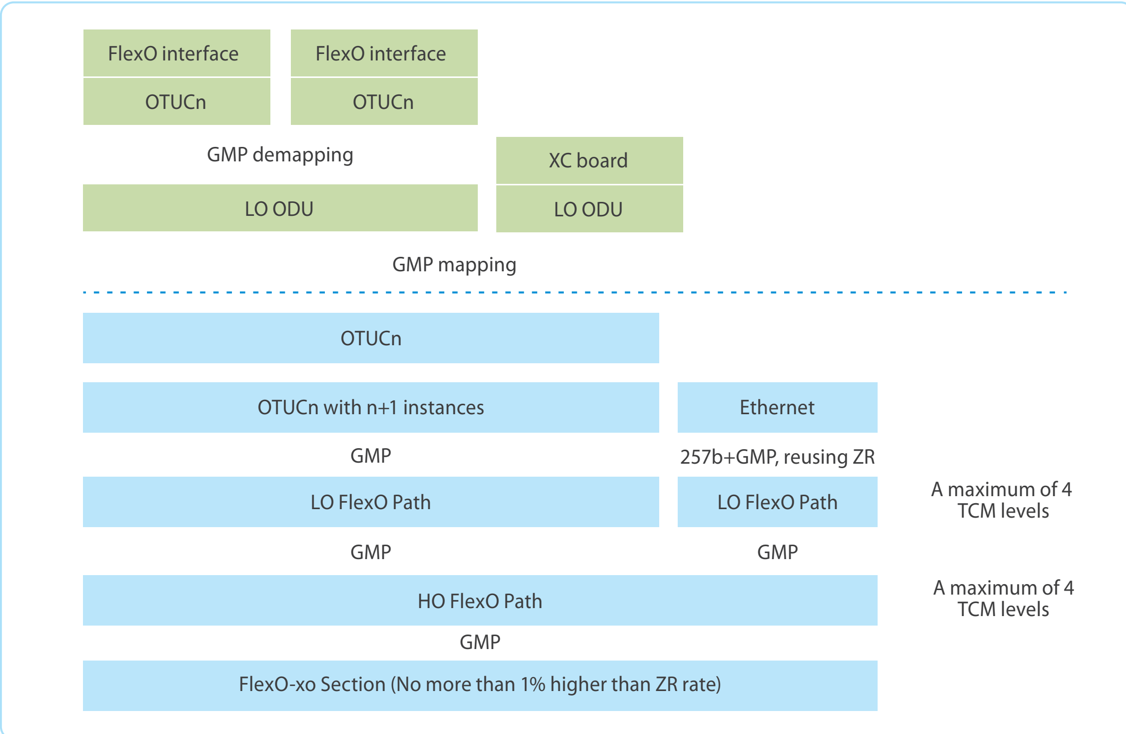

Fig. 2 Functional hierarchy of B1T OTN.

in accordance with the network technology requirements.

Another important change is the decrease in the interface bit rate. By reducing the number of mapping and multiplexing levels and narrowing the bit-rate differences between different levels, the 100G instance bit rate of the B1T OTN interface increases by no more than 1% compared with that of the ZR interface, enabling the reuse of related components.

In addition to carrying Ethernet clients, B1T OTN maintains backward compatibility and can support the transport of ODU from the traditional OTN interface in the B1T OTN network. To enable efficient service transport and maintain large-granularity scheduling of B1T OTN 100G tributary slots, OTUCn can be used as an entity for aggregating multiple low-rate ODUs, which are then mapped to the new FlexO path layer using bit rate reduction technologies. Fig. 2 shows the functional architecture of the entire B1T OTN network.

The standardization of B1T OTN achieved a breakthrough at the ITU-T SG15 Plenary meeting in March 2025, with the formal initiation of G.709.1 Amendment 1, which specifies the B1T OTN technologies. The core of this amendment lies in the frame structure design of the new FlexO path layer and the multiplexing relationships between different levels. The standard is scheduled for approval in July 2026, after which the development of standards related to B1T OTN equipment will commence.

Conclusion

The short-reach and metro 800G optical transmission standards have largely been completed by international standardization organizations, while Chinese standardization organizations are focusing on the long-reach application and band extension of 800G DWDM. In terms of B1T, 1.6T high-speed optical transmission has become a key focus for standardization organizations worldwide, including ITU-T, OIF, IEEE 802.3, and CCSA. Technologies such as modulation formats, interface technologies, band extension, C+L integration, hollow-core fibers, and satellite optical communication will be key areas for future standardization. ZTE TECHNOLOGIES

Large AI Model-Based Solution for Intelligent Optical Network O&M

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With the rapid expansion of OTN networks and increasing architectural complexity, traditional optical networks urgently require AI technologies to address cost and efficiency challenges from fault prediction and prevention, as well as complicated and repetitive O&M operations, improving O&M quality and driving the evolution of network technologies.

To meet the digital and intelligent transformation requirements of optical network O&M, introducing large AI models to deliver intelligent capabilities across the full lifecycle—planning, construction, maintenance, optimization, and operation—has become a widely recognized approach to accelerating the evolution towards higher-level autonomous optical networks.

Focusing on the new intelligent O&M paradigm empowered by large AI models for optical networks, two typical application solutions developed by ZTE are presented: intelligent network fault diagnosis and network traffic analysis & prediction.

Intelligent Network Fault Diagnosis

Optical network architectures are becoming increasingly complex, with diverse fault symptoms and a large number of alarms, making rapid root cause localization difficult. Delimiting and locating equipment and line faults remains challenging, and locating fiber line faults requires additional equipment. Traditional manual analysis involves multiple steps, is time-consuming, and suffers from low accuracy.

To address these network O&M issues, ZTE has launched a network fault diagnosis system based on large AI models, as shown in Fig. 1. This system implements AI-based root cause analysis of network alarms and large model-based automated fault diagnosis. In addition, knowledge graph technology is introduced to enhance fault diagnosis accuracy and improve the operational efficiency of the network management system (NMS) through natural language interaction.

AI-Based Root Cause Analysis of Network Alarms

For OTN networks, the system makes comprehensive root cause analysis of hardware faults, including equipment boards and optical modules, as well as potential faults of network fibers such as fiber breaks, fiber deterioration, and co-cable routing. Compared to traditional manual expert analysis, the next-generation intelligent system preprocesses massive alarms and achieves rapid and accurate alarm root cause analysis using small-model AI algorithms.

The procedure consists of three main steps. First, raw alarms are processed by applying high-frequency filtering and expert-defined rules. Then, massive alarms are automatically aggregated based on a time-space correlation clustering algorithm. Finally, the correlated alarms are analyzed using a fault propagation graph and a graph neural network algorithm to identify the root cause alarms.

With the introduction of AI analysis, the system achieves over 90% accuracy in root alarm identification, significantly improving work order dispatch accuracy, reducing the number of work orders, and ultimately enhancing efficiency.

