Key Technologies in Open Optical Transmission Systems

Issue 01

Date 2017-03-21

HUAWEI TECHNOLOGIES CO., LTD.

Trademarks and Permissions

Notice

Huawei Technologies Co., Ltd.

Address: Huawei Industrial Base
Bantian, Longgang
Shenzhen 518129
People's Republic of China

Website: http://www.huawei.com

Email: support@huawei.com

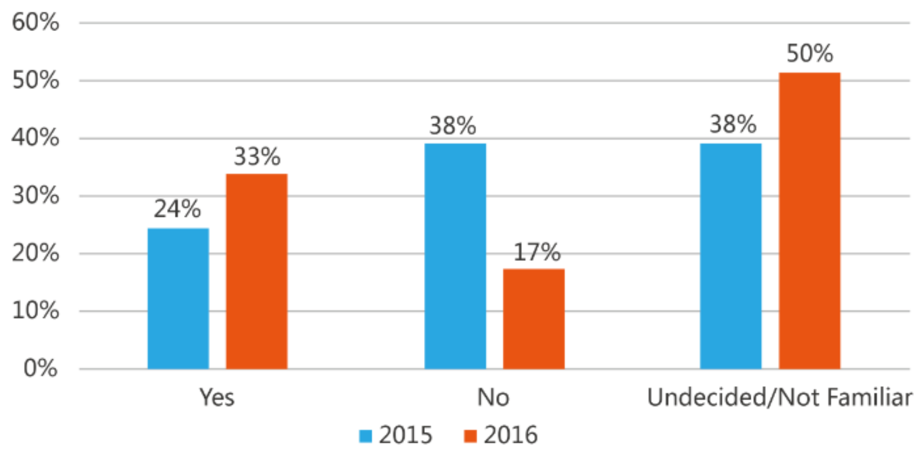
Contents

1 Optical Networks Are Trending Toward Openness

Optical networks are facing significant changes, including increasing demands from new services such as 4K/8K video, VR/AR, cloud computing, 5G, and data center services, as well as ever-changing customer requirements. Communication networks need to provide high performance and sufficient openness to enable flexible, intelligent, and diversified service deployment. In addition, many Internet companies plan to enter the network market. For example, Google's Project Loon aims to increase internet access in remote areas, and Facebook's Telecom Infra Project (TIP) aims to reimagine network infrastructure. These projects are breathing new vitality into the optical network market and introducing new ideas about communications network innovation.

According the IHS report *100G+ & ROADM Strategies Global Service Provider Survey*, network openness is gaining traction and consensus in the industry. In 2015, the percentage of respondents who were willing to use open network architecture was only 24%. However, this percentage had increased to 33% by 2016. Meanwhile, the percentage of respondents who were unwilling to use open network architecture decreased from 38% to 17%.

Figure 1-1 Respondents willing to use open network architecture (source: IHS survey)

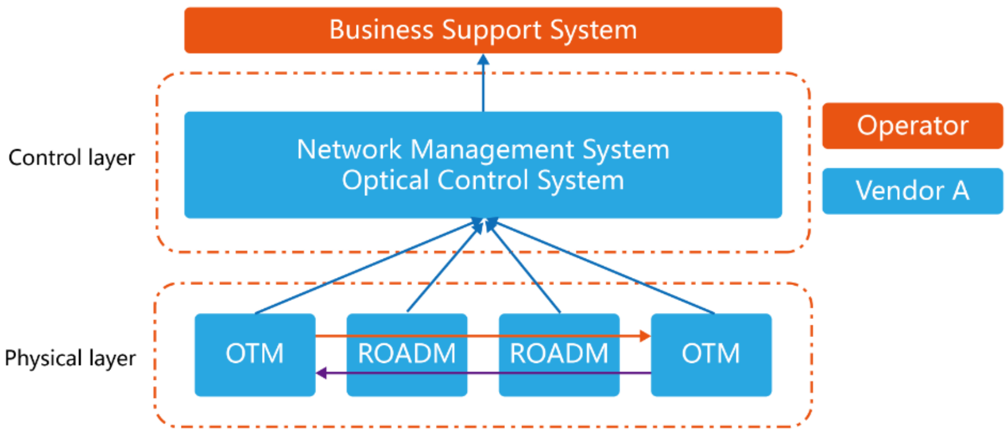


This change indicates that the industry is trending toward open network architecture. However, the percentage of undecided or unfamiliar respondents rose to 50% in 2016, indicating that many within the industry are still hesitant to adopt open architecture.

