Constructing Intelligent Ultra-High-Speed Optical Networks with Ultimate Performance

— Huawei's New Generation High-Speed Coherent Transmission System

HUAWEI

Trademarks and Permissions

Notice

Huawei Technologies Co., Ltd.

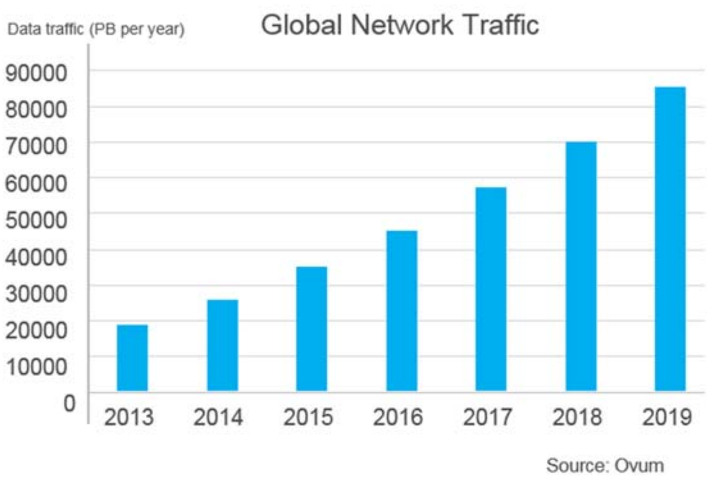
Address:	Huawei Industrial Base Bantian, Longgang Shenzhen 518129 People's Republic of China
Website:	http://www.huawei.com
Email:	support@huawei.com

Contents

1 Challenges to Optical Networks in the New Era

1.1 Moore's Law on Optical Fibers

According to a report from Ovum, global network traffic has been rapidly growing since 2013, doubling roughly every three years. Driven by 5G, 4K video, and enterprise private line services, network traffic will increase by over 25% each year in near future. In some countries, such as China, network traffic will grow by up to 40%.



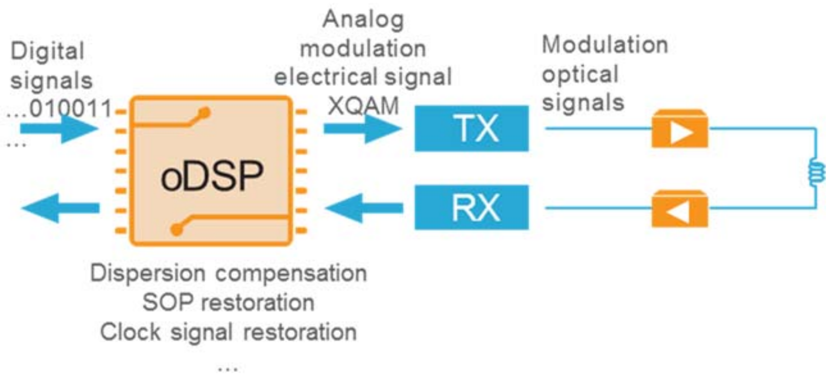
Optical network transmission technology has been developing rapidly to meet the world's growing bandwidth needs. From 10G to 100G, the single-wavelength rate of 200G has gradually matured and has been deployed in large scale. 400G technology is starting to see commercial use, while the 600G and higher rates will soon enter commercial deployment. From the perspective of single-fiber capacity, the optical network has an empirical law similar to Moore's Law, which is that single-fiber capacity doubles roughly every three years.

1.2 Transmission Capacity and Distance Must Be Balanced in Speeds Beyond 100G

Improving single-wavelength rate is the most effective way to cope with the Moore's Law on optical fibers. However, the theoretical Shannon's limit is being approached. The higher the single-wavelength rate, the shorter the transmission distance. In fact, transmission distance is the biggest limiting factor for most high-speed transmission scenarios above 100G. For most networks, it is beneficial to double single-fiber capacity. However, if long transmission distances are required and electrical regeneration sites must be added to the network, network construction cost is greatly increased. Therefore, optical networks must develop towards higher rates while maintaining a transmission distance that meets requirements.

