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Key Points of OXC Technology and Application Strategy

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Abstract: ***This article elaborates on the technical characteristics and engineering design principles of Optical Cross-Connect (OXC) technology from various perspectives, including its advantages, application scenarios, and design essentials. It highlights that in the era of algorithmic networks, to meet the requirements of ubiquitous access, high-speed interconnection, and flexible scheduling in an all-optical infrastructure system, the OXC/ROADM+OTN optical-electronic integrated system will become the next-generation transmission network.***

Keywords: Computing Power Network; All-Optical Infrastructure System; ROADM; OXC.

1. INTRODUCTION

With the joint release of the "Implementation Plan for the Coordinated Innovation System Computing Hub of National Integrated Big Data Centers" by the National Development and Reform Commission and four other ministries in May 2021, the era of China's computing network has officially begun. In the past two years, China's three major telecom operators have successively released China Mobile's "White Paper on Computing Power Networks" [1], China Telecom's "White Paper on Cloud Network Integration 2030 Technology" [2], and China Unicom's "Action Plan for China Unicom to Build a New Digital Information Infrastructure", marking the beginning of the three major telecom operators' layout and construction of computing power networks. As the carrier of computing power data, the all-optical base system has been prioritized for construction in various provinces. Among them, all three telecom operators consider the all-optical network composed of OXC equipment as an important component of the all-optical base system. Yang et al. (2025) [1] developed a novel big data approach for AI-based economic cycle prediction, while their subsequent work (Yang et al., 2025) [2] applied convolutional neural networks for stock market sentiment analysis. Complementary research by Ji et al. (2025) [3] demonstrated AI's effectiveness in developing personalized retail strategies, and Yang et al. (2025) [4] integrated large language models (LLMs) for cross-asset risk management across multiple financial markets. Further extending financial applications, Yang (2025) [5] created dynamic hedging strategies using LLM-driven sentiment analysis. In healthcare technology, Ming et al. (2022) [6] established the feasibility of telemedicine for pediatric patients, while Yuan (2025) [7] advanced medical imaging through contrastive multimodal learning for chest X-ray analysis. Legal technology innovations were introduced by Wang et al. (2025) [8] through their explainable LLM system for regulatory compliance automation. Sustainable architecture saw significant contributions from He et al. (2024) [9] and Xu (2025) [10], who optimized healthcare facility design using graph convolutional networks. Medical robotics progressed with Liu et al. (2025) [11]'s capsule neural network approach for controlling spider-like surgical robots. Urban planning applications were demonstrated by Ge et al. (2024) [12], while Yang (2024) [13] merged LLMs with knowledge graphs for medical text mining. Cognitive science research by Peng et al. (2025) [14] revealed exercise intensity's impact on executive function, while logistics optimization was advanced by Luo et al. (2024) [15] through their transformer-GCN hybrid algorithm. Financial technology innovations continued with Wang et al. (2025) [16]'s deep reinforcement learning system for supply chain finance and Wang et al. (2025) [17]'s end-to-end autonomous driving solution. Finally, Xi et al. (2024) [18] enhanced LLM problem-solving capabilities, while Wang (2024) [19] improved financial fraud detection using ensemble learning.

2. EVOLUTION OF OXC EQUIPMENT TECHNOLOGY

OTN solves the problem of electrical cross exchange for particles below 100G rate, but OXC equipment is still required for optical channel business exchange for particles above 100G rate. OXC optical switching refers to the direct exchange of input optical signals to any optical output port without any optical/electrical conversion. Optical switching is one of the key technologies in all-optical networks, which can overcome the capacity bottleneck limitation of electronic switching; At the same time, it improves the flexibility and reliability of the network.

The concept of optical switching was proposed as early as the beginning of 2000, but based on the technology at that time, wavelength level cross connections could only use OTM back-to-back hopping fibers for optoelectronic wavelength conversion. It was not until WSS devices matured that ROADM equipment began to be gradually commercialized in the early 2010s, especially after cloud network integration in recent years, ROADM and OXC began to be widely commercialized. After the maturity and large-scale commercial use of ROADM and OXC technologies, the trunk transmission network will be upgraded from a linear structure to a ring structure with protection functions, and even a Mesh mesh network structure with flexible protection functions, which can fully adapt to the business characteristics of multiple protection levels and flexible and variable demands under cloud network collaboration.

The transmission system went through two stages in optical wave switching: traditional wavelength division system and ROADM, until the commercialization of optical backboards before entering the OXC stage.

2.1 Traditional wavelength division multiplexing system (OTM)

Traditional wavelength division multiplexing (OTM) systems usually require the use of business card point relays for intermediate communication at each OTM site, where all calls are made up/down; Scheduling is achieved through fiber optic jumper scheduling, and scheduling must undergo "optical electrical optical" conversion. The service port rate is basically the line rate or a customized smaller rate TMUX branch.