1.2 Three Major Driving Factors of Open Optical Networks

Currently, most optical networks use closed systems, in which all the hardware equipment and control software of each network are provided by the same vendor, and hardware and software are closely coupled. In past decades, such closed systems had the advantages of proven high performance and commercial feasibility. However, as network services continue to develop, closed systems have been found to have many drawbacks and cannot adapt to various emerging network applications, such as 4K/8K video, VR/AR, cloud computing, 5G, and data center services. Optical networks need to be opened up to resolve the problem.

Figure 1-2 Closed transmission system, with the physical layer and control layer provided by the same vendor



In open optical networks, the network can consist of software and hardware modules provided by multiple vendors, increasing telecom operators' network independence. The three driving factors of open optical networks are as follow:

1.2.1 Quickly Adopt The Latest Technologies

In a closed system, a single vendor or technology can exclusively determine device communication and overall network management. Common standards are not used, and communication between the networks of different vendors is difficult, which makes vendors hard to switch to the solutions with latest technologies.

Telecom operator services become restricted by legacy networks and fail to adopt the latest technologies. As a result, their market competitiveness is reduced. In addition, it is difficult to apply new technologies to existing network services, hindering technological development and promotion.

Open optical networks help operators eliminate their dependence on a single vendor. Operators construct convenience channels between the networks of different vendors without compromising performance to promote the development of new technologies and free competition in the industry, which enables quick adoption of the latest technologies.

1.2.2 User-defined Network, Fast Service Provisioning

Traditional networks mainly carry data services and do not have many service types. Operators generally use a few options and configurations provided by equipment vendors to meet customer requirements. Current networks need to provide various services, such as 4K/8K video, VR/AR, cloud computing, and 5G services, in different scenarios and for different types of customers. Such customers include individuals, government and enterprise customers, and financial customers. Network requirements vary depending on application types. The rigidity of closed networks is therefore a major disadvantage.

Equipment vendors also face the challenge of varying network requirements driven by services. Vendors may not research and customize devices for all types of applications. To better satisfy operators' requirements, equipment vendors can give operators autonomy in network configuration and provide a unified platform for operators or end users to configure networks, improving the efficiency of both vendors and operators.

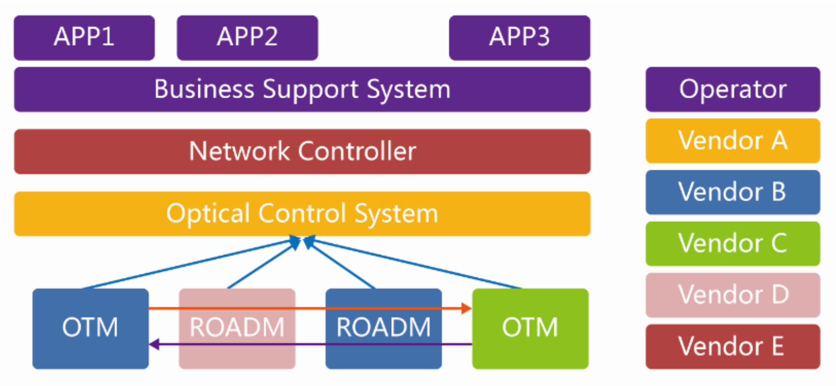
1.2.3 Lower OPEX

Open optical networks enable quick adoption of the latest technologies, allowing operators to easily manage and reduce network OPEX. However, the benefits of open networks should not be overstated. According to a Cignal AI report (*Investor Call: China, CFP2-ACO, ROADMs & More*), unlike the high profit margin (up to 65%) of switches, the profit margin of optical network equipment has decreased to a low level. In fact, Compared with over the top (OTT) DCI networks, operator networks are much more complex. High openness means complex network integration, O&M, and management and may sharply increasing OPEX. Therefore, the openness of optical networks should not be pursued at the expense of cost reduction.

