White Paper on 800G C+L Super-Large-Capacity Optical Transport Technology

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V1.0	2024/03/22	Yu Wenbo, Yang Zhenqian	The first version
V1.1	2024/05/31	Yu Wenbo	The modulation format in this paper is PM-QPSK, PM-16QAM, or PS-16QAM.

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1. Development Trend

1.1 The Demand for 800G Ports Keeps Rising

To cope with the rapid growth of service traffic, the 100G/200G/400G port rate on the service side of the backbone network in the WDM system is continuously upgraded: From the commercial use of 100G in 2012 to the large-scale deployment of 200G WDM in 2016 and then the emergence of 400G WDM in 2020, the traffic spike drives the update and iteration of the transport rate. 800G WDM test is now needed in overseas operator markets, such as Globe in the Philippines and Viettel in Vietnam.

1. **Number of ports:**

Before 2025, 400G grows fast and 100G&200G is relatively stable. After 2025, 800G+ will develop rapidly, with a CAGR of 49.9% in 2022 - 2028. At present, it has a certain amount of port shipments. It is predicted that it will exceed 200G in 2027 and become the mainstream system rate.

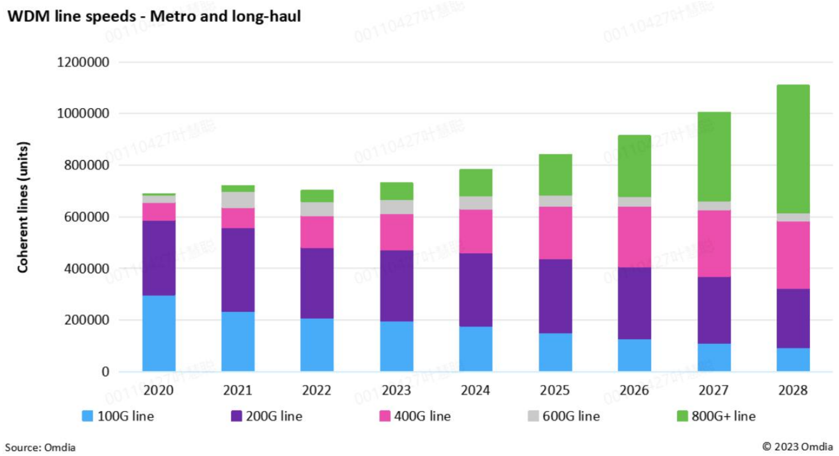

Figure 1.1 OTN Line-Side Port Shipment Forecast (2020~2028)

2. Market space:

800G+ accounted for 11.11% in 2022, and will mount to 29.79% in 2025 and 59.43% in 2028, with the CAGR of 38.41% between 2022 and 2028.

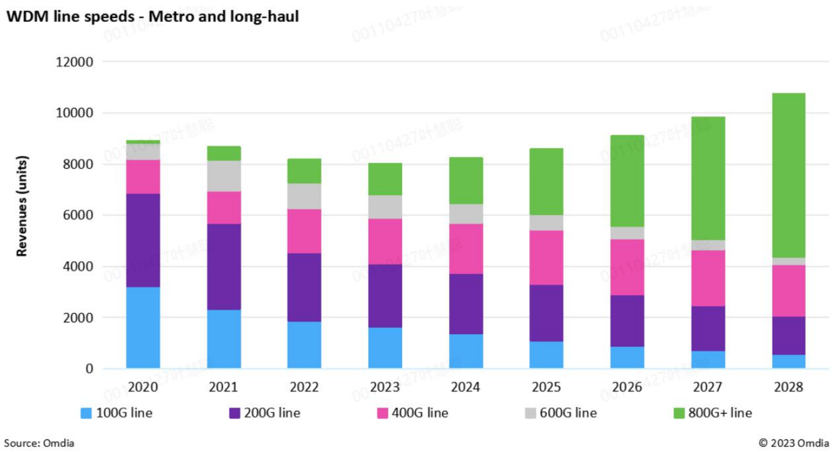

Figure 1.2 OTN Line-Side Market Revenue Forecast (2020~2028)

1.2 Backbone Network and MAN Require Greater Capacity

The expansion of cloud computing, big data and high-definition services is driving a noticeable increase in Data Center (DC) traffic. The 800G solution can help operators cut the cost and power consumption per Gbit to build a greener network infrastructure.

1. **DCI and short-haul MAN:**

The application scenario analysis shows that 70% of the DC traffic occurs inside the area, while the transmission distance between the DCI and short-haul MAN in the area is generally within 100 km. Currently, the 800G technology can meet the requirements of DCI/short-haul MAN. In the DCI scenario, the proportion of 800G ports delivered is 16.6% in 2023, and 37.4% in 2025. 800G will be the main application rate in the DCI scenario.

2. **Backbone and long-haul MAN:**

The transport in backbone and long-haul MAN scenarios may reach hundreds of kilometers, and the rate is still 400G or below. In 2023, 800G shipments hosted 0.4% in metro scenarios, and 0.2% in backbone. 800G is now seldom used, but it is estimated to gradually evolve to 800G from 2025.

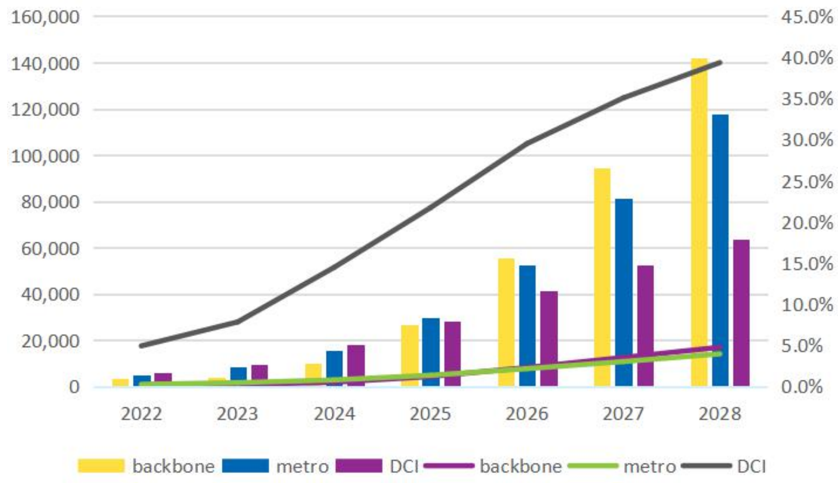

Figure 1.3 800G Shipment Growth in the DCI Scenario (Source: 2024 Dell'Oro)

1.3 800G Industry Chain Is Maturing

The commercial use of 800G requires innovation in the industrial chain. The maturity of the electrical-/optical-layer industrial chains is critical to 800G deployment.

1. **Electrical-layer industry chain:**

According to the DSP evolution route, the first-generation 800G (96G-Baud fixed module) DSP was put into commercialization in 2020, with a transmission distance of about 100 km. The industry's second-generation 1.2T (130Gbd fixed module) DSP was launched in 2023~2024. In the same year, the ZTE also unveiled the 800G pluggable module, which has more advantages in cost and power consumption. After 2025, 1.6T (192Gbd) and 2.4T DSPs will further extend the 800G transmission distance, and can be gradually applied to long-haul metro and trunk scenarios.