Large Model-Based Automated Fault Diagnosis

Traditional fault diagnosis is performed manually using tools, which can take a long time to diagnose a single fault. In complicated fault scenarios, the process highly relies on the experience of the O&M personnel, making it difficult to ensure timely fault recovery. Leveraging large model technologies, the

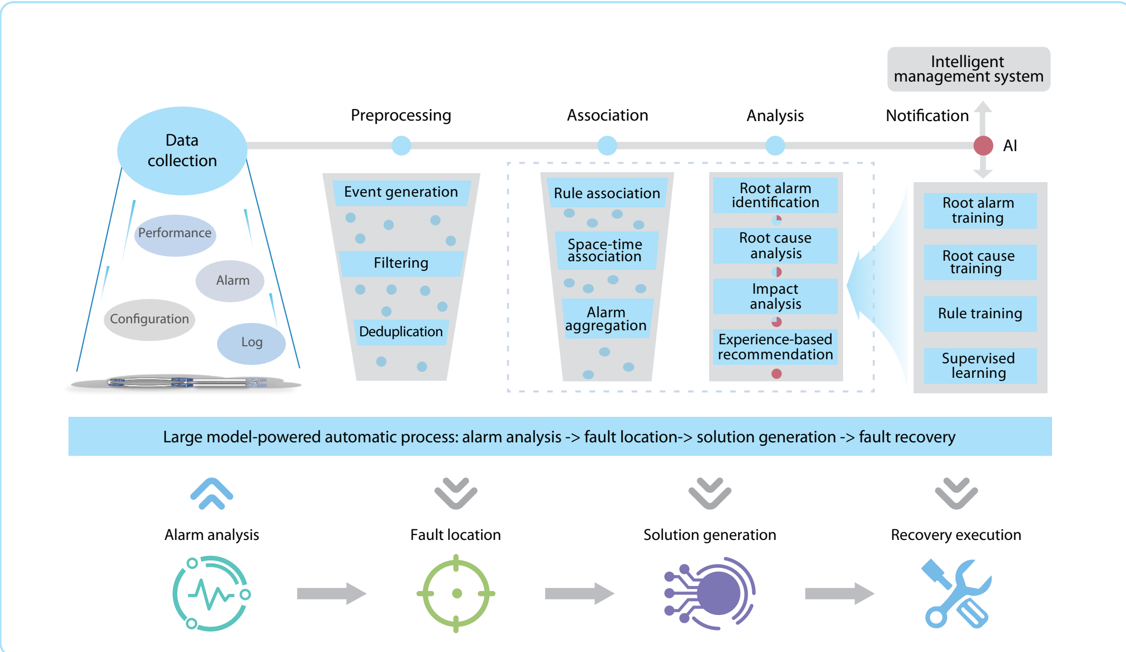

Fig. 1 ZTE's large model-based network fault diagnosis system.

system intelligently generates diagnosis solutions and implements automated scheduling, eliminating the reliance on operator expertise for fault diagnosis and significantly enhancing O&M efficiency.

Using the powerful natural language processing and knowledge inference capabilities of ZTE's Nebula Telecom Large Model, the system can accurately identify fault symptoms described in natural language input or fault work orders, and generate corresponding diagnosis solutions. With the orchestration and scheduling capabilities of the large model, the system automatically performs alarm analysis, fault location, solution generation, and recovery execution through internal API invocation, based on the generated diagnosis solution. This capability reduces the average fault diagnosis time from hours to less than five minutes. Moreover, based on the continuous learning capability of the large model, the solution can better adapt to different network environments and fault scenarios, further improving both the efficiency and accuracy of fault diagnosis.

Knowledge Graph for Improved Diagnosis Accuracy

Knowledge graph technology is introduced into the fault diagnosis system to construct a corresponding knowledge graph based on information and knowledge related to fault O&M, including resource information and troubleshooting knowledge. For example, resource information is structured into a resource knowledge graph and troubleshooting-related knowledge into a fault knowledge graph. The system then performs inference based on the constructed resource knowledge graph, incorporates relevant knowledge from the fault knowledge graph, and utilizes the existing rule library to generate the fault diagnosis result.

At present, the combination of large models and knowledge graphs has become a consensus in the industry. Large models enable language understanding, while knowledge graphs enrich the way knowledge is represented. Together, these technologies complement each other to improve inference capabilities and further improve the fault diagnosis accuracy.

Natural Language Interaction for Enhanced NMS Operation Efficiency

Large model technologies are driving the evolution of network management operation from a graphical user interface (GUI) to an artificial intelligence user interface (AUI). During routine O&M,

users can add, delete, modify, and query network information and configurations using natural language, without the need to learn and remember specific usage methods and function entries of the NMS, improving the NMS operation efficiency by more than 90%.

Network Traffic Analysis & Prediction

The service traffic carried by each optical channel in an optical network varies over time, making it difficult for users to promptly and accurately identify traffic bottlenecks during network O&M. Additionally, users are unable to analyze or predict traffic trends for each channel in the future phases of the network, nor can they plan bandwidth resources in advance.

To solve the above network O&M challenges, ZTE has launched the network traffic analysis & prediction system (as shown in Fig. 2), enabling fine-grained network O&M and intelligent service operation guidance. It also supports the visual display of a digital map.

Fine-Grained Network O&M

Based on AI modeling and prediction algorithms for network traffic, the solution overcomes the traffic perception blind spots of traditional OTN networks. By combining the advantages of traditional O&M and traffic management, it provides reference for network capacity expansion, avoiding both user experience degradation caused by delayed capacity expansion and the waste of investment from blind capacity expansion.

Compared to traditional OTN networks, the intelligent system represents an innovative leap in traffic management, transforming it from "nonexistent" to "available" and from "zero" to "one". It has transformed the rigid-pipe O&M philosophy of OTN. By identifying port traffic-related indicators, it enables soft analysis of hard channels, delivering fine-grained management and predictive analysis for network O&M.

- **Real-time traffic analysis**

The solution provides multi-dimensional traffic analysis capabilities. When traffic reaches a threshold, it triggers a threshold-crossing alarm to guide service diversion and avoid service impairments. The solution provides port traffic analysis at the minute, hour, day, and month levels. When peak bandwidth utilization reaches 90%, a threshold-crossing alarm is triggered to guide the maintenance personnel to divert services timely, thus preventing service quality degradation. In addition, based on current traffic analysis, the system can identify network bottlenecks and recommend targeted capacity expansions.