2 Challenges of Opening the Network Optical Layer

One method of opening up optical networks starts from the bottom optical-layer transmission to completely decouple software and hardware. This allows for maximum openness, but it also brings some challenges.

Figure 2-1 Network architecture with a fully open optical layer

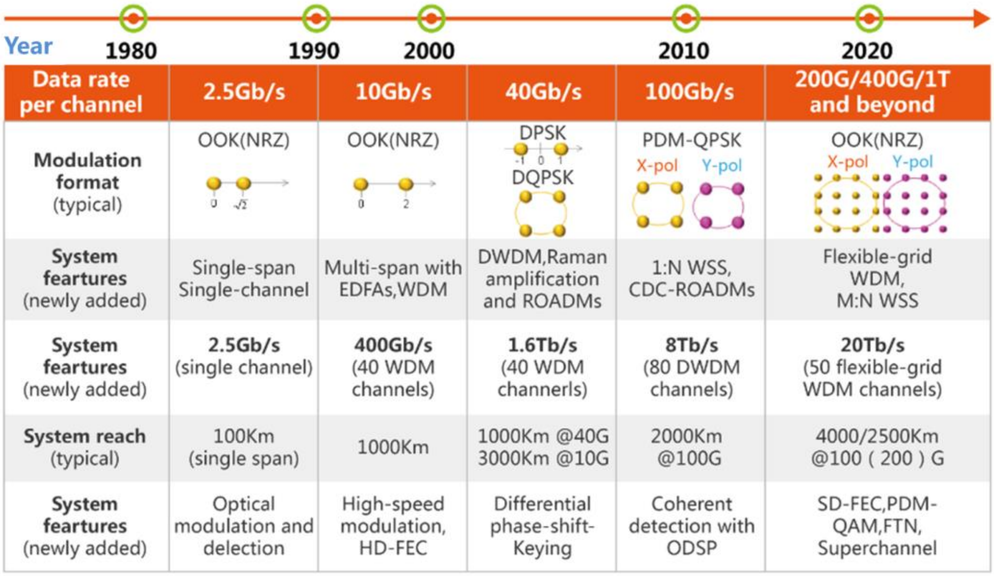


Currently, the major challenges are system integration, fault location and network security, transmission performance, and interconnection standards.

2.1 System Integration

In an optical network system, system integration is the biggest bottleneck. Analog signals in optical network systems are more complex and prone to interference than digital signals. With 100G, 200G, or even 400G transmissions, complex higher-order modulation signals with ultra-high speed are transmitted in optical fibers, as shown in Figure 2-2.

Figure 2-2 Increasingly complex technologies with the development of optical communication systems



Year	1980	1990	2000		2010	2020
Data rate per channel	2.5Gb/s	10Gb/s	40Gb/s		100Gb/s	200G/400G/1T and beyond
Modulation format (typical)	OOK(NRZ)	OOK(NRZ)	DPSK DQPSK		PDM-QPSK X-pol Y-pol	OOK(NRZ) X-pol Y-pol
System feartures (newly added)	Single-span Single-channel	Multi-span with EDFAs,WDM	DWDM,Raman amplification and ROADMs		1:N WSS, CDC-ROADMs	Flexible-grid WDM, M:N WSS
System feartures (newly added)	**2.5Gb/s** (single channel)	**400Gb/s** (40 WDM channels)	**1.6Tb/s** (40 WDM channerls)		**8Tb/s** (80 DWDM channels)	**20Tb/s** (50 flexible-grid WDM channels)
System reach (typical)	100Km (single span)	1000Km	1000Km @40G 3000Km @10G		2000Km @100G	4000/2500Km @100 (200) G
System feartures (newly added)	Optical modulation and delection	High-speed modulation, HD-FEC	Differential phase-shift-Keying		Coherent detection with ODSP	SD-FEC,PDM-QAM,FTN, Superchannel

Transmission failures may be caused by minor performance differences in optical module hardware or minor differences in software parameters. Over 100 parameters across many dimensions make an optical transmission network into a complex and sophisticated system. Efficient, stable, and reliable system integration requires research teams to have deep theoretical knowledge and accumulate extensive experience in technical practices.