2. **Optical-layer industry chain:**

The C+L solution is becoming mature and gradually deployed, so it can be adopted in 800G DCI scenarios. As metro/backbone networks will evolve to 800G after 2025 and the single-wavelength spectrum width will reach 200GHz~300GHz, C+L band resources will not be enough, and have to expand to band S or even U. Major vendors have carried out research and tests on the S+C+L. The S-band OA technology and the SRS effect suppression solution are still main challenges, so it will take time to commercialize the S+C+L.

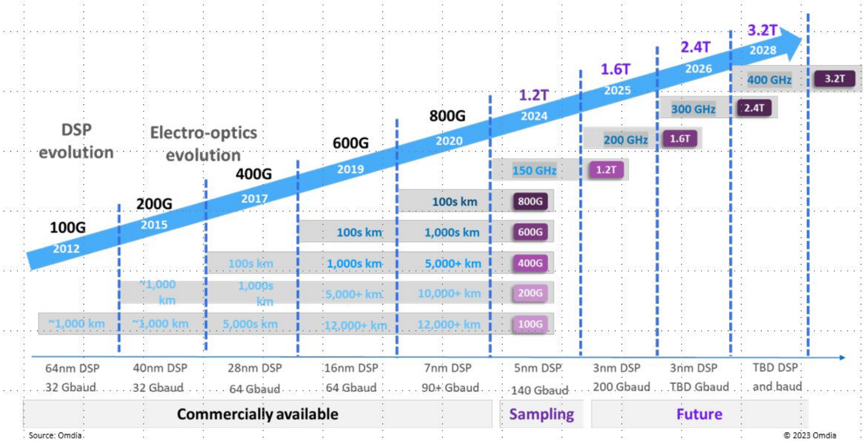

Figure 1.4 Fast Evolution Of DSP Expedites the 800G Solution Maturity

Based on the above analysis, 800G is commercially available on a small scale and is mainly used for DCI/metro short-haul transport. With the development of the industry and the maturity of the industrial chain, it is estimated that 800G will explode in 2025, and will gradually move to MAN/backbone scenarios.

2. Key Technologies

2.1 800G Optical Modules for High-Speed Transport

The functions and features of the coherent optical module determine the transport capability of the OTN system. To ensure transport performance, the 800G coherent optical module must have the following capabilities:

1. The highest baud rate is above 130Gbd. The baud rate can be adjusted continuously or at multiple levels.
2. Multiple line rates and modulation codes are adjustable, and common modulation modes such as 200G QPSK, 400G 16QAM, 400G PS-16QAM, 400G QPSK, 800G PS-16QAM, and 800G 16QAM are supported.
3. The output optical power of the module should be at least -9dBm, and the working band should cover the extended C (C++) and extended L (L++).
4. The back-to-back equivalent OSNR tolerance of the 800G PS-16QAM code pattern is at least 1 dB higher than that of the current 400G 64GBd PM-16QAM. These performance and features are guaranteed by advanced DSP algorithms, chips, and high-speed coherent optical components.

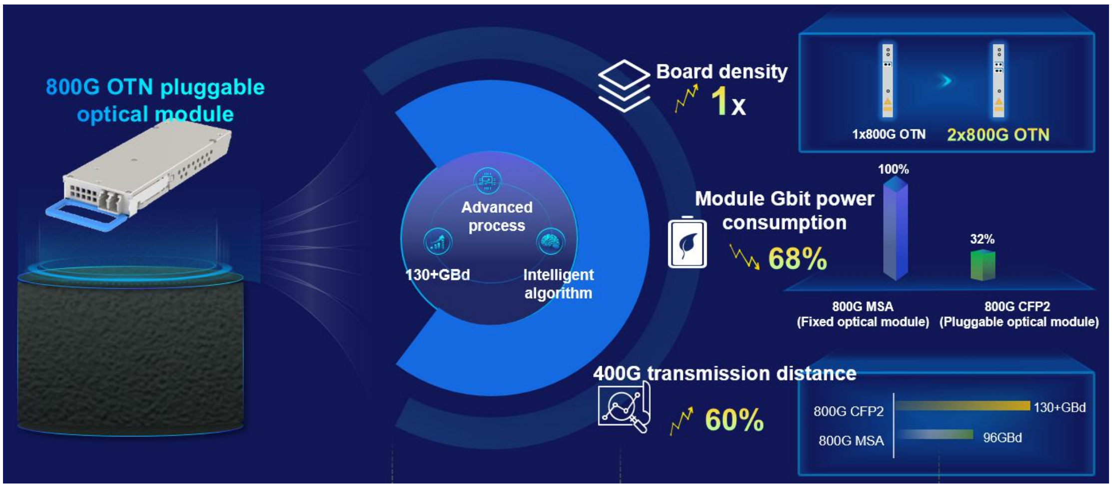

Figure 2.1 Advantages of 800G OTN Pluggable Modules

In 2023, ZTE released the world's first 800G OTN pluggable solution. Compared with fixed modules, pluggable modules have obvious advantages.

First, a pluggable module is smaller than a fixed one by 50%, reducing the space usage and doubling the board port density.

Second, the pluggable module can decrease the single-Gbit power consumption by 68%, which can significantly lower the energy consumption of the entire system. In addition, the pluggable design facilitates fault maintenance.

2.1.1 Advanced DSP Chips and Algorithms

A coherent DSP chip consists of hard IP and soft IP. The details are as follows:

1. Soft IP: Include Forward Error Correction (FEC), coherent modulation/demodulation, and constellation shaping algorithms, and integrate the Framer function.
2. Hard IP: Include DA/AD and high-speed SERDES. For the 130Gbd system, the DA/AD has the sampling rate of as high as 170GSa/s, the multiplexing or time interleaving technology architecture is required to increase the bandwidth, and the 5nm CMOS process is used to reduce power consumption. The SERDES needs a maximum of 16 channels, at least 12 of which support 106/112G PAM4.

Obviously, the coherent DSP is the core technology of the coherent optical module and even the OTN system. To effectively focus on applications, it evolves into two types: high performance and low power consumption.

1. Low-power DSP: It integrates standard FEC and simplified balancing algorithm for line-side interconnection and interworking. It is applicable to network layers sensitive to integration and power consumption. A MAN is the main application scenario.
2. High-performance DSP: It can cover all scenarios. However, due to large size, high power consumption and high cost, it is mainly used for ULH trunk lines and

large-capacity short-haul scenarios.