- **Intelligent traffic prediction**

By using AI algorithms such as linear regression

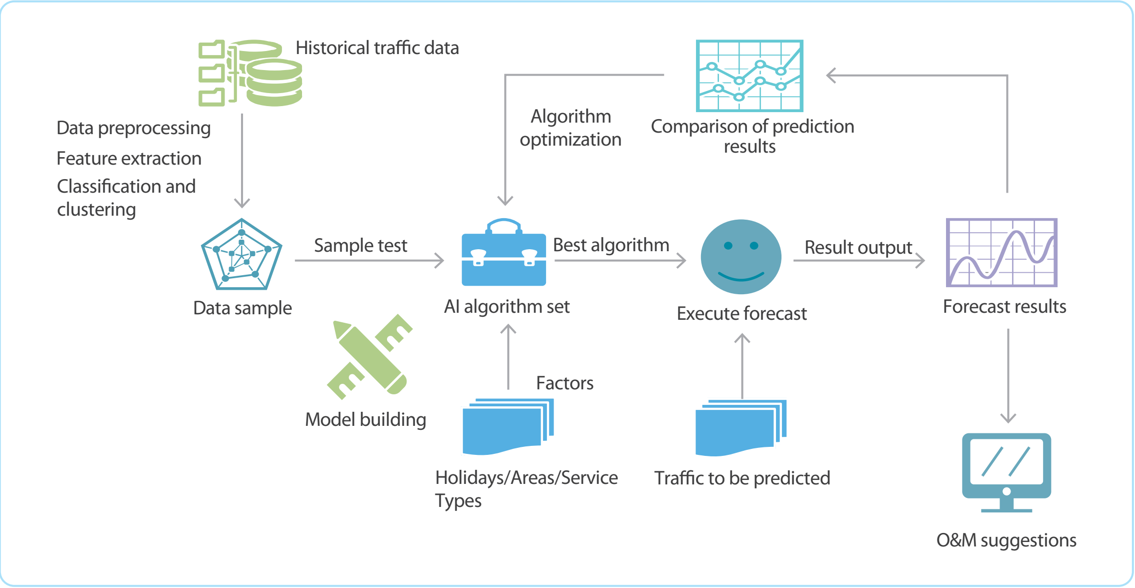

Fig. 2 ZTE's network traffic analysis & prediction system.

> **Based on real-time traffic analysis, the network traffic analysis & prediction system provides timely alerts for traffic bottlenecks, improves O&M efficiency by over 30%, and predicts future traffic trends through AI big data analysis.**

and time series, along with long-term big data analysis and prediction, the system implements traffic prediction curve assessment, detects network bottlenecks and service overload risks in the future, and discovers bandwidth requirements in advance. This helps guide global network traffic optimization and capacity expansion planning.

Intelligent Service Operation Guidance

Based on OTN network service traffic data, the system is capable of building models of network service usage patterns. By analyzing behaviors such as zero traffic, traffic decline, traffic surges, and traffic fluctuations, and incorporating traditional OTN port and user status analysis, it enables intelligent service O&M.

- **Service fault management**

Through time-based traffic analysis, the system builds a data model of user service usage patterns and evaluates service reliability based on traditional OTN performance analysis data (such as port status, optical power, and bit errors). It can quickly identify zero-traffic user faults and respond to interruptions, minimizing the impact on services.

- **Service anomaly alert**

The system analyzes traffic changes over time based on user service usage patterns to generate early warnings of potential customer churn. It also proactively monitors long-term "zero-traffic" user behavior to prevent customer churn risks and the invalid occupation of network resources.

- **Package change alert**

The system analyzes the quality degradation of services that exceed package limits and dynamically adjusts the bandwidth for customers in a timely manner to prevent impacts on service quality. It also detects customer service growth trends timely and provides package expansion alerts to the front-end teams.

Visual Display of Digital Map

Real-time traffic monitoring data for network ports and services can be visualized and managed on a digital network map.

- **Multi-dimensional analysis:** Provides multi-dimensional statistical analysis based on port, user rate, bandwidth utilization, peak/valley value, average value, and TOPN.
- **Traffic map:** Displays the entire network traffic data in real time, including traffic/utilization rankings, coloring, map drill-down, and service proportions.
- **Trend analysis:** Displays trends for peak and average values of rates, traffic, and bandwidth utilization for ports and services in the near future, based on historical traffic statistics.

ZTE's intelligent OTN network fault diagnosis system uses AI technologies to achieve minute-level diagnosis efficiency with an accuracy rate exceeding 90%. Based on real-time traffic analysis, the network traffic analysis & prediction system provides timely alerts for traffic bottlenecks, improves O&M efficiency by over 30%, and predicts future traffic trends based on AI big data analysis, thus facilitating the transformation and upgrade of O&M from passive maintenance to proactive prevention. ZTE TECHNOLOGIES

AI-Computing Optical Networks: Scenarios and Trends

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The AI-Computing Optical Network provides optical connectivity within, between, and to AI-Computing Data Centers. It is a key technology for enabling mesh interconnections to support high-speed direct connections between these centers. This paper explores the main application scenarios and future development trends of the AI-Computing Optical Network, aiming to provide a reference for research and practice in relevant fields.

Main Application Scenarios of AI-Computing Optical Networks

Driven by the demands of AI-Computing, the development and deployment of the AI-Computing Optical Network will accelerate. Optical networks are present in various deployment scenarios of AI-Computing Data Centers. Fig. 1 illustrates the overall architecture of an AI-Computing Optical Network.

As shown in Fig. 1, central DCs, regional DCs, edge DCs, and far edge DCs are deployed from the backbone network to the MAN. These DCs are connected to the AI-Computing Optical Networks via the WDM/OXC NE, with each DC directly connected to the optical network and assigned different bandwidths based on service requirements. Regional and central DCs have a large scale. To enable the scale-up of AI-Computing Data Centers, multiple PODs can be interconnected through the OXC to build a GPU pool with more than 10,000 cards. The access network is deployed with WDM/OTN devices and ultra-far edge DC devices to facilitate enterprise access to computing-related services, such as federated learning, enterprise training data processed without persistent storage, and services combining inference and training.

Intelligent management and control of AI-Computing Optical Networks is key to efficient computing power scheduling. By utilizing a unified computing network orchestration system, an all-optical network management system, and a computing power management platform (computing network brain), efficient resource scheduling and computing power provisioning can be achieved for end-to-end integrated computing and network services.

High throughput in an AI-Computing Optical Network also requires end-to-end network coordination. Information about packet loss caused by changes in network delay or suboptimal conditions needs to be promptly synchronized with the GPU NIC driver configuration. The parameters of the RDMA NIC are dynamically adjusted according to network latency, and RoCE network buffers are modified to adapt to changes in round trip time (RTT), ensuring lossless transmission of AI-Computing Optical Networks and efficient use of computing resources.

In general, AI-Computing Data Centers, driven by both hardware acceleration and technological innovation, are developing rapidly. They will gradually evolve to virtualize the diverse GPU cards, currently dispersed across multiple locations, into a single "Super AI-Computing Data Center," similar to general-purpose computing services. This Super AI-Computing Data Center is used for super-large-scale joint training and inference services and can be virtualized into a lot of intelligent computing services that can be leased to enterprises and even individual users, allowing everyone to access these services as easily as as tap water.

At present, an AI-Computing Optical Network mainly includes scenarios such as DCI, DCN, and DCA.