High-quality, stable system performance can be achieved only by the close integration of software, hardware, overall design, optimization, and testing. In addition, monitoring, commissioning, and configuration software are needed to ensure that the complex and sophisticated transmission system can tolerate accidents and natural disasters and be used in extreme environments.

Vendors invest hundreds of millions of dollars in research per year, with most of that investment focusing on optical transmission systems. After years of technological accumulation and development, vendors become specialized in the field. After opening up the optical layer of networks, vendors hand over system integration to operators. Operators then set up optical transmission systems by themselves or by outsourcing. This means that operators and the companies to which they outsource need extensive experience in optical transmission systems and sufficient personnel capabilities. If they lack these, building a transmission system with complete functions may prove impossible, forcing operators to spend more money on O&M.

2.1.1 Transmission Performance

To meet network requirements for latency, bandwidth, and intelligence, optical transmission systems require advanced technologies that utilize information science and quantum physics science. Advanced software configuration and commissioning are therefore required, to achieve optimal efficiency, improve transmission performance, and reduce per-bit transmission costs. However, standard hardware and software cannot achieve systematic collaboration and optimization and may not maximize the capabilities of hardware and software, which wastes resources.

2.1.2 Fault Location

In a network consisting of multiple vendors' hardware and software, collaboration between all parties is vital. High openness means many vendors are involved, network uncertainty is high, and no single party understands the entire network and takes responsibility for fault location on the entire network. This means that if a fault occurs, fault demarcation and location are difficult, which is a risk that must be borne by operators. In a traditional network system, equipment vendors are responsible for network reliability. Because an equipment vendor generally provides a complete solution, the equipment vendor is capable of fully evaluating and testing overall system reliability to ensure service continuity.

2.1.3 Network Security

When a network is fully open, network construction information (such as site location, optical amplifier deployment, and fiber layout) is relatively transparent, and this transparency is easily exploited to attack the network, bringing high security risks.

2.2 Interconnection Standards

Standards are the greatest driving force in the optical network industry. Currently, there are no interconnection standards regarding optical-layer openness, partly because optical transmission is highly complex and standards are difficult to determine.

Due to these challenges, opening up the optical layer of networks sacrifices system performance, fault location convenience, and transmission performance. This means that currently, opening up the optical layer is applicable only to simple point-to-point short-haul transmission networks. These include some Internet companies' DCI applications, with few service types and granularities, short distances, and evenly-distributed traffic.

However, this approach is unsuitable for operators' complex, large-scale mesh networks, which feature various service types and granularities, massive pass-through sites, and significant traffic fluctuations. Limited by physical-layer transmission principles and fully open architecture, opening up the optical layer of networks will be difficult to implement in the near future. As a result, most parties in the industry remain hesitant about opening up the optical layer.

3 Interface Openness at the Control Layer and Integration at the Transmission Layer

Based on this analysis, the largest obstacle for optical network openness is the physical characteristics of optical transmission itself. Optical network openness sacrifices transmission performance and brings system stability and security risks, making it applicable only to simple DCI short-haul transmission networks. For complex operator networks, optical network openness cannot satisfy the various service bearer requirements for bandwidth, latency, and reliability. In addition, markets do not currently require operators to open up the optical layer of networks.