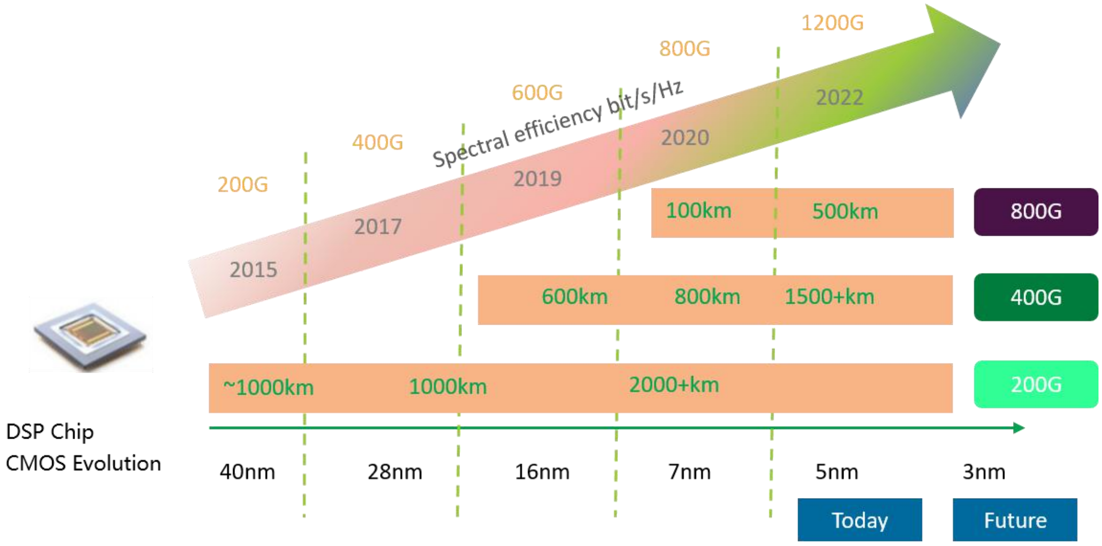

Figure 2.2 Technology Evolution of Coherent DSP

As shown in Figure 2.2, because of the progress of the CMOS technology, the performance, power consumption, and size of each generation of DSP are continuously improved. This increases not only the maximum operating rate of optical modules and the transmission distance of 400G/800G signals, but also the number of logic gates that can be implemented under the restrictions of unit area and power consumption with the decrease of the transistor size. Therefore, new DSPs allow the rapid implementation of some innovative and complicated DSP algorithms.

Two typical applications are TDHM and PCS, which are made possible in 16nm/7nm coherent DSP to greatly improve the flexibility of optical module/system configuration. The code pattern and baud rate can be optimized as required to meet the requirements for back-to-back tolerance, ROADM pass-through, and transmission distance in different scenarios. For 5nm and 3nm DSP chips, some more advanced algorithms, such as high-performance private FEC (LDPC, TPC, and MLC), high-degree/code modulation, ultra-Nyquist (FTN), multi-electronic carrier (DSCM), non-linear compensation algorithm, and neural network algorithm, may be gradually applied in high-performance DSP chips to further enhance the transport performance of 800G.

By virtue of its excellent supply chain management and technological innovation capabilities, ZTE makes full use of its advanced DSP capabilities, ranging from 28nm to 16nm and then 7nm and 5nm. Growing together with upstream and downstream partners in the industry, ZTE continues to practice the industrial development philosophy of increasing speed, cutting prices and promoting dual-carbon goals, and to reduce the power consumption of modules, boards, and devices, making optical transport faster, more intensive, and greener. For example, the world's first 130Gbd 800G pluggable optical transport module adopts the industry-leading 5nm chip process, which deceases the size by 50% and power consumption by 68% than the fixed module. In-house chip capabilities, like 400G/800G DSP and 1.6T Framer, are also being strengthened. Looking into the future, the application of ultra-strong DSP algorithm, 3nm process, and in-house chip capabilities will bring greater improvement and differentiated competition points for high-speed optical systems, which is worthy of expectation.

2.1.2 High-Speed Coherent Optical Components

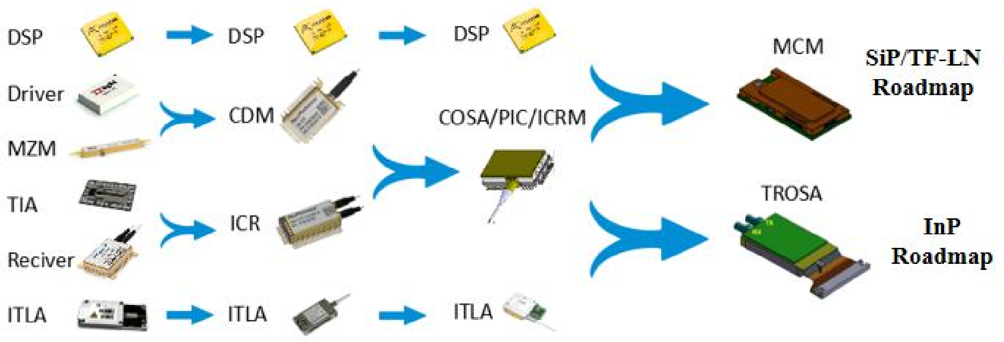

Figure 2.3 Technology Evolution of Coherent Optical Components

As coherent optical modules are developing to small size and low power consumption, coherent optical components should be more integrated. As shown in Figure 2.3, there are two technical routes to continuously boost the miniaturization and integration of components.

1. SiP technology roadmap

Modulation, reception, and driving amplification can be encapsulated into an ICRM, and even DSP die can be co-encapsulated into a MCM. Thus an external light source and an OA can be added to basically form an optical transceiver module. The MCM integrated encapsulation not only makes the component small, but also shortens the high-speed signal routing and increases the bandwidth of the component by more than 10%. This greatly compensates for the insufficiency of the upper bandwidth limit of the SiP technology, and also reduces the cost to a certain extent. The 64Gbd MCM has been widely put into commercial use, and 130Gbd MCM will. When the baud rate rises to 192Gbd or even 256Gbd, the problem of insufficient SiP modulation bandwidth is expected to be exposed. The TF-LN technology is required at the transmitting end. Currently, there are some TF-LN-based modulation chips or CDM component samples, with a bandwidth of up to 110GHz, demonstrating huge application potential. The material characteristics of TF-LN also indicate that it can be partially compatible with the SiP process, and it is expected to continue to maintain non-hermetic encapsulation, which further raises its commercial opportunities.

2. InP Technology Route

The modulating and receiving components made of III-V compound materials can take advantage of on-chip integrated active components. The light source and SOA amplification are easier to implement than the SiP. Therefore, the TROSA integrating ITLA and modulating/transceiving can be available, and externally works with the DSP for coherent transceiving. Theoretically, the bandwidth of the InP modulator is higher than that of the SiP, the output optical power is higher, and the transport capability is stronger. However, in the 400G era, especially in the case of 130Gbd, the performance of the module depends not only on the component bandwidth, but also on the compensation and cooperation of the DSP algorithm. The collaborative design and optimization of optical components and electrical chips are also very crucial, accelerating the vertical integration of optical chips, optical components, and DSPs with other electrical chips.