1.3 oDSP Algorithm Is the Key to High-Performance High-Speed Transmission

A typical coherent transceiver transmission system consists of three parts: optical digital signal processors (oDSPs), transmitters, and receivers. oDSP is a core component of the entire system. It not only encodes and decodes digital signals and analog signals, but also compensates for many costs in transmission links. For example, a typical 100G coherent transmission link can travel over thousands of kilometers without any dispersion compensation module. This is because the oDSP algorithm can compensate for the link dispersion penalty, simplify the link, and greatly improve transmission performance. Therefore, the capability of the oDSP chip determines the transmission capability of the system, including the transmission capacity, transmission distance, and per-bit power consumption. Moreover, from the perspective of the industry chain, other components besides oDSP, such as transmitters and receivers, can be selected from multiple mature vendors, making oDSP the most important differentiator in technical strengths of different vendors.



2 Key Technologies of Huawei's Next-Generation oDSP Algorithm

Huawei's next-generation coherent oDSP algorithm uses two unique and key technologies that improve transmission performance:

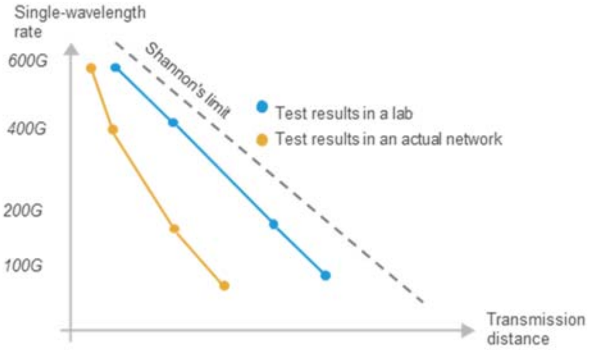
- Channel-matched shaping (CMS): Based on the transmission link status, transmission performance is optimized at the system layer to maximize the capacity and distance of the transmission.
- Artificial Intelligence (AI) neurons: In a distributed architecture, all key parameters of the optical-layer on the entire network are monitored in real time and network intelligence is enabled based on the AI algorithm.

In addition, with the industry-leading TSMC 16nm FinFET manufacturing technique and a simplified chip architecture, the system power consumption can be greatly reduced.

2.1 Core Technology 1: CMS

2.1.1 Why CMS

Currently, the biggest challenge of 400G/600G transmission is distance. In terms of single-system capability, the performance improvements are close to reaching Shannon's limit. However, while the transmission distance can reach 2000 km in a lab, in an actual network, it only achieves 500 km. What causes the transmission performance to shrink? This is the problem Huawei CMS was made to solve–improving the transmission performance of the real network, not what can be achieved in the lab.