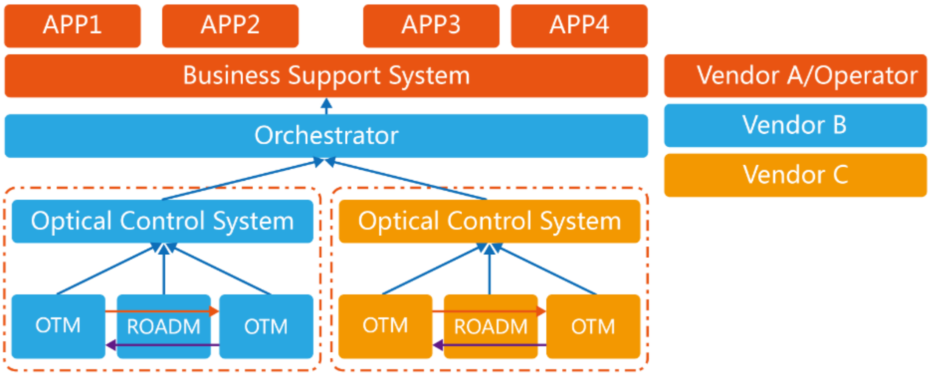
Instead, telecom operators and end users can obtain more autonomy and implement unified service management, allocation, and interworking between different telecom operator networks by implementing more practical solutions. One such solution is as follows:

- Use open northbound interfaces (NBIs) to connect to a third-party network control and planning system. Grant telecom operators maximum network autonomy to implement interworking between different vendors' networks, optimize network resources, and reduce costs.
- On bottom-layer transmission networks, maintain the integration implemented by equipment vendors to guarantee high system performance, security, and reliability. This means that operators do not need to invest large amounts of time and money for research and management at the physical layer that is irrelevant to specific services.

1. **Fully open NBIs to grant customers network control rights.** In the bottom-layer optical transmission system, equipment vendors are responsible for overall system integration to guarantee high performance and reliability. Equipment vendors also fully open upper-layer software control rights and define and launch NBI standards to implement system connections for telecom operators, granting end users more network configuration autonomy.

2. **Interconnect different vendors' networks and implement unified management for telecom operators.** Interface protocols must be promoted to become industry standards, so that the operation system of an operator can globally control different vendors' networks, achieving interconnection and free configuration between them.

Figure 3-1 Interface openness at the control layer and integration at the transmission layer



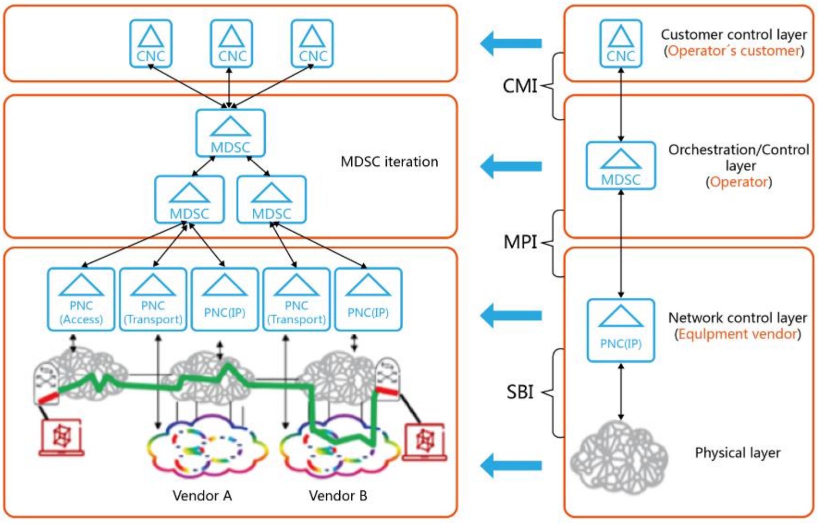
3.1 ACTN Architecture

Abstraction and Control of TE Networks (ACTN) architecture was proposed by the IETF at the end of 2013. It uses hierarchical architecture of controllers to achieve compatibility with control plane technologies on existing networks and evolve these technologies to implement Transport SDN (TSDN). The ACTN architecture has strong support among many operators and vendors.