In 2021, ZTE launched 400G pluggable coherent optical modules based on MCM and TROSA components, which adopt the compact CFP2. SiP MCM and InP should be continuously explored for 130Gbd coherent optical modules to optimize performance, power consumption, and costs. The application of the new TF-LN material system, processing platform, and advanced encapsulation technology can improve the component bandwidth and reduce the component size and cost. The application prospects are wide in long-haul B400G and metro 800G optical transport systems. ZTE and industry partners are actively promoting R&D together.

2.2 Broadband C+L Transport System

As the long-haul transport system advances from single-wavelength 200G to single-wavelength 400G or even 800G, the spectrum width occupied by signals is continuously getting larger. The traditional C++ band that can only carry 40-wavelength services is unable to enhance the single-fiber capacity. Therefore, it is necessary to further expand the spectrum resources to the C+L (C6T +L6T).

Figure 2.4 shows the evolution of the C+L system. In the first phase of the discrete architecture, the C+L system has been capable of large-scale commercialization in 2023. Considering the system service scheduling capability, integration and costs, it will gradually develop into an integrated system, and is expected to be commercially available in 2024. The integration evolution will go through three phases: WSS integration, WSS/OTU integration, and WSS/OTU/OA integration.

The phased evolution of C+L integration is reasonable. At present, the C+L integrated WSS technology is mature. A single-wavelength 800G will work together with the integrated WSS technology for high-speed and large-capacity transport. From the perspective of current market demands, it is estimated that the C+L integrated WSS system will be put into large-scale commercial use in 2024, and the corresponding ROADM sites will be equipped with the C+L integrated scheduling capability. The subsequent OTU integration can support smooth capacity expansion of the existing network. The broadband tunable ITLA and SOA technologies associated with the OTU integration also have corresponding roadmaps. However, there is still uncertainty between the integrated OA technology and mass production, and the related integrated erbium fiber is still in the research phase, so the specific policy relies on the development of the technology.

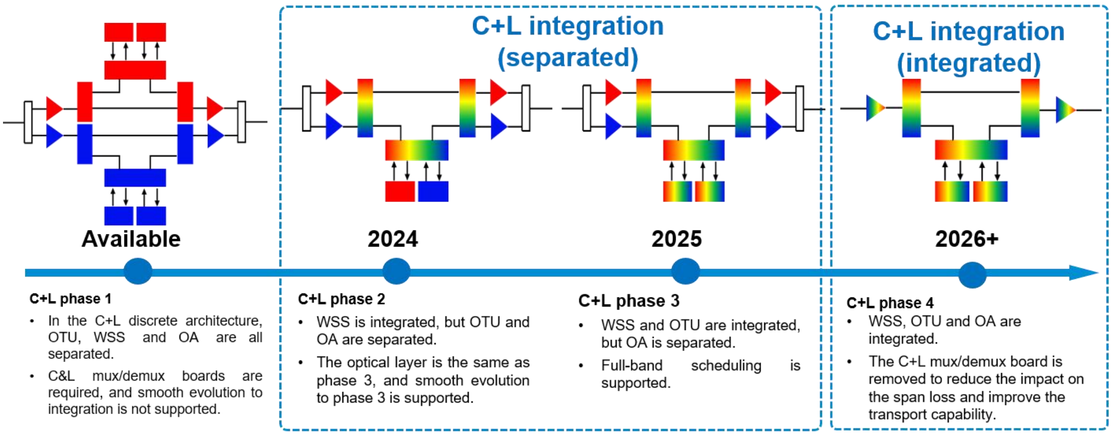

Figure 2.4 400G C+L System Evolution Route

With the evolution of the C+L system and the extension of the WSS from C++ to L++, the C6T +L6T integrated WSS has been gradually released in the industry, supporting the development of OXC towards the C+L integration. The LCOS-based Optical Wavelength Selector Switch (WSS) is a general choice of OXC vendors. It can flexibly schedule signals of any wavelength from the input port to the output port of any line. It is a core component of the OXC for optical cross-connection and wavelength-level optical layer scheduling.

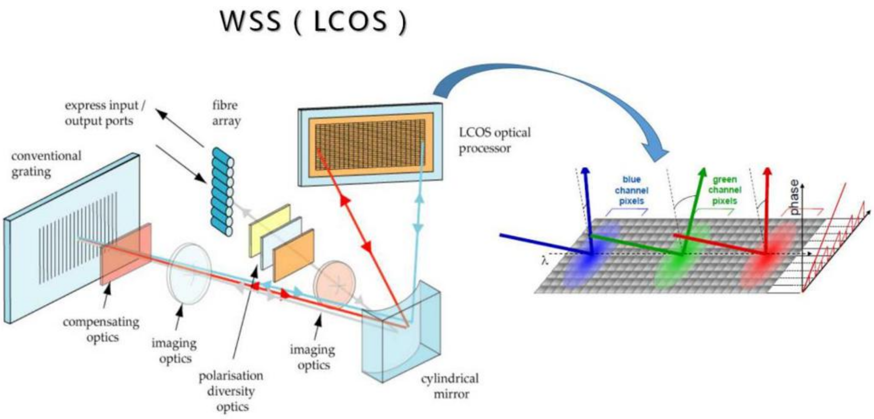

Figure 2.5 WSS (LCOS) Structure

1. C/L Separation

The C++ and L++ WSS and OA employ the discrete architecture, and are multiplexed through the C\L Mux/Demux. In the OXC system, the C++ and L++ boards are independent of each other.

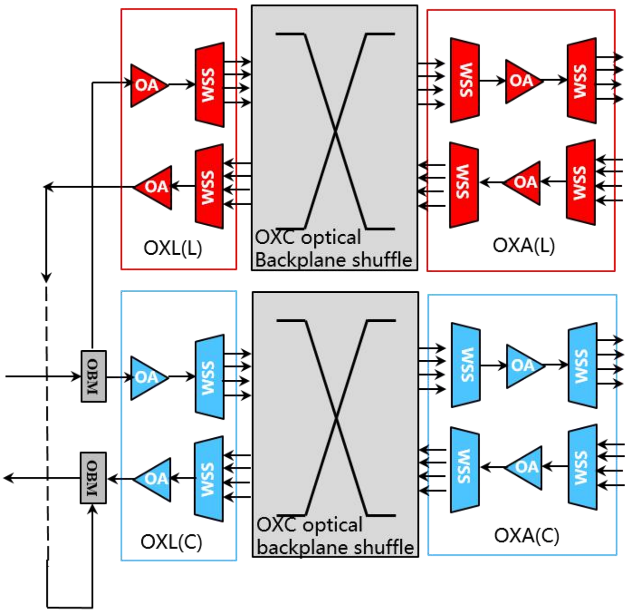

Figure 2.6 C+L Discrete OXC Architecture

2. **WSS Integration and OA Separation**

The WSS supports C+L integration and OA separation. In the OXC system, C+L boards are integrated by further combining the C++ and L++ OAs physically.