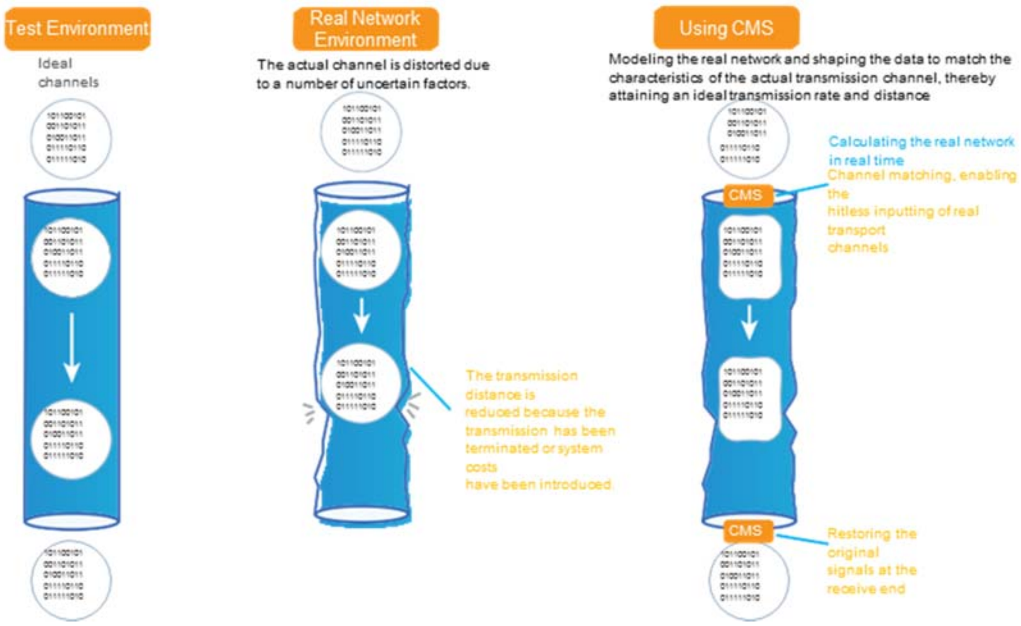


The main reason for the performance difference is the imperfections of a real network. In a lab, the best and most reliable components are used to perform the test in the most stable environment, and the results are very close to the theoretical limit. However, in a real network, the situation is far from ideal. The optical fiber quality, power distribution in the fiber, noise of the amplifier, curve of the filter, ambient temperature of the fiber link, and the weather conditions are all varied. Each of these factors introduce a penalty to the actual performance of the optical network system. Finally, the costs of different factors are superimposed. As a result, the overall system performance deteriorates, shortening the transmission distance, or even causing the link to fail. For an actual network, eliminating a wide variety of factors that hinder performance and compensating for penalties of the network is a practical and urgent problem for those who use the actual network. This is the basis for Huawei to introduce the CMS when designing coherent algorithms.

2.1.2 About CMS

In Huawei's next-generation coherent oDSP algorithm, the unique CMS technology is developed to fill the gap between the real networks and lab conditions. This technology is a combination of shaping, compression, compensation, and error correction technologies that deal with different types of transmission costs in an actual optical network.

Figure 2-1 Optimizing transmission performance in a real network by using CMS

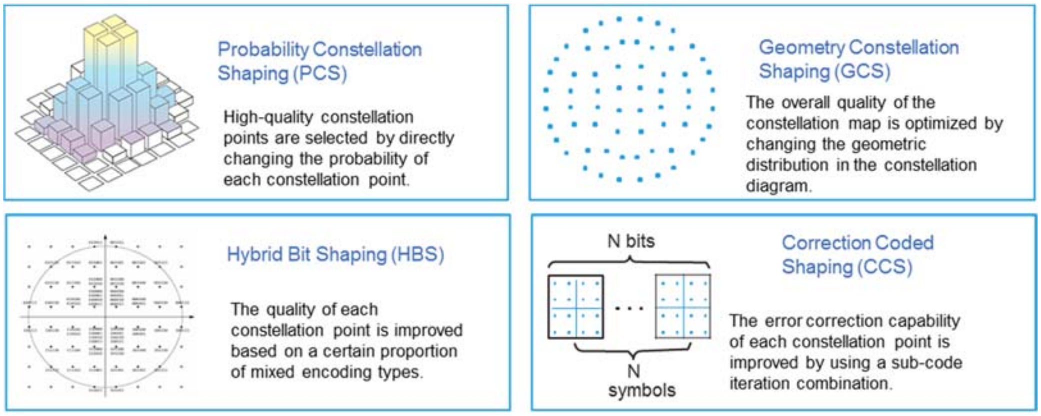


CMS detects the transmission of a channel and sets up a model of the channel in real time. Then, at the transmit end, the signals are compressed and shaped to match the channel model. At the receive end, the signals are compensated for and corrected to recover the data. The shaping, compression, compensation, and error correction algorithms are based on the real channel damage model and are automatically optimized by the built-in algorithm to achieve real-time dynamic self-optimization of transmission links. In addition, by quickly iterating the channel model parameters, CMS can improve the accuracy of the channel model and achieve better channel matching. The entire optimization process is automatically completed by the oDSP chip.