AI-Computing Data Center Interconnection (DCI)

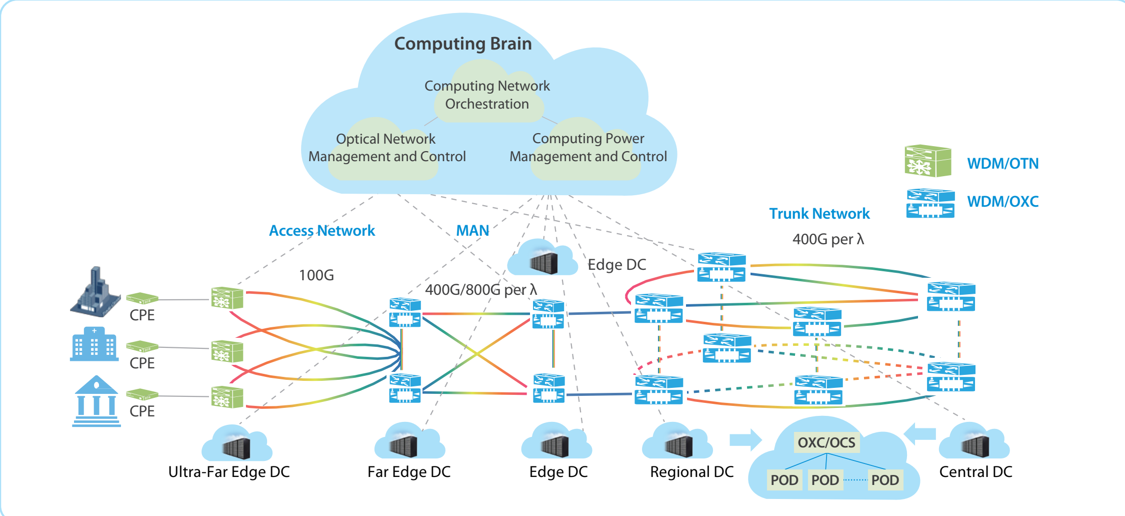


Fig. 1 Overall architecture of AI-Computing Optical Network.

As the core transport nodes for computing power, the efficient interconnection of AI-Computing Data Centers is crucial for the coordinated scheduling of computing power resources. The AI-Computing Optical Network uses all-optical DCI technology (WDM/OXC) to establish all-optical connections between data centers with a single-fiber capacity of 100 Tbps. This high-speed interconnection coordinates and dispatches computing power to meet increasing demand, effectively alleviating pressure on individual single data centers and supporting customers' local access to computing resources.

Specifically, core and regional AI-Computing Data Centers are generally located in areas with intensive computing demands and abundant energy resources. They involve the construction of ultra-large AI-Computing Data Centers or clusters of such centers, enabling interconnection among centers with over 10,000 GPU cards. With a 4:1 convergence ratio, the bandwidth demand can reach thousands of Tbps. Edge AI-Computing Data Centers, interconnected with core and regional centers, are located in core city-level equipment rooms, key equipment rooms in developed districts and counties, or high-traffic integrated business areas. They deploy 1000+ GPU cards, 100+ GPU cards, or even fewer to the customer edge, enabling 1 ms access to computing resources.

AI-Computing Data Center Network (DCN)

In the AI-Computing Data Center, the network is converged with a 1:1 ratio, and network performance directly affects the utilization efficiency of computing resources. The AI-Computing Optical Network uses the all-optical cross-connect scheduling technology (WDM/OXC) to optimize the performance and reliability of hybrid optical–electrical networking. This technology improves the utilization efficiency of computing power in data centers, supports the efficient execution of large-scale parallel computing tasks, reduces bit power consumption, is insensitive to port rates, and extends the network's evolution period. It meets the challenges of zero packet loss, low latency, and high-burst traffic in the internal networks of AI-Computing Data Centers.

Specifically, the OXC and WDM technologies are used in each POD network inside the AI-Computing Data Center, enabling a per-port transmission capacity of 100 Tbps. An interconnection capacity of 4000 Tbps for a 10,000-GPU pool can be achieved with 40 pairs of optical fibers, greatly reducing the OPEX and CAPEX of the network. The rate of the GPU NIC in the internal network of the AI-Computing Data Center evolves every two to three years. However, OXC is not sensitive to the rate, and can support the smooth evolution and hybrid networking of the AI-Computing Data Center Network from 200GE, 400GE, and 800GE to 1.6TE.

Data Center Access (DCA)

The computing power access network is the “first hop” for users to access computing power resources, and its performance directly impacts user experience. Through access technology of the government and enterprise private line, the AI-Computing Optical Network supports high-quality, flexible access at rates ranging from 10 Mbps to 100 Gbps for customers such as parks, enterprises, and governments. It enables 1 ms access to edge AI-Computing Data Centers, 5 ms access to regional AI-Computing Data Centers, and 20 ms access to core AI-Computing Data Centers.

Trends in AI-Computing Optical Networks

The development of AI-Computing Optical Networks faces many technical difficulties and requirements. Ultra-high-rate transmission, All-Optical Cross-Connect, optical network-aware computing-power services, AI intelligence, low-carbon and secure control, and new optical fibers are the development trends for AI-Computing Optical Networks in the next 10 years.

Continuous Breakthrough in Ultra-High-Speed Optical Transport Technology

With the continuous growth of traffic, optical networks are evolving to higher rates. At present, 400G has become the mainstream for backbone network construction, and the T-bit era, including 800G, 1.2T, and even 1.6T, is accelerating. Optical DSP chip technology has reached its extreme limits. To achieve a bandwidth of 1.6 Tbps, SerDes rates need to be boosted to approximately 450 GBd.

As the single-wavelength rate increases, the spectrum bandwidth also grows. However, the single-fiber capacity doesn't increase linearly. Therefore, expanding to additional bands, such as C+L and S+C+L, will be key to increasing single-fiber capacity and meeting the ultra-large bandwidth requirements of interconnections between AI-Computing Data Centers.

In terms of modulation, single-wavelength rates, subcarriers, and multi-lane technologies are advancing in parallel, and optical-electrical integration, such as co-packaged optics (CPO), is used to improve efficiency and reduce power consumption.

Ubiquitous All-Optical Networks with Service Awareness and End-Network Coordination

In the medium to long term, all-optical networks will become the core infrastructure of the computing power era. By optimizing DCA, DCI, and DCN, all-optical networks can enable more efficient resource scheduling. The all-optical network is a key technology that supports 1 ms access to AI-Computing Data Centers, 5-20 ms interconnection between AI-Computing Data Centers, and microsecond-level interconnection among PODs in AI-Computing Data Center Networks.

Key technologies for all-optical networks include the evolution and efficiency enhancement of all-optical cross-connects and coherent tunable optical modules, the full digitalization of the optical layer, and advancements in control plane technology. Routing in the AI-Computing Data Center will be synchronized with ROADM/OXC-based switching, realizing all-optical routing and one-time provisioning of all-optical services. Comprehensive digitalization of optical fibers and optical components will enable the digitization of analog signals and real-time simulation of nonlinear data. With enhanced control plane technology, optical layer services will achieve provisioning efficiency comparable to that of the electrical/IP layer, while optical layer recovery will attain performance comparable to that of protection switching, with service interruption times of less than 50 ms.