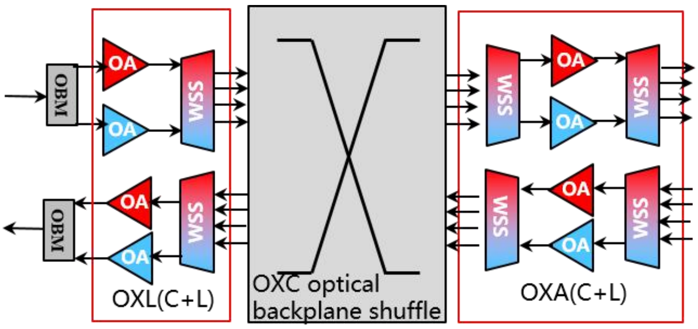

Figure 2.7 C+L WSS Integrated OXC Architecture

3. WSS and OA Integration

The OA further integrates wide-spectrums, and the OXC adopts a completely integrated and minimalistic architecture.

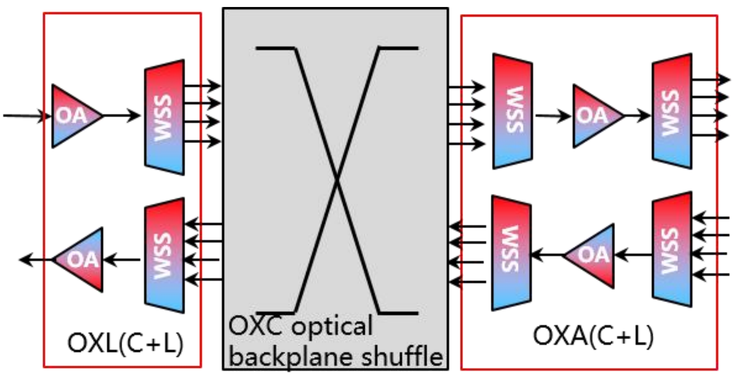

Figure 2.8 C+L Fully Integrated OXC Architecture

With the development of the network, the optical-layer scheduling degrees of core nodes rise, so more high-degree OXCs are needed. The C+L system supporting 40-degree add/drop, and the 48/64-degree OXC products will soon arrive. Technically, the C+L integrated M*N WSS or MCS solution for CDC add/drop is a problem that must be solved in the OXC system. As the 400G transport rate further evolves to 800G, the related components supporting the S band are also undergoing rapid iteration.

From the perspective of the entire system architecture, the integrated coordination and scheduling will drive the integration of optical and electrical cross-connect devices. With increasing maturity of core components and chip technologies and further improvement of integration, the entire system will be more environmentally friendly, energy-efficient, and low-carbon.

As the foundation of an intelligent all-optical network, the OXC, combined with the application of management and control coordination and scheduling, global intelligent power management, and optical label technologies, will allow one-stop intelligent commissioning and O&M, simplified power adjustment in the C+L system, service tracing, misconnection detection, and automatic scheduling, further evolving to be more intelligent in the future.

2.3 Power Management for Flexible Performance Optimization

When the WDM/OTN system is operating, the main optical power must keep the power budget in system design to ensure that the receiving end can run properly. If the fiber parameters are inconsistent with the budget design during network commissioning or fiber attenuation changes in network O&M, the power of service optical signals will vary, and services may be interrupted in serious cases. When the WDM/OTN system is in operation, the optical power of wavelength channels may alter due to the insertion loss of the fiber connector, that is, the optical power point deviates from the optimal working point, so the SNR of the optical transport link may deteriorate, the communication quality may be degraded, or even services are disconnected. The conventional manual adjustment has a large workload and cannot be done in a timely manner. Therefore, it is necessary to introduce the APO (Automatic Power Optimization) in optical networks. In recent years, ZTE has enabled the function to make network debugging faster and operation more stable.

In terms of APO adjustment, the network can be divided into two layers of OMS and OCH according to the WDM network architecture.

1. **OMS APO**

An OMS starts when a common signal is multiplexed and then enters a fiber for transport, and ends when it is demultiplexed. As shown in Figure 2.9, the OMS power adjustment aims to employ the OA to overcome the optical cable loss and satisfy the overall OSNR budget requirements of the system.

For the OMS, the APO ensures the stability of the system power budget when the fiber parameters during network commissioning are inconsistent with the power budget design or the fiber line attenuation changes in network O&M, thus alleviating the impact on services. After the OMS APO is enabled, the workload of measurement and compensation configuration caused by manual power budget adjustment can be reduced, avoiding manual measurement and configuration errors and decreasing maintenance manpower.

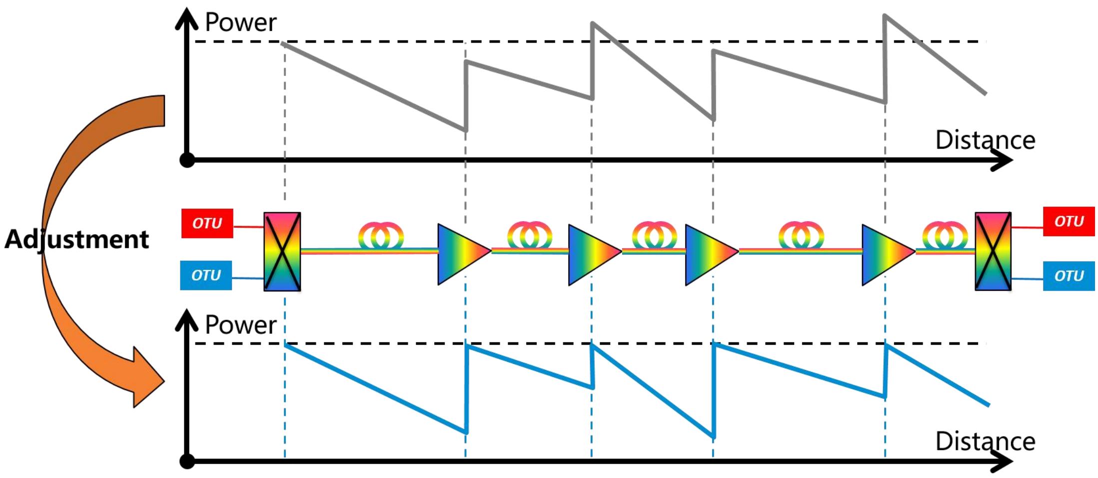

Figure 2.9 OMS Power Management Effect

2. OCH APO

The OCH starts when line-side services are multiplexed and ends when the service receiver demultiplexes them. The OCH power adjustment aims to make the service channel power meet the launching power requirement of the system power budget. And the power of each channel can be adjusted finely to reduce the differences in OSNR and receiving BER between channels at the transmitting end and achieve the performance planned in the system budget.

The OCH APO can automatically adjust the wavelength channels with abnormal power back to the best working point, which reduces the complexity of manual maintenance. In Figure 2.10, the power performance is used to show the situation before and after channel APO power optimization. The actual process is that there is some unevenness in the power after optimization. However, the unevenness is the result of adjustment for balancing transport performance such as OSNR.