Specifically, CMS includes the following key technologies that deal with system costs from three aspects:

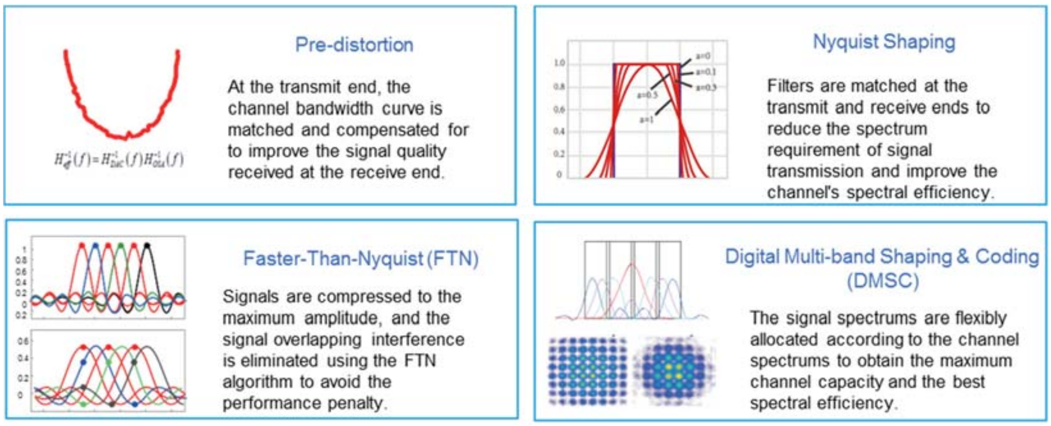
- Constellation shaping: compensating for noise penalties

  On real transmission links, the system noise penalty is mainly introduced by components, such as the transmitter, optical amplifier, driver, and nonlinearities in fiber. It is difficult to measure the noise accurately and the noise level can change, especially when components get old or when the optical power is changed. In the constellation diagram, high-quality constellation points are selected to mitigate the impact of noise. The key technologies are as follows.



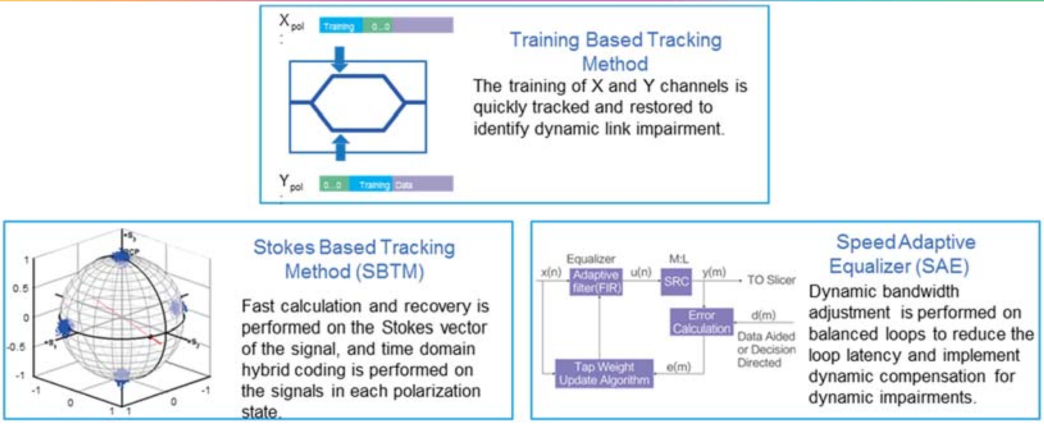
- Spectrum shaping: compensating for channel bandwidth penalties

  A channel bandwidth penalty refers to the transmission cost caused by severe signal attenuation. This is caused by a mismatch between the transmission signal and the physical bandwidth of a component, such as a modulator, filter, AD/DA, or receiver, in a transmission channel. Multiple spectrum shaping technologies are used to compensate for the impairment caused by the channel, mitigating the impact. The key technologies are as follows.