Hierarchical architecture of controllers is the most important feature of ACTN architecture, which is shown in Figure 3-2. The ACTN architecture primarily contains controllers at three layers. The full names of three important roles are as follows:

- PNC: physical network controller
- MDSC: multi-domain service coordinator
- CNC: customer network controller

Figure 3-2 Basic ACTN architecture



A PNC is responsible for configuring NEs, monitoring the physical topology of the network, and passing the topology information to the MDSC. PNCs can be divided into different categories of controllers, such as transport and IP, by control target. If devices at the physical network layer are provided by different vendors, different PNC transport controllers must be used to control each single-domain network.

An MDSC is usually deployed to the orchestration layer for coordinating different single-domain PNCs and communicating creation requests and connection bandwidth changes on physical networks. MDSCs can also be iterated at multiple layers on a large-scale network, and can overlap PNCs on a small-scale network.

As a CNC directly connects to the application layer, it intelligently adapts to application-layer requirements and delivers corresponding customer-layer instructions. The main functions of a CNC are requesting the creation of a virtual network topology and deploying services in this topology. To satisfy different customer requirements, multiple CNCs are used to control different network areas separately or implement different network configurations.

The modules at different layers use different interfaces for information interaction. A southbound interface (SBI) is located between the physical layer and the network control layer, an MDSC-PNC-interface (MPI) is located between the network control layer and the network orchestration layer, and a CNC-MDSC interface (CMI) is located between the orchestration/control layer and the customer control layer.

Operators can coordinate the three types of controllers to resolve the major problems inherent in the closed system architecture of traditional transport networks.

1. Open optical network systems implement service interworking between different vendors' networks and able to adopt the latest technologies.

Transport networks are complex and contain technical information at different layers, such as OTN and optical-layer network. Because traditional architecture is limited by distributed controllers, optimizing configurations for a global, multi-layer, multi-domain topology is difficult. Using ACTN's hierarchical controller architecture, equipment vendors can use PNCs to effectively control physical networks and coordinate MDSCs and PNCs to obtain networkwide all-domain topology information. This helps operators efficiently manage large-scale networks, implement service interworking between different vendors' networks, and able to adopt the latest technologies.

2. The end user–oriented customized network grants users maximum autonomy.

Operators are generally required to provide connections or even an entire network for end users. The timeliness and convenience of deploying and maintaining networks can bring huge benefits to end users. Due to the minimal automation of traditional networks, rolling out a private line connection typically takes several weeks to several months, and the connection has a fixed bandwidth and is difficult to maintain. ACTN uses CMIs to implement unified service models for end users and quickly roll out customized networks, create services, and dynamically adjust bandwidth.

3. Equipment is configured flexibly and costs are reduced.

Due to ever-changing market requirements, vendors and interfaces vary depending on requirements. With traditional architecture, operators generally need to replace devices in a large scale or temporarily adjust transport network architecture. These methods are difficult to configure, expensive, and time-consuming. Using ACTN architecture, operators can simply add PNCs and corresponding interfaces on MDSCs without replacing devices, achieving flexible device configuration and effectively controlling service update time and costs.

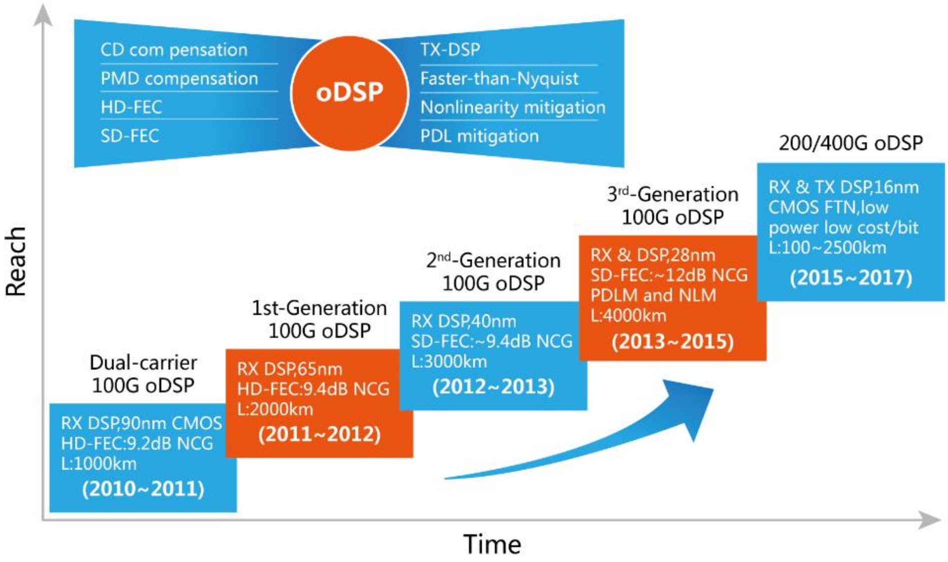
Since 2016, the IETF has made a rapid progress with the YANG data model. Major model documents, such as topology model and connection model documents, have been accepted by workgroups, and a corresponding RFC will be released soon. In July 2016, IETF 96 Hackathon activities verified the YANG model of topologies and services for application on ACTN MPI interfaces. Many tier-1 telecom operators, equipment vendors, and scientific and academic organizations participated. Huawei will extend interoperability tests of ACTN architecture to multi-vendor and multi-domain scenarios to verify various topology and service models.