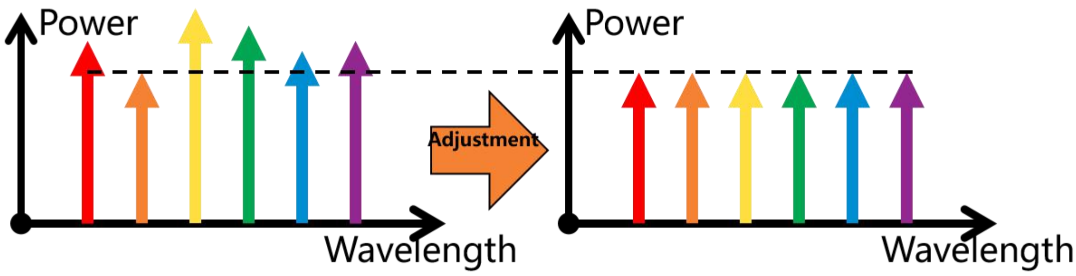

Figure 2.10 OCH Power Management Effect

At present, the APO has almost become the standard feature of ZTE's beyond-100G optical transport projects. It supports efficient and convenient commissioning and provisioning of a large number of new and expansion projects, and maximizes the OSNR margin of optical links and the flatness of wave channels.

To ensure stable transport performance when wavelengths are dynamically added or deleted, a wide-spectrum C+L system (12THz) needs the dummy wavelength filling technology to ensure that the channels are always in full configuration. There is a strong SRS effect in the system with full channel configuration, and the optical power transfer from a short wavelength to a long one is very obvious.

1) From the performance point of view, the SRS transfer has a cumulative effect. After multiple sections of transport, the power of a short wavelength at the receiving end is obviously lower than that of a long one, and the OSNR flatness is obviously degraded.

2) From the perspective of O&M, the Raman effect varies with the launching power, so the power balance of the C+L system needs continuous iteration to reach the designed target value.

Therefore, to ensure that service performance always meets design requirements, the system needs to automatically balance power during commissioning, capacity expansion, and O&M to maintain system performance. Compared with the C-band system, the C+L system has higher requirements for the performance and efficiency of the automatic power balancing function.

1) In a commissioning scenario, the APO can automatically adjust service power to meet performance requirements.

2) In a capacity expansion scenario, the APO can efficiently fulfill end-to-end automatic service provisioning.

3) In an O&M scenario, the APO can perform automatic O&M when a link is degraded to ensure system performance.

Based on the principle of filling wavelength configuration and true-false wavelength replacement in the C+L system, the APO algorithm is designed to assure faster commissioning and debugging and better steady-state performance of the C+L system. It is also divided into two levels: OMS and OCH.

For OMS power adjustment, the APO needs to compensate the uneven power between bands and iteratively adjust the OA gains of band C and L, or that within bands and iteratively adjust their OA slope.

For OCH adjustment, the APO needs to compensate the residual power unevenness and adjust the WSS channel attenuation of band C and L.

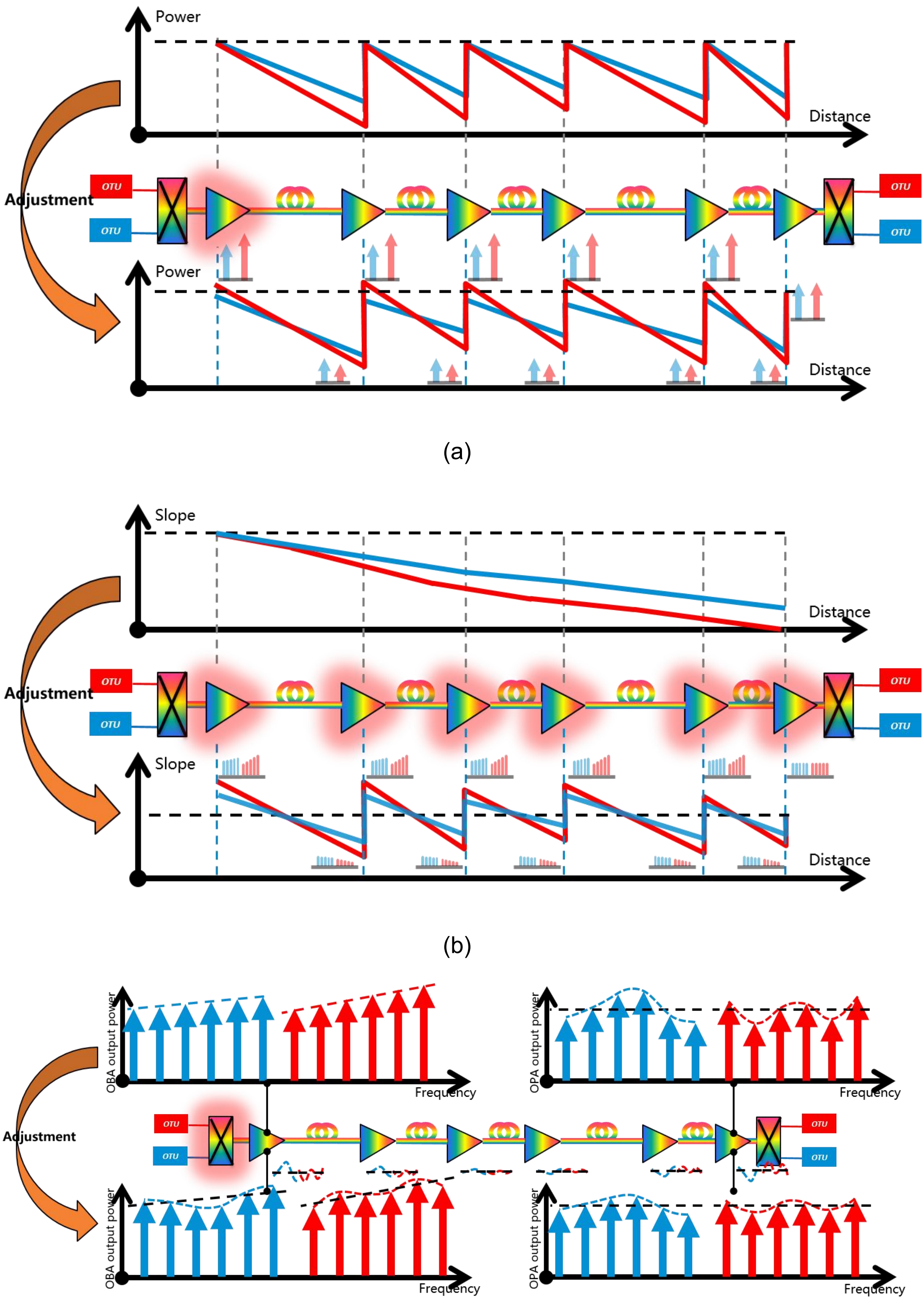

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Figure 2.11 Power Balancing Effect of C+L System

After adjustment by the APO algorithm, the OMS output power is shown in the red curve in Figure 2.12. After the APO algorithm is used to effectively manage the system power, the power flatness is significantly increased. The power flatness of the C band is about 1.5 dB, and that of the L band is about 0.5 dB.