- Dynamic distortion shaping (DDS): compensating for dynamic interference penalties

  Real networks contain a lot of uncertainties. Optical fibers get damaged, components get old and start experiencing more faults, and weather conditions can also have a negative impact. Together, these can result in unpredictable distortions, such as signal phase and polarization made to transmission channels. Based on DDS, the algorithm matches the actual transmission channel in real time and quickly traces and compensates for the channel change, minimizing the penalty for dynamic interference and improving the reliability of the entire system. The key technologies are as follows.



Using multiple technologies, CMS quickly adjusts the optimal configuration to match the actual channel, solving the problems that negatively affect the transmission distance of high-rate optical signals. In addition, because the transmission settings can be adjusted in real time, the optical signals that use CMS technology can flexibly adapt to different deployments in various network environments. This reduces difficulties in network deployment and O&M, and improves system reliability.

2.1.3 CMS Highlights

- Better transmission performance on the live network, ensuring transmission capacity and distance

  CMS leverages combinations of technologies and a flexible adjustment mechanism. By automatically setting up and optimizing a real network model, CMS can quickly find the optimal configuration that matches the channel and ensure that the transmission capacity and transmission distance meet requirements.

- Improved system reliability

  CMS can detect changes in channel status (such as component deterioration, fiber stress change, and non-linear effects) and dynamically adjust the algorithm optimization policy within a certain range to ensure optimal performance.

- Simplified deployment and O&M

  CMS can automatically match the actual channel and quickly converge to the optimal configuration by quickly iterating the model parameters. This reduces the complexity of manual deployment, O&M, and configuration.

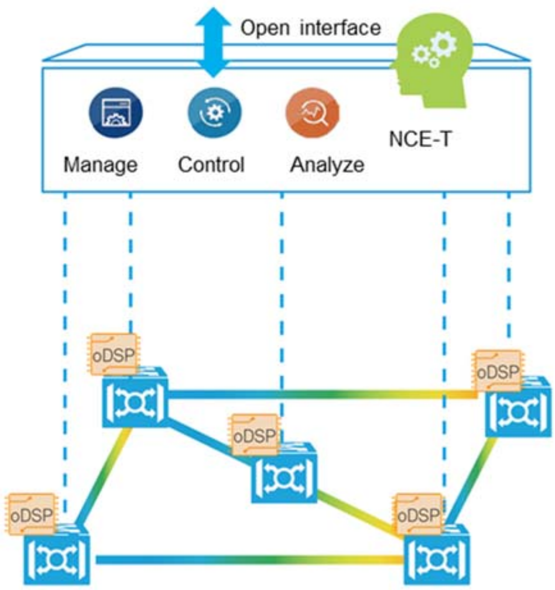
- Compatibility with legacy and new networks

  CMS supports flexible grids and supports smooth upgrades of legacy networks with 50 GHz channel spacing.

2.2 Core Technology 2: Optical-Layer AI Neurons

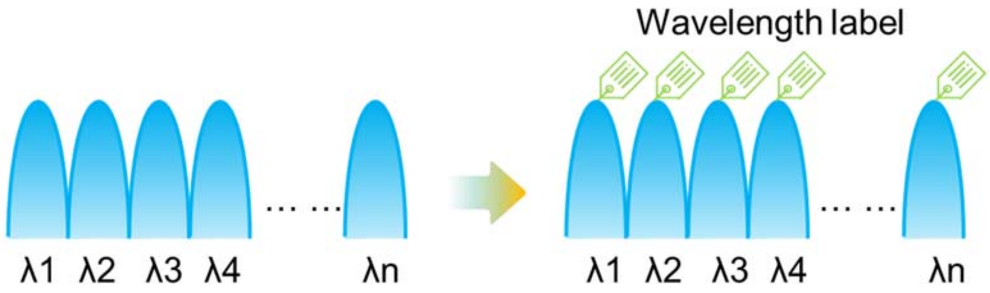
2.2.1 Why Optical-Layer AI Neurons

AI is a key technology for enabling network intelligence. Massive and accurate optical-layer network status parameters are basis for the commercial use of artificial intelligence. The oDSP is widely distributed on each node of the network and has certain analysis capabilities. The oDSP integrates the optical-layer AI neuron function module to fully cover the optical layer in distributed mode without having to transform network devices (function modules are embedded and no extra devices are required). This allows the module to accurately detect all optical-layer network status parameters in real time for AI analysis and calculation at the control layer and enables carriers to pre-warn, schedule, configure, and optimize network faults in a regional or global manner.