2.2 Adjustable optical add/drop multiplexing equipment ROADM

The optical add/drop multiplexer ROADM can be divided into direction independent adjustable optical add/drop multiplexing devices (D-ROADM), wavelength and direction independent adjustable optical add/drop multiplexing devices (CD-ROADM), and wavelength, direction, and competition independent adjustable optical add/drop multiplexing devices (CDC-ROADM), all of which use WSS on the line side to achieve direction independence and facilitate flexible direction scheduling [5].

2.3 Optical Crossover Device OXC

Due to the fact that the number of fiber jumps between WSS connections is on the square level of the dimension, when the dimension is large, the number of fiber jumps in ROADM will be extremely large, which will cause great difficulties in construction, maintenance, wiring, and later expansion of dimensions. The optical crossover device OXC, which uses an optical backplane instead of fiber skipping, not only reduces the complexity of fiber skipping, but also saves the required machine space. OXC is a ROADM that replaces fiber skipping with an integrated backplane, and fundamentally still belongs to the category of ROADM. It can be considered that the optical crossover device OXC is a further upgrade of the dimmable optical add/drop multiplexing ROADM.

3. ADVANTAGES OF OXC EQUIPMENT

Compared to traditional OTM and ROADM, OXC devices have four significant advantages, which are reflected in space energy consumption, fiber deployment, intelligent operation and maintenance, and business scheduling efficiency.

3.1 Save space and energy consumption

The OXC device adopts highly integrated circuit boards, with one slot corresponding to one line dimension, equivalent to a sub rack of traditional OTM or ROADM. The space occupation is only 1/9 of the original, and the power consumption is only 40% of the original, which meets the requirements of energy conservation and emission reduction.

3.2 Simplification of Fiber Optic Layout

Traditional ROADM relies entirely on single board stacking, and the optical exchange ROADM system is built by manually jumping fibers through ODF racks. The higher the dimension, the larger and more complex the number of connected fibers, and the lower the efficiency of fiber deployment and operation. When adding new optical dimensions in the later stage, the wiring difficulty is extremely high.

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Taking n-dimensional lines as an example, each dimension of ROADM needs to be connected to other dimensions and local up and down dimensions, so the number of jumper fibers is 2xC2n=n (n+1). When n=32, the number of jumper fibers is 1056. If there are higher dimensions in the future, their complexity will double by the square of n.

The OXC device has replaced the fiber skipping between different dimensions of ROADM with an optical backplane, achieving "0" fiber skipping between dimensions.

3.3 Intelligent operation and maintenance

The data information of traditional ROADM is not real-time network information, only from the network management database, making it difficult to accurately locate faults and verify the correctness of routing (such as configuration errors, fiber connection errors, etc.).

OXC devices can achieve end-to-end visibility of wavelength resources and wavelength routing, and visualize the status between dimensions. They also add wavelength labels for optical layer OAM, which can monitor and analyze the network conditions such as optical power, OSNR value, and ZTE frequency of specific links in real time. Key information such as link parameters, signal quality, wavelength paths, and network resources can be analyzed in real time.

3.4 Improvement of operation and maintenance efficiency

In addition to network management allocation, the traditional ROADM system also requires the deployment of optical fibers at the station when opening links, resulting in low efficiency. Especially when adding new planes or devices, the required time is calculated on a monthly basis, which is difficult to meet the time requirements for quickly opening or testing services in the network.

The network of OXC devices is equivalent to using an optical backplane to lay out all the required fiber jumpers in advance, and later opening links only requires configuration in the network management system. Link testing only takes a few minutes, and the expansion of the optical layer dimension is only a few hours. Adding new networks can be completed in a few days.

4. APPLICATION SCENARIOS OF OXC DEVICES

OXC devices have the ability to quickly connect various dimensions, so they are mainly deployed in hub rooms to connect various line dimensions. At this stage, OXC devices are deployed slightly differently in metropolitan area networks and backbone networks.

In a metropolitan area network, the core office building of a city has multiple loops and links that are accessible. The business transfer between these loops and links is connected using patch cords in traditional networks. Due to the fact that most of the city's business is concentrated in 1-3 core office buildings, the number of patch cords in the core office building is very large. If one OXC device is used to replace multiple OTM/ROADM transmission devices in the core office building, all the business transfer and landing of loops and links will be centralized in the OXC device, greatly saving data center space and power consumption. As the price of OXC equipment decreases in the later stage, OXC equipment can gradually sink to various transmission nodes, completing ubiquitous access to nodes in various regions.