Service Ethernet interfaces in all-optical networks need to support service awareness, enabling the perception of customer service types, optical fiber network changes, and latency variations. Based on service types, the interfaces ensure SLA fulfillment, and perform optimal path selection. They determine path latency according to optical fiber changes and notify the computing power orchestration system, which then notifies RoCE switches to adjust interface buffers based on round-trip time (RTT). For service interfaces supporting buffering and priority flow control (PFC), automatic parameter adjustment and buffer size matching can be performed to achieve 100% throughput.

All-optical networks can enable one-hop access to computing power by deploying AI compute acceleration cards at the access, aggregation, and core layers. They provide customer services with proximate access to AI-Computing Data Centers, support 1 ms access, and empower OTN private line customers with one-hop access, secure isolation, and high reliability.

Intelligent Evolution

The in-depth integration of AI and optical networks will become a key trend in future development. The optical network itself has a strong foundation in management and control systems, and is well-suited for AI integration. The bidirectional empowerment of AI and optical networks is key to achieving network intelligence.

Through AI technology, real-time simulation and planning of optical networks can be achieved, empowering intelligent network O&M. By integrating GPUs into network equipment, online parameters of optical layer devices and optical fibers are collected for big data analysis, enabling the training of proprietary models. This allows for one-time activation of the optical layer network. After optimizing the efficiency of the control plane, optical layer services recovered by WSON can achieve performance comparable to that of protection switching.

AI-driven O&M and optimization enhance O&M efficiency, rationalize network resource utilization, improve network energy efficiency, and reduce overall network CAPEX and OPEX.

Green, Low-Carbon & Controllable Development

Driven by policy and market focus on sustainable development, green and low-carbon will become core competencies of the computing power industry. In the future, enterprises will need to meet energy-saving and carbon reduction goals through technological innovation (e.g., realizing data collection in data-intensive regions, building super-large AI-Computing Data Centers in energy-rich regions for training, and enabling high-speed WDM/OTN interconnection between data-intensive and energy-rich regions) and management optimization, promoting the transformation of computing power development from a "scale-and-speed model" to a "quality-and-efficiency model".

Leveraging the high bandwidth and low latency of AI-Computing Optical Network, along with regional electricity price differences, algorithms can be employed to find the optimal balance point. This aims to achieve coordinated optimization of power resources, optical network bandwidth, and computing power energy efficiency between energy-rich and data-intensive regions, promoting green and low-carbon development.

From a security perspective, designating AI-Computing Data Centers in energy-rich regions as backup and disaster recovery centers for data-intensive regions enhances their security and controllability. This necessitates relying on optical networks for high-bandwidth interconnection between AI-Computing Data Centers.

Exploration of New Fiber Technologies

New optical fiber technologies (such as multi-core fiber and hollow-core fiber) are currently in the pilot construction and transmission verification phase. These technologies are expected to further enhance the transmission capacity and performance of optical networks but still face challenges in large-scale manufacturing and adaptability testing in existing networks.

Hollow-core fibers can offer superior spectral efficiency, extending the spectrum to the S-band to achieve S+C+L single-fiber spectral capacity, while enabling a 35% reduction in fiber latency. This is a key technology for the future development of AI-Computing Data Centers, capable of significantly boosting bandwidth and reducing latency.

As a critical infrastructure in the computing power era, the AI-Computing Optical Network is driving the efficient utilization of computing resources and the high-quality development of the digital economy. In the future, with breakthroughs in ultra-high-speed optical transport technology, widespread deployment of all-optical networks, and accelerated intelligent evolution, the AI-Computing Optical Network will play an even more crucial role in the compute era. Concurrently, the development of green initiatives and new optical fiber technologies will provide strong support for the sustainable development of the AI-Computing Optical Network. ZTE TECHNOLOGIES

Application Outlook for Terabit Hollow-Core Fiber Optical Transport Systems

Yan Baoluo

Chief Engineer of WDM Technology Planning, ZTE

During the past two years, the proliferation of generative AI large models has doubled computing demand, necessitating that optical networks—the bedrock of computing infrastructure—evolve toward lower latency, higher bandwidth, and ultra-long distance. Over the last 50 years, optical fiber communication systems based on solid-core single-mode fiber, which operates on the principle of total internal reflection, have reached their technical limits in terms of communication latency, single-fiber capacity, and transmission distance due to inherent limitations in fiber refractive index, loss, and nonlinear effects. A new optical fiber system is urgently needed to break this bottleneck.

Anti-resonant hollow-core fiber, with its three disruptive characteristics—ultra-low latency, ultra-low loss, and ultra-low nonlinearity—is regarded by the industry as the "next-generation transport medium" and has seen rapid development in recent years. Since its proposal by the University of Bath in 2007, this technology has undergone multiple structural evolutions. In 2022, the hollow-core fiber group at the ORC Center, the University of Southampton, UK, optimized a double-nested anti-resonant nodeless fiber featuring five nested tube units (DNANF-5), achieving a minimum loss of 0.174 dB/km, and in 2024, in collaboration with Microsoft, achieved a DNANF-5 with a loss coefficient of 0.08 ± 0.03 dB/km. In the same year, Chinese enterprises reported losses at the 0.1 dB/km level, with single-draw lengths reaching 10 km. At this stage, anti-resonant hollow-core fiber has surpassed solid-core single-mode fiber in loss performance, marking a breakthrough in loss reduction.

Characteristics and Application Potential of Hollow-Core Fiber

Leveraging its three disruptive characteristics—ultra-low latency, ultra-low loss, and ultra-low nonlinearity—hollow-core fiber is expected to provide significant application benefits, such as low latency, enhanced reliability, and reduced networking costs, across numerous optical transmission scenarios. It holds broad application potential in interconnection of intelligent computing clusters, financial high-frequency trading, relay protection services in power systems, ultra-long-distance networking, and next-generation Tbit/s ultra-high-speed long-haul optical transmission systems. Compared with single-mode fiber, hollow-core fiber demonstrates remarkable improvements across multiple performance metrics.

Ultra-Low Latency and Applications

In hollow-core fiber, the light transmission medium is changed from glass to air, resulting in a transmission speed increase from approximately 2×10^8 m/s to nearly the speed of light, which reduces latency by 30% compared to single-mode fiber, equating to a latency reduction of 1.5 μs per kilometer.

In intelligent computing interconnection scenarios, industry benchmarks and remote validation tests have shown that communication latency during data-parallel (DP) distributed training across intelligent computing clusters cannot be fully masked by optimization algorithms, leading to reduced computing efficiency. The latency savings offered by hollow-core fiber can mitigate the latency-induced computing resource waste, providing critical physical-layer support for efficient collaboration in large-scale intelligent computing clusters.