2.2.2 About Optical-Layer AI Neurons

The optical-layer AI neurons are a functional module integrated into the latest generation of Huawei oDSPs (also integrated into all OA nodes) to sense the running status parameters of all wavelength channels at the L0 optical layer. Unlike other solutions in the market, optical-layer AI neurons are completely integrated into network devices and modules, and no additional devices are required. The functional principles are as follows: At the transmit end, the oDSP loads optical-layer labels to all wavelength channels. When the wavelength passes through any node that has the detection function in the network, the label of the wavelength channel is extracted, and a series of optical-layer states are digitalized, thereby achieving the visualized management and control of optical-layer networks.



The optical-layer AI neurons are only limited to sensing optical signal transmission status parameters at the L0 layer, and are used as a basis for overall optical network optimization, which specifically includes the following status information:

- Optical signal-to-noise ratio (OSNR)
- Dispersion
- Polarization state
- Polarization change
- Non-linear effect
- Link margin
- Filtering

2.2.3 Benefits of Optical-Layer AI Neurons

- Visualized management and control of optical-layer wavelengths

  The oDSP adds labels to all wavelengths so that wavelengths on the entire network can be traced to implement transparent and visualized management and control at the optical layer.

- Embedded functional modules to facilitate deployment

  The optical-layer AI neurons are integrated into network devices and can be deployed in a distributed manner on the entire network without additional components. In this way, the optical-layer running status of each node can be accurately located and sensed.

- Support for AI applications and evolution to the Intent-Driven Network (IDN)

  Based on the optical-layer AI neurons, all status parameters of the optical-layer network are sensed, and the AI optimization algorithm at the control layer is used to implement intelligent network management and control, and support smooth evolution to the future IDN. A typical application is the early warning of network risks. Based on the massive optical-layer network status parameters fed back by the oDSP, the AI system establishes a digital model for the optical network, and determines a running mode of the specific network by using the autonomous learning function. If a parameter changes abnormally, even if the service is not interrupted, the AI system detects the potential risks, determines the abnormal parameter type, and accurately isolates the abnormal device to achieve early warning. Based on this, O&M personnel can determine whether to perform maintenance in advance or arrange subsequent network maintenance plans. In addition, other possible applications include dynamic network performance optimization and dynamic allocation of optical-layer resources.

3 Huawei's High-Speed Coherent Transmission Solution for Beyond 100G

To better support various applications beyond 100G, Huawei extends its technical roadmap in the oDSP algorithm, and launches two features in the latest generation oDSP series to handle high-performance and low-power consumption scenarios, respectively.

3.1 High Performance

- Flexible adjustment of rates ranging from 100G to 600G, and the channel spacing ranging from 50 GHz to 75GHz
- New CMS algorithm that improves transmission performance by 30% to 60% compared with the previous chip
- Embedded optical-layer AI neurons
- TSMC 16nm FinFET manufacturing technique
- Module form: 4x5 miniaturized MSA
- Application scenarios:
  - 100G/200G ultra-long haul backbone networks (supporting transmission over 3000 km, such as backbone networks and submarine cable applications)
  - Interconnection scenarios with 400G to 600G (supporting 80 km to 500 km transmission, such as data center interconnections and metro networks)
  - Complex mesh network topologies
  - Networks whose traffic direction is difficult to predict, and the optical-layer topology needs to be reconstructed frequently (for example, WSON)
  - Networks where the deployment environment is poor and a large margin is needed

3.1.1 Low Power Consumption

- Adjustable 100G/200G rates
- Compact chip design with ultra-low power consumption (0.1 W/Gbit)
- New CMS algorithm that especially optimizes 50 GHz channel spacing transmission, while supporting 200G transmission over 1600 km to facilitate smooth upgrade and capacity expansion of 50 GHz channel spacing on the live network
- Embedded optical-layer AI neurons