In inter provincial and intra provincial trunk networks, traditional networks may have multiple loops and links passing through the core office buildings of various cities, and business transfer is carried out through fiber skipping, which is complex to schedule. Especially when crossing different manufacturers' planes, optical and electrical transfer is required, and the business between two cities is likely to be transferred through provincial capitals or other central cities, which cannot achieve the shortest path and minimum latency [3]. It also wastes more branch line cards. Once there is a fault between planes, the fault location is also complex, and it is economically and operationally inconvenient. After adopting the all-optical base system composed of OXC devices, the most convenient route can be selected between any two cities without the need to go through major hub buildings such as provincial capitals for transfer. As long as there is no need for optoelectronic conversion within the OSNR threshold, the delay is also small, and there is no waste of branch line cards for transfer. At the same time, due to the use of all-optical networks, performance testing can be set as needed, and fault location is simple and convenient. With sufficient reserved ports, configuring and changing links only requires network management operations, without the need for new fiber deployment.

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To meet the requirements of ubiquitous access, high-speed interconnection, and flexible scheduling of all-optical base systems [1], the use of OXC/ROADM+OTN instead of traditional WDM for optoelectronic linkage is currently the best matching cloud network fusion optoelectronic linkage transmission network structure. The transfer of 100G and below business particles is completed through OTN electrical cross connection, and 100G and above business particles are completed through OXC optical channel cross connection.

5. DESIGN POINTS OF ALL-OPTICAL BASE SYSTEM FOR OXC EQUIPMENT NETWORKING

The all-optical base system composed of OXC devices has high requirements for latency, security, flexibility, and intelligence, especially for the characteristics of jumping into the cloud and network following the cloud. Network indicators need to be planned in advance during network design to meet the requirements of all-optical carrying and transmission.

5.1 Link OSNR Planning

In order to meet the requirements of wireless regeneration and switching optical paths for the entire network and one hop direct connection, it is necessary to plan at the beginning of network design that all links must still meet the OSNR threshold value at the end of their lifespan, in order to ensure the requirement of direct connection between any two points and one hop throughout the entire lifespan. When designing a provincial operator's provincial all-optical base system in 2022, the author calculated the OSNR values at the end of life under various parameters between any two stations in the province when selecting OXC equipment. By comparing the OSNR performance of QPSK and 16QAM, selecting the channel spacing, and comparing the 200G and 400G channel rates, in order to ensure all-optical one hop direct transmission, after balanced selection, the configuration of 200G with QPSK 75GHz channel spacing was finally chosen [4].

5.2 Reserve resource planning

In traditional WDM networks, in order to meet sudden business demands, each operator reserves a portion of network resources to cope with such demands. Corresponding to the one-dimensional network structure of ring and chain, some links are generally reserved in segments with high traffic volume.

The all-optical base system composed of OXC devices is a mesh structure mesh network, upgraded to a two-dimensional planar network structure. Opening services can be completed in minutes, and later opening services only requires unused channels and idle ports between service links. Therefore, if the link utilization rate of the all-optical base system of OXC devices is less than 100% in a fully occupied state, as long as a certain number of lines and branch ports are reserved at the source and destination nodes, it can quickly meet the needs of sudden services. The port reservation method is obviously more flexible and adjustable than the link reservation method. In the early stage, ports can be reserved based on the statistical situation of each station's business volume. These reserved ports can be adjusted according to actual sudden business needs in the later stage. Due to their statistical reuse characteristics, the overall proportion of reserved port resources is less than that of traditional reserved links.

5.3 Changes in Expansion Methods

In the one-dimensional ring and chain network structures of traditional WDM, if the local segment resources are fully allocated and used up (such as 80 waves), it is difficult to solve the capacity problem by expanding the local segment separately. This is because the demand between the locally added optical multiplexing segments and the original segments is not determined, so the number of fiber hopping and switching schemes is difficult to determine. Therefore, the newly added optical multiplexing segments cannot be well integrated into the original WDM one-dimensional network, and usually have to create a new loop or link throughout the entire process to meet the demand.

The all-optical base system composed of OXC devices is a two-dimensional mesh structure mesh network. Therefore, when the local link resources are fully utilized, simply adding a line dimension link on this local link can seamlessly integrate the added link into the two-dimensional all-optical base system network.

Compared to the transmission OTN network, the expansion method of the all-optical base system network composed of OXC devices has been changed from building a complete set of loops to adding optical line dimensions to local multiplexing links to solve the problem of resource shortage, save construction investment, and facilitate smooth network expansion.

6. CONCLUSION

With the advent of cloud network integration and the formation of the East Data West computing pattern, an all-optical base system based on OXC/ROADM+OTN optoelectronic linkage for all-optical high-speed interconnection and all-optical flexible scheduling will become a standard configuration for the new generation of transmission networks.

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