In financial high-frequency trading scenarios, brokerage firms typically place their servers as close as possible to the exchange to minimize communication latency; however, a large number of servers still cannot be deployed in close proximity. Hollow-core fiber and its supporting equipment are expected to trigger a new generation of upgrades in financial dedicated lines. Since 2020, at least two anti-resonant hollow-core fiber cables have been deployed overseas for financial dedicated lines.

By the end of 2024, Microsoft had announced plans to deploy 15,000 km of hollow-core fiber over the next 24 months for data center interconnection and large AI model training. In the power industry, high-voltage power transmission requires synchronization of differential protection information between relay protection devices. The industry generally mandates a unidirectional transmission latency of ≤10 ms to meet the rapid response requirements of relay protection. Hollow-core fiber effectively reduces link latency, ensuring prompt fault response in ultra-long-distance power transmission relay protection.

Ultra-Low Loss and Applications

Solid-core single-mode fiber is fundamentally limited by Rayleigh scattering, making it difficult to achieve a loss below 0.14 dB/km. In contrast, anti-resonant hollow-core fiber has already achieved ultra-low loss coefficients at the 0.1 dB/km level. Furthermore, after being cabled in multiple domestic locations, the average loss of anti-resonant hollow-core fiber can be maintained at 0.15 dB/km within the C-band's 4 THz range.

In medium- to long-distance backbone and MAN transport scenarios, hollow-core fiber offers a loss coefficient optimization of 0.05 dB/km compared to G.652D fiber. Based on a standard 80 km span model, this translates to a 4 dB improvement in signal-to-noise ratio (SNR), which can revolutionize transmission distance/margin, reduce the number of regenerators/repeaters, and consequently lower networking costs and forwarding latency.

In ultra-long-distance power transmission scenarios, for a similar 300 km single-span transmission, hollow-core fiber can provide nearly 15 dB of performance gain, thereby reducing the networking cost of ultra-long-distance power backbone networks.

Ultra-Low Nonlinearity and Applications

Compared to conventional solid-core single-mode fiber, the nonlinear coefficient of hollow-core fiber can be reduced by three to four orders of magnitude, effectively eliminating the nonlinear limitations that prevent optical communication systems from approaching the Shannon limit. This enables high-power transmission for high-order QAM signals, leveraging the increased power to enhance the SNR at the receiver.

Furthermore, the issue of Raman power transfer, which arises from wavelength band expansion in single-mode fiber, will no longer be a constraint in hollow-core fiber, theoretically supporting ultra-broadband DWDM. It is estimated that, in long-distance transmission scenarios, hollow-core fiber can increase transmission capacity by two to three times compared to single-mode fiber.

In medium- to long-distance backbone and MAN scenarios, long-haul trunk transmission using G.652 single-mode fiber typically employs a 400G QPSK 130+ GBd configuration with 150 GHz spectral spacing. In contrast, hollow-core fiber can support 1.2T 64QAM with three times higher spectral efficiency. When combined with high-power amplifiers, long-distance transmission can still be achieved, enabling optical layer simplification and reduced networking costs. For next-generation 200G+ optical transmission, the ultra-low nonlinearity of hollow-core fiber supports long-distance transmission with 1.6T PS-64QAM using high-power optical amplifiers, extending the reach by nearly 10 times compared to single-mode fiber.

ZTE's Exploration in Hollow-Core Fiber Optical Transport Systems

In 2023, ZTE, in collaboration with a leading Chinese operator, proposed a nonlinear coefficient measurement scheme based on the nonlinear phase shift induced by high-order QAM transmission. By amplifying a 400G 64QAM signal with high-power optical amplifiers, they verified that the Kerr nonlinear coefficient of hollow-core fiber is at least three orders of magnitude lower than that of single-mode fiber after 1 km transmission.

In 2024, with significant advancements in hollow-core fiber loss reduction and single-draw length extension, ZTE, together with a Chinese enterprise, demonstrated for the first time the penalty-free transmission of a 1.2T PS-64QAM signal with a single-wavelength launch power of 3W over 20 km of anti-resonant hollow-core fiber. This also proved the extremely low Raman power transfer in hollow-core fiber, laying a foundation for ultra-high-speed, ultra-broadband, and high-capacity transmission system applications.

Since May 2024, major Chinese operators have successively deployed hollow-core cables domestically. In collaboration with China Telecom, ZTE deployed a 10.4 km, 2-core hollow-core fiber between the Hangzhou Intelligent Computing Center and Yiqiao IDC data center. Utilizing fiber loopback, they demonstrated the first ultra-low latency data center interconnection, featuring a single-wavelength mixed rate of 1.2T and 800G within the C+L bands and a single-fiber capacity exceeding 100 Tbps.

In September of the same year, ZTE assisted China Mobile in demonstrating the first domestic ultra-low-loss (minimum loss reaching 0.13 dB/km) C+L-band 800G transmission over a hollow-core cable between the Wuxi Liyuan and Sunan data centers. During this in-network deployment, the engineering challenge related to CO2 gas absorption was identified, which is now recognized as a critical issue in hollow-core fiber applications that needs to be addressed.

To further explore the potential of hollow-core fiber in high-capacity and long-distance transmission, ZTE conducted a series of laboratory experiments demonstrating single-fiber bidirectional ultra-high-capacity transmission of 377.6T over 100 km in the S+C+L-bands, increasing the current single-fiber capacity record by over 1.5 times. By utilizing self-developed silicon photonic external-cavity nano-packaged high-power S-band tunable lasers, the optical signal-to-noise ratio (OSNR) at the S-band transmitter and receiver sensitivity were significantly improved. Furthermore, the Flex Shaping algorithm was employed to select the baud rate, modulation format, and channel spacing based on channel characteristics. Specifically, 85 GBd PS-144QAM was configured on an 87.5 GHz grid in the C band, 98 GBd PS-144QAM on a 100 GHz grid in the L band, and 49 GBd PS-144QAM on a 50 GHz grid in the S band. To mitigate issues related to filtering and device bandwidth, an optical domain algorithm for equalization and spectral shaping was used for compensation, ultimately achieving the desired metrics.

Regarding long-distance transmission capability, a world record was demonstrated in the laboratory for single-wavelength transmission exceeding 1 Tbps over 10,000 km in hollow-core fiber. This represents an increase of at least 10 times in transmission distance compared to single-mode fiber at the same data rate. This achievement is due to the ultra-low nonlinear characteristics of hollow-core fiber and the use of high launch power to enhance the SNR after transmission. During ultra-long-distance transmission, inter-modal interference, in-band non-flatness, and filtering effects also become prominent. To address these issues, ZTE has carried out optimization of hollow-core fiber specifications and algorithms. Thus, high-order QAM modulation, high-power optical amplifiers, and channel impairment compensation algorithms are particularly crucial for unlocking the full transmission potential of hollow-core fiber systems. ZTE is actively researching these devices and algorithms, focusing on evaluating the feasibility and necessity of metrics required for engineering applications.