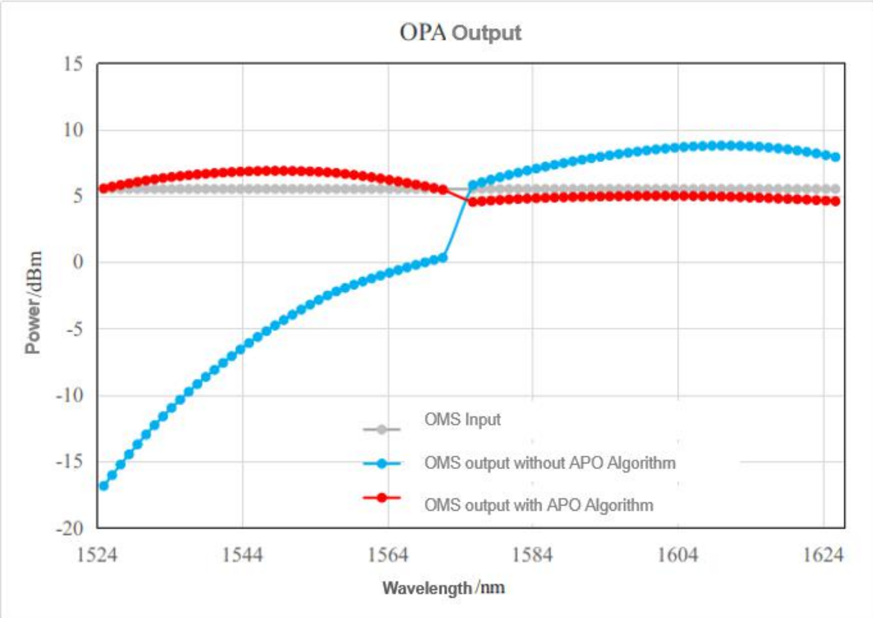


Figure 2.12 Power Distribution of C+L System Across a OMS Before and After Power Adjustment

3. Technical Progress and Application Suggestions

3.1 Related Standards and Industry Chain Progress

1. Progress of International Standards

Standards related to 800G and beyond coherent optical modules and transport systems are formulated by the ITU-T, IEEE 802.3, OIF and other standards organizations, and by the MSA initiated by 800G Pluggable MSA, IPEC, OpenROADM, Open ZR, and other vendors. At present, single-wavelength 800G optical modules are hot topics in R&D application and standardization in the industry.

In terms of 800G short-haul applications, the Optical Interconnection Forum (OIF) is developing specifications for 800G LR and ZR, including optical system parameters, FEC, DSP, and OTN mapping, which are expected to be completed by the end of 2024. The progress of OIF standards has an important impact on the technical trend of 800G standardization of ITU-T and IEEE 802.3.

In February 2023, the ITU-T SG15 Q6 workgroup decided to restart 400G standardization and adopt an open attitude towards 800G standardization. In addition, Q6's future demands for C+L extension frequency bands are recognized in 800G DWDM applications, and Q6's performance in 800G standardization is worth expecting.

The IEEE802.3 has absolute authority on Ethernet interface specifications. It is standardizing 800G/1.6T Ethernet interfaces, including single-channel 100G and 200G interfaces with different transmission distances. In 2023, the IEEE 802.3dj discussed whether the 800G 10 km application employs IMDD or coherent technologies. Finally, it decided to set two project objectives for 800G 10 km and use different technical solutions. It is developing 800GBASE-ER1 and 800GBASE-LR1 standards. It can be seen that with the increase of the single-channel rate, the coherent technology is continuously moving downward and expanding its application scenarios.

2. Progress of Chinese Standards

The standardization of high-speed optical transport modules and systems is implemented by the China Communications Standards Association (CCSA) TC6. Most industry standards are formulated based on advanced foreign standards and domestic application needs. The overall development speed is basically the same as that of international standards.

CCSA-related standards have been formulated: The standards for optical transport and modules with the rates of 100Gbit/s and below have been developed, and the 200Gbit/s approval draft mainly selects the 200Gbit/s QPSK, 8QAM, and 16QAM codes, and the 400Gbit/s metro standard actually adopts the single-wavelength 200Gbit/s dual-carrier solution.

The CCSA TC6 WG1 has successively completed a series of industry standards for the Nx400G Optical Wavelength Division Multiplexing (WDM) system, including Technical Requirements for Nx400G WDM System, Technical Requirements for Metropolitan Area Nx400G WDM System, and Technical Requirements for Extended C-Band WDM System. These standards cover the applications of 400G backbone, MAN, and extended C-band. The modulation formats are 2x200Gbit/s PM-16QAM/PM-QPSK and 400Gbit/s PM-16QAM.

The CCSA is also actively promoting 800G-related standards. At the meeting held in December 2023, the draft of the industry standard "800Gb/s Phase Modulation Optical Transceiver Module - Part 1: 1×800Gb/s" was reviewed and approved, and the draft of "800Gb/s Intensity Modulation Pluggable Optical Transceiver Module - Part 1: 8×100Gb/s" was discussed and approved. In addition, the key fields such as the 1.6T intensity modulation optical module, 1.2T coherent module, and C+L integrated optical components are discussed.

3. Industry Progress

Currently, major device vendors have the 800G PS-16QAM transport capability based on130Gbd+, band CE and C++ can be put into commercial use, and L has samples.

The 130Gbd coherent DSP chip, together with C++-/L++-band ITLA, ICRM and other optical components, supports the commercial capability of the 800G PS-16QAM in 2014, and can be compatible with code patterns such as 400G QPSK. As the core component of the optical system, the OA and the WSS are the most critical. The EDFA and the WSS supporting band C++ and L++ have been commercially available on a large scale, and the bandwidth supports 6THz. The WSS that supports the C+L integrated 10THz technology has the commercial capability, while the C+L integrated 12THz technology is expected to be gradually put into commercial use in 2024.

These industry situations and standard progresses mark the accelerated arrival of the 800G optical transport era. High-speed coherent optical modules and new wide-spectrum optical components will continuously promote 800G and beyond transport capability improvement and industrial progress.

3.2 Transport Pilot and Verification

ZTE is the first to launch the 1.2T MSA prototype in 2021, complete the 1.2T MSA @400G QPSK laboratory test in 2022 and the 400G QPSK live network test in 2023, and release the 800G DCFP2 solution in 4Q23.

In 2024, ZTE will continuously explore the 800G technology, and the 800G OTN pluggable solution will make breakthroughs in the following three aspects:

1. High performance: Compared with the 800G MSA solution, it doubles the board density, reduces the Gbit power consumption by 68%, and enables the transmission distance equivalent to the 1.2T MSA.
2. Full scenario: The full series of OTN products support the 800G+ OTN solution and cover all scenarios including DCI, MAN, and regional trunk.
3. Large capacity: It has the largest OTN platform in the industry, with a single slot of 1.6T (2x800G) and a single subrack of 100T+ electrical cross-connect capacity.