3.2 Optical-Electrical Integration

On the upper-layer control plane, Huawei uses ACTN architecture to meet network openness requirements. On the physical transmission plane, traditional equipment vendors integrate optical-electrical technologies and related algorithms in transmission systems to guarantee transmission performance and reliability, satisfying future multi-service bearer requirements for bandwidth, latency, and reliability.

In the electrical domain, Huawei uses advanced technique manufacturing processes to enhance the performance of chips and modules and launches CFP and CFP2 miniaturized and long-haul modules. These chips and modules, coupled with improved modulation format error correction algorithms and high-speed communication simulation modeling, increase the per-wavelength rate to 400 Gbit/s. This gain is achieved without sacrificing transmission distances, pushing the optical link performance to the limit of Shannon's capacity. With the movement of OTN closer to end users, oDSP technologies such as error correction, dispersion compensation algorithms, and nonlinearity compensation and flexible higher-order modulation algorithms are used. This maximizes the bandwidth and performance of optical components and minimizes per-bit transmission costs.

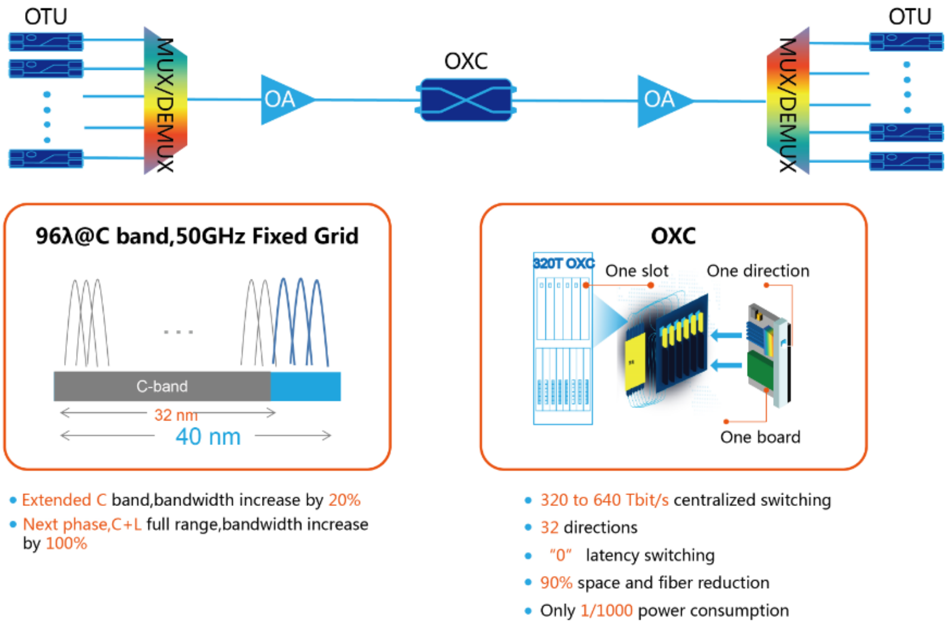
Figure 3-3 Continuous oDSP technology evolution