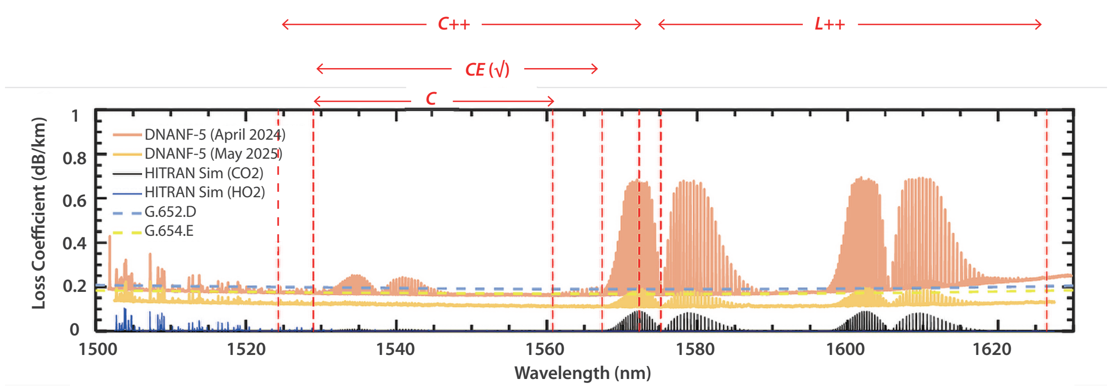


Fig. 1 Loss spectra of a single-mode fiber and a hollow-core fiber, and the additional loss spectrum due to gas absorption in the hollow-core fiber.

Hollow-Core Fiber Application Challenges and Outlook

Although hollow-core fiber almost comprehensively outperforms solid-core single-mode fiber in key metrics, a significant number of issues remain to be resolved before its commercial deployment. Gases such as CO2 and water vapor within hollow-core fiber produce characteristic absorption peaks at specific frequencies, which exhibit varying widths and non-uniform distributions. During the transmission of service light, the spectrum will experience "dips," greatly impacting signal modulation-demodulation and clock stability, thereby restricting the usable range for wavelength division multiplexing (WDM) spectrum (see Fig. 1).

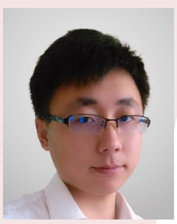
Gas absorption characteristics can be semi-quantitatively analyzed by leveraging the HITRAN database in conjunction with gas pressure, temperature, and molecular density within the hollow-core fiber environment. Currently, there is an urgent need for fiber manufacturers to improve their fiber drawing processes and for equipment manufacturers to conduct research on gas absorption compensation algorithms.

On the other hand, the light guiding mechanism of anti-resonant hollow-core fiber does not inherently support the complete elimination of higher-order modes. Various mechanical factors such as fiber connection points, bending, and coiling can also lead to the excitation of these higher-order modes, causing inter-modal interference. This effect becomes increasingly pronounced during ultra-long-distance transmission and requires focused optimization.

In terms of O&M, hollow-core fiber presents several challenges. Its backscattering coefficient is 30 dB lower than that of single-mode fiber, resulting in a 14–15 dB reduction in the measurable dynamic range of existing optical time domain reflectometers (OTDRs). Furthermore, pressure differences at splice points can cause external gas to be drawn into the hollow core, creating gas density variations that produce "bulges" in reflection peaks at the splice points, which in turn expand detection blind zones. To compensate for the gap, simultaneous optimization of both optical detection devices and algorithms is required.

At the current stage, the structure of hollow-core fiber is not yet standardized, and its widespread adoption is limited by factors such as manufacturing processes and production capacity. Consequently, its current price is 2000 times higher than that of single-mode fiber, hindering large-scale deployment. ZTE remains committed to collaborating with upstream and downstream industry partners to drive hollow-core fiber systems from technical verification towards commercial deployment in the future. ZTE TECHNOLOGIES

China Telecom and ZTE Complete World's First C+L Band Integrated 80×800G WDM Trial on Live Network



Zhang Yu

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Amid the accelerating wave of global digital transformation, optical communication technology is driving the rapid evolution of the information society. As the core infrastructure for massive data transmission, the upgrade of optical networks has always been a focal point for the industry. In 2025, China Telecom and ZTE completed the world's first 800G C+L integrated optical transponder unit (OTU) live network trial on the North China ROADM backbone network, marking a major breakthrough in ultra-high-speed optical communications. This trial validated the commercial viability of the full-band 800G solution and laid a solid foundation for China Telecom's future 400G/800G all-optical ROADM networks. It also promotes industry standardization and ecosystem collaboration—representing a milestone in global optical communication development.

Industry Trend: From 200G/400G to 800G

With the explosive growth of big data, AI, and smart manufacturing, global network traffic continues to surge. Traditional single-wavelength 200G/400G optical transmission systems can no longer meet the demands for ultra-large bandwidth and ultra-long-distance transmission. Optical network technology is advancing toward 800G, while the occupied spectrum is expanding from the traditional C-band (1530–1565 nm) to the C+L band (1524–1626 nm) to improve spectrum utilization.

Against this backdrop, C+L integrated systems have become an industry trend. The extended C-band (1524–1572 nm) and extended L-band (1575–1626 nm) together expand spectral bandwidth from 6 THz (extended C-band) to 12 THz, significantly boosting transmission capacity. However, expanding to the C+L band imposes higher requirements on optical modules, devices, and network architecture. Seamless cross-band scheduling, reducing equipment complexity, improving system integration, and controlling costs have therefore become urgent challenges. The collaboration between China Telecom and ZTE aims to address these challenges.

C+L Integrated OTU Breakthrough

As early as 2023, China Telecom proposed that all-optical ROADM networks should be built on the extended C+L band with a 12 THz spectral width, while emphasizing the integrated design of key boards and devices. To meet this goal, China Telecom and ZTE conducted long-term technological research and development. In 2024, the two parties successfully completed laboratory verification of the 400 Gbps ultra-long-distance extended C+L band integrated optical modules, and in early 2025, they launched the world's first 800G C+L integrated OTU live network trial on the ROADM backbone.

The core of this trial lies in the innovative design of the C+L integrated OTU. Traditional optical modules must separately support the C-band and L-band, resulting in high equipment complexity and cost. The integrated OTU module adopts a unified design that enables joint scheduling across C+L bands, greatly improving system flexibility and spectrum utilization. During testing, the team combined C+L integrated wavelength selective switch (WSS) devices to build a truly integrated C+L architecture, validating the following key capabilities:

- **80×800G system transmission capacity:** Stable operation in complex live network environments, supporting 80×800 Gbps high-speed transmission to meet ultra-large bandwidth demands.
- **C+L full-band optical-electrical seamless scheduling:** Simultaneous support for C+L bands with arbitrary spectrum switching, significantly enhancing spectrum utilization.
- **WASON protection and recovery capability:** With WDM-based automatically switched optical network (WASON) technology, the system achieves rapid fault recovery, ensuring network reliability.