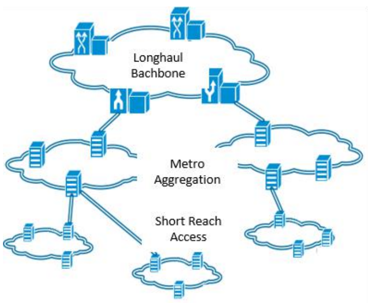
The main pilot projects and verifications are as follows:

1. In 2020, China Unicom Shandong and ZTE jointly tested the 800G OTN solution. Band C++ is used to increase the capacity, which is 1.5 times higher than that of band C. In addition, the 800G solution occupies only the 100GHz channel spacing, raising the spectrum efficiency by four times than the traditional 100G solution occupying 50GHz spacing, and enabling the single-fiber transport capacity to reach 48T through the extension of spectrum resources and the improvement of spectrum efficiency.
2. In 2021, China Mobile and ZTE jointly set the 800G 2,000 km LH transport record based on G.654.E fibers. The ZTE employs single-wavelength 800G boards, flexible shaping, low-noise OAs and G.654E fibers to greatly extend the maximum transmission distance of the 800G system.
3. In 2022, China Telecom and ZTE jointly completed the "industry's first 130GBd 800G 16QAM lab" innovative test. This solution is based on G.652 fibers and common EDFAs for 1,050 km long-haul transport.

4. In September 2023, ZTE and Turkcell demonstrated the ZTE 800G 16QAM capability. At the beginning of 2024, in the verification with Turkcell, the maximum transmission distance of the 800G OTN terrestrial system is 2,000 km.

In the future, ZTE will continue to explore the ultra-high-speed OTN field and actively promote the commercial breakthroughs of 800G technologies in domestic and overseas operators.

3.3 Application Scenario Recommendations and Analysis



Baud Rate	Modulation Format	Single-wave rate	Channel spacing	Application Scenario
64 Gbd	16QAM	400G	75 GHz	Metro & DCI
90 Gbd	PS16QAM		100 GHz	Metro
130 Gbd	QPSK		150 GHz	Longhaul
90 Gbd	PS64QAM	800G	100 GHz	Short-Reach DCI
130Gbd	PS/16QAM		150 GHz	Metro
130Gbd	PS64QAM	1.2T	150 GHz	Short-Reach DCI

Figure 3.1 Modulation Format and Application Scenarios of 800G and Beyond Optical Transport

Based on the above analysis and judgment, the transport capabilities and application scenarios of different 800G modulation technologies are summarized as follows:

1. 800G short-haul DCI scenario: Employ the 130Gbd 16QAM or reduce the rate to the 90Gbd PS-64QAM.
2. 800G metro scenario: In a <600 km transport scenario, the 130Gbd PS-16QAM is a proper solution, with C+L 12THz for 80-wavelength full configuration. In a 600~1000 km transport scenario, the 130Gbd PS-16QAM also needs to cooperate with G.654E new fibers and low-noise Raman amplifiers.
3. 800G trunk scenario: It is recommended to lay new G.654E fibers and reduce the distance between sites to control the span loss to within 20 dB. The 130Gbd technology can be used to upgrade 800G. In the future, 180Gbd or even 256Gbd coherent optical modules can be employed to avoid strong dependence on new fibers and amplifiers.
4. Single-wavelength 1.2T scenario: Currently, the 130Gbd technology can only support 100 km-level single-span transport for short-haul DCI. However, pluggable modules can be available within 1~2 years, but it is estimated that there are still challenges in power consumption.

4. Outlook

4.1 Market Prospect

The single-wavelength 800G technology based on the C+L system is becoming mature, and the overall demands are increasing. At present, the 800G has a small commercial scale and is still dominated by DCI/metro short-haul transport scenarios. With the development of the industry and the maturity of the industrial chain, it is estimated that the 800G will explode in 2025 and gradually move toward metro/backbone networks.

1) For metro and DCI scenarios that pursue advanced technologies or rates, it is predicted that 800G products will be deployed at the earliest. When the 400GE port of the IP network is put into commercial use or the access network traffic is further increased, the MAN/DCI core large-traffic scenario will require upgraded or new 800G networks.

2) In the WDM backbone network scenario, it is expected that the mature 400G solution will be mostly used in the short term, but the 800G solution still has chances in some scenarios requiring high rates.

Based on the above analysis, the operator's 800G network deployment suggestions are as follows:

1) In some existing networks, 800G and existing wavelength channels can be used together. If the existing network is a ROADM system with flexible grids, the optical layer can be upgraded directly without reconstruction.

2) In new projects, 800G networks can be built to improve system capacity, and the single-wavelength rate can be evolved to 1.2T or beyond in the future. The C++ solution can be used in the short term. In the future, devices can smoothly evolve to C+L or even C+L+S.

4.2 Technology Evolution Prospect

To support the further development of the single-wavelength 800G technology based on the C+L system, C+L OA integration is one of the key technologies in the next step for higher system integration and better cost improvement. After the OA integration, the C+L system is closer to the existing C-band system in structure, and component cost control and system O&M are easier. However, the design, manufacturing, final performance and power consumption indicators of the integrated erbium fiber are facing great challenges.

To extend transmission distance, G.654E fibers need to be introduced together with distributed Raman amplifiers.

From the perspective of single-wavelength capacity development, single-wavelength 800G based on 192GBd PS-16QAM or even 256GBd QPSK is the evolution direction of the next-generation high-speed module. The 192GBd PS-16QAM can work with the G.652 fiber for short-haul DCI scenarios, with the G.654 fiber for a MAN, and with the high-performance FEC technology and the G.654 Raman OA even for trunk transport. The 256GBd QPSK is undoubtedly used in long-haul transport scenarios, but its optoelectronic components face great challenges.

In addition, to ensure that the capacity of a single fiber remains unchanged, the spectrum width will be further extended to the S band. For the S+C+L system, the performance of S-band amplifiers, fiber loss, SRS effect, and multi-band power balancing will be great challenges.

5. Abbreviations

Abbreviation	Term	Description
QPSK	Quadrature Phase Shift Keying	It is a four-phase modulation mode with good anti-noise features and frequency band utilization. It can be used in coherent optical communication systems.
M-QAM	M-Quadrature Amplitude Modulation	It is another common modulation mode in coherent optical communication systems.
WDM	Wavelength Division Multiplexing	It is a technology that combines two or more wavelengths of optical signals (with various information) at the transmitting end through a multiplexer, and couples them to the same fiber of the optical path for transport.
OTN	Optical transport network	It refers to a transport network that transmits, multiplexes, routes, and monitors service signals in the optical domain, and assures performance indicators and survivability.
ROADM	Reconfigurable Optical Add-Drop Multiplexer	It is a component or device used in a Dense Wavelength Division Multiplexing (DWDM) system. It can dynamically add or drop service wavelengths through remote reconfiguration.
WSS	Wavelength selective switch	It is a ROADM sub-technology.
APO	Automatic Power Optimization	Automatic Power Optimization

PS	Probabilistic constellation shaping	It obtains a shaping gain by changing the probability distribution of each constellation point.
OSNR	Optical signal noise ratio	It is a parameter that indicates the optical signal quality.
OTDR	Optical Time Domain Reflectometer	Optical Time Domain Reflectometer