In the optical domain, the integrated use of OXC, silicon photonics integration, and optical-layer digitization technologies creates a new-generation optical layer. The optical waveguide-based wavelength switching of the OXC provides multi-degree, non-blocking all-optical switching with over 600 Tbit/s cross-connect capacity, satisfying sharply increasing requirements for switching capacity of super core nodes. The silicon-based photonics integration technology improves the performance of optical components, such as optical modules and amplifiers, while reducing their size and power consumption. These components are plug-and-play, making construction of an agile optical layer easier.

Meanwhile, the usable bands of optical fibers are extended to C-, L-, and S- bands, improving per-fiber capacity to 80 Tbit/s or more. Along with the detection, optimization, and protection algorithms of electrical-layer chips, this technology allows the visualization of optical-layer resources and automatically optimizes performance.

Figure 3-4 Next-generation optical-layer platform



On the entire transmission network, in addition to a bandwidth resource pool using scalable and programmable hardware, Huawei uses a platform for managing cloudified network node resources. This enables centralized management of network-wide pooled resources. Massive datasets, containing network fault history, board fault rate, and component information, are processed using advanced Big Data analysis algorithms and artificial intelligence technologies, helping predict and prevent faults and automating services. This also improves the reliability and self-healing capabilities of networks and achieves 99.9999% reliability with the help of ASON. Networks can then withstand accidents and natural disasters, and telecom services can continue to run without any interruption in harsh environments.

3.3 Huawei CloudOptiX Solution

Huawei CloudOptiX solution uses ACTN architecture to open TSDN NBIs, standardizing upper-layer network control and supporting interconnection with third-party control software, as well as granting operators maximum autonomy. The solution effectively strengthens collaboration between vendors and technologies and enables close vendor-operator cooperation. This optimizes resource configurations and reduces network costs.

Based on an OTN+OXC photoelectric architecture, Huawei CloudOptiX solution supports 100G, 200G, 400G and even future 600G ultra-high bandwidth transmission. It guarantees low latency in links, matches corresponding latency management algorithms, and carries different types of services at multiple granularities, ensuring optimal performance and high reliability for transmission networks.

CloudOptiX uses the open network architecture of TSDN to implement self-service bandwidth application, adjustment, and reservation and flexible bandwidth policies. This shortens service time to market and improves network agility. By leveraging the centralized management architecture of TSDN and various resource visualization and performance monitoring applications, CloudOptiX provides real-time insight into key performance indicators and network resources. This guarantees high resource utilization and O&M efficiency. CloudOptiX also combines intelligent planning methods and hardware to achieve high network reliability and provide powerful assurance for telecom services.

4 Conclusions

With the increasing diversity of network services, telecom operator networks need to evolve from closed to open systems to speed up iteration. This evolution satisfies operator and end user requirements for customized and independent network configurations to build flexible and open optical transmission networks.

However, optical networks are highly complex. Fully opening the physical layer makes system integration difficult and brings risks to system stability, reduces transmission performance, and increases OPEX. Therefore, fully opening the bottom physical transmission layer of optical networks is not practical for complex operator networks.

When vendors integrate bottom-layer optical transmission systems and operators control upper-layer networks, all parties in the industry can maximize their capabilities. Operators gain maximum network autonomy without adverse impacts to system performance and stability. Based on the existing standards and technologies, Huawei promotes software interface standardization to connect bottom-layer transmission systems and upper-layer control systems. This allows services on different vendors' networks to interconnect and interwork with each other and to be freely dispatched.

Huawei CloudOptiX solution integrates the latest technologies in both the electrical and optical domains to cloudify network devices and guarantee the stable, reliable, and sustainable evolution of bottom-layer transmission systems. On the control plane, CloudOptiX uses the IETF ACTN architecture to open standard NBIs and enables operators to focus on network services. Operators gain network configuration autonomy and services can interconnect and interwork between different vendors' networks. Network resource configurations can be optimized, reducing OPEX.