Test results show that the C+L integrated OTU module reduced spare-part types by 50% and doubled spectrum switching capability, effectively lowering both CAPEX and OPEX for operators. The module's pluggable design also reduced its size by 60% compared to traditional fixed modules, cut per-gigabit power consumption by 68%, saved data-center space, and significantly reduced overall system energy consumption—providing a new solution for building green, low-carbon networks.

Live Network Validation: A Milestone

The trial demonstrated the feasibility of C+L integration and its tremendous potential in real-world networks. As a key backbone node of China Telecom, the North China 400G ROADM network operates in complex environments with diverse service demands, requiring high levels of stability and scalability. During the trial, the team conducted multidimensional testing to comprehensively evaluate the C+L integrated OTU module in scenarios such as long-haul transmission, multi-service bearing, and dynamic spectrum allocation. This achievement provides an important reference for future deployment of 400G/800G all-optical ROADM networks. C+L integration will serve as a key enabler for building intelligent, efficient, and green optical networks, driving a leap from single-wavelength expansion to full-band collaboration.

Industry Impact: Driving Standards and Ecosystem Collaboration

The cooperation between China Telecom and ZTE also has profound implications for industry standards and ecosystem collaboration. The mature application of C+L integration will accelerate standardization and provide unified technical specifications for global optical equipment vendors, while serving as a model for collaboration among universities, research institutions, and enterprises.

Together with ecosystem partners, the two companies validated full-spectrum optical-electrical scheduling capabilities and promoted the development of corporate and industry standards, laying the foundation for large-scale commercialization. Meanwhile, ZTE made breakthroughs in key technologies such as DSP, ITLA, and ICRM, achieving innovations in 130-GBd high-speed parallel ADC, new doping techniques, and optical component co-packaging, further enhancing device performance and reliability.

The success of this trial not only resolves core challenges in optical network evolution but also injects new momentum into the global communications industry through innovative technology. ZTE TECHNOLOGIES

Türk Telekom and ZTE Complete World's First 1.6T DWDM Trial over 12 THz Spectrum on Live Network

Li Songbo

Optical Network Product Planning Manager, ZTE

As Türkiye's largest integrated telecom operator, Türk Telekom provides a comprehensive suite of services—spanning mobile, fixed, and data communications—to tens of millions of residential and business customers. With the booming global digital economy and the promotion of 5G network construction in Türkiye, building ultra-wide and ultra-high-speed optical network infrastructure has become a common goal for Turkish operators. In this evolving landscape, continuing to lead the development of advanced optical infrastructure to fully realize Türkiye's potential as a strategic Eurasian hub has become a core priority for Türk Telekom.

In March 2025, ZTE and Türk Telekom jointly completed the 1.6 Tbps OTN trial with 12 THz bandwidth on the live network in Istanbul, Türkiye's largest city, achieving ultra-high-speed transmission of 400GE/800GE services. The success of this trial not only validates that ZTE's 12 THz Tbit OTN solution is the optimal choice for single-fiber capacity exceeding 100 Tbps, but also lays a solid foundation for Türkiye's large-scale 5G deployment, industrial digital transformation, and economic growth across Eurasia.

High-Speed OTN Opens a New Era of Interconnection

The global digital transformation is driving exponential growth in international traffic. With the rise of scenarios such as large AI model training, multinational intelligent manufacturing, and cloud-end collaborative R&D, the scale of global cross-border data flows is undergoing a structural leap. For instance, the single cross-border transmission of 100-billion-parameter large-model data exceeds 500 TB. The cross-border transmission of global AI training data is expected to increase by 30 times over the next two years, surpassing 10 EB per year by 2028. Additionally, the globalization of intelligent manufacturing drives industrial traffic to new heights, with leading enterprises averaging 2.5 PB of data transmission per month, an eightfold increase from 2020.

The ultra-high-speed growth of global traffic is driving the evolution of optical networks toward 400G and 800G capacity on a single wavelength. The spectrum width occupied by signals continues to expand. The traditional C++ band that can only carry 40-wavelength services is no longer sufficient to meet the growing requirements for single-fiber capacity. Expanding spectrum resources to the C+L bands (12 THz in total) has therefore become an inevitable choice for the global communications industry.

Collaborative Innovation to Set New Industry Boundaries

Türk Telekom and ZTE have maintained a deep, long-term partnership in ultra-high-speed optical networking. Building on the success of their 100G/B100G hybrid metro network—which won the "Best Mobile Transport Solution to Connect 5G Services" award at the 2022 5G MENA—the two companies achieved another milestone in March 2025 with the first 12 THz, 1.6 Tbps OTN live network trial in Istanbul.

Leveraging ZTE's flagship optical transmission product, the ZXONE 9700, this trial also utilizes ZTE's in-house developed 1.6 Tbps optical module, providing a single-fiber capacity of up to 96 Tbps and doubling the spectrum bandwidth of traditional solutions. The key optical-layer component, the wavelength selective switch (WSS), features integrated C+L band support, further optimizing costs and power consumption. In addition, any switching of the spectrum in the C+L band can be implemented, significantly improving the flexibility of the transmission system. Compared with the previous-generation 1.2 Tbps optical module, the 1.6 Tbps optical module used in this trial achieves a 25% reduction in power consumption per gigabit, effectively saving operational costs for Türk Telekom and supporting its strategic objective of developing a green and low-carbon optical network.

To verify the feasibility of the 1.6 Tbps solution for follow-up application in commercial networks, the ZTE technical team and the Türk Telekom team conducted in-depth on-site discussions and systematically tested a wide range of planned commercial network scenarios. Special verification was performed on the ZTE 1.6 Tbps solution within the ultra-wide spectrum range of 6 THz (C) + 6 THz (L). The test items covered 400GE/800GE independent service access, hybrid service access, transmission stability, multi-span transmission, and external wavelengths. The final validation results showed that the solution was stable in all test scenarios, laying a solid foundation for subsequent large-scale deployment.

Win-Win Cooperation, Driving Türk Telekom's Network Upgrade

Bearer networks lay the foundation for network construction. As a leader in the Turkish communications industry, Türk Telekom is committed to providing high-quality and seamless communications services to users in the region based on its profound technological expertise and continuous innovation. The successful verification of the 1.6 Tbps solution based on the C+L-band system will not only solidify its leadership in the local market, but also reinforce its image as a technological pioneer in the global arena. As the 1.6 Tbps solution matures, it will fully meet Türk Telekom's future demand for increased optical network bandwidth during 5G service development, effectively supporting service transmission between Europe and Asia, and significantly improving Türk Telekom core competitiveness in the transnational communication services.

As a pioneer in international transmission networks and a long-term strategic partner, ZTE will collaborate with Türk Telekom to explore the evolution of existing infrastructure based on this successful pilot. This partnership aims to build a next-generation "intelligent, efficient, and green" optical network, accelerating Türkiye's 5G development. Moving forward, they will drive the large-scale commercial deployment of the 1.6 Tbps solution, contributing practical insights to the global optical communications industry and catalyzing technological iteration to address the challenges of future traffic growth. ZTE TECHNOLOGIES

ZTE

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