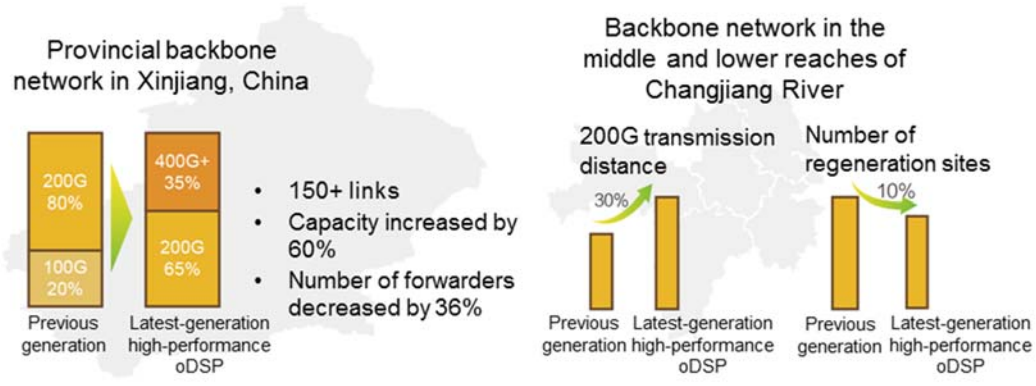
- TSMC 16nm FinFET manufacturing technique
- Module form: CFP-DCO
- Application scenarios:
  - Metro scenarios with low power consumption and high integration
  - Existing networks to be upgraded and expanded based on a fixed spacing of 50 GHz
  - Other scenarios requiring low power consumption and pluggable optical modules

3.2 Case Analysis

3.2.1 Case 1: High Performance Reduces Network Construction Costs

The high-performance oDSP can help customers obtain a larger transmission capacity and lower per-bit cost. On the one hand, Huawei's high-performance oDSP supports flexible rates ranging from 100 Gbit/s to 600 Gbit/s. Customers can select the most appropriate line rate based on the actual channel conditions. Therefore, a larger transmission capacity or lower per-bit cost is obtained. On the other hand, thanks to the latest CMS algorithm, the performance of the latest generation high-performance oDSP is improved by 50% to 100% compared with that of the previous generation. In this way, more links can be upgraded to 200G or even greater for the regional backbone network while the number of regeneration sites and the network construction cost are reduced.

One example is the provincial backbone network in Xinjiang, China. There are over 150 links in total. Compared with the previous 8013 chip (or compared with the previous 100G/200G system), the latest generation high-performance oDSP increases the link coverage rate of over 200G from 78.8% to 100%. 35.2% of the links can be further increased to 400G, while the capacity can be increased by 60% and the number of forwarders can be decreased by 36.5%.

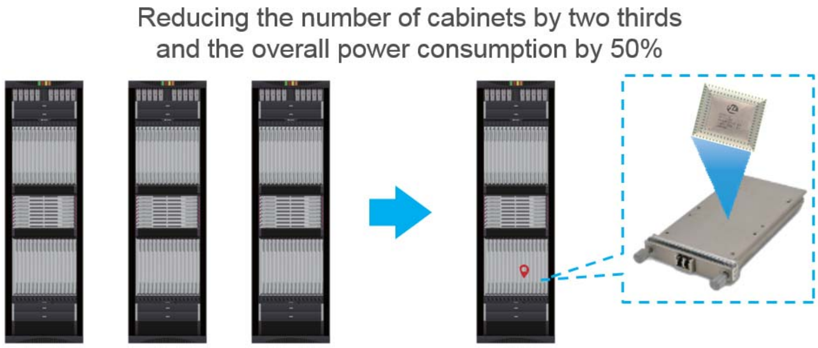


Even for long-haul backbone networks that have high performance requirements and cannot reliably use higher-order modulation (higher than 200G), Huawei's latest high-performance oDSP CMS algorithm can still help customers reduce the number of regeneration sites. The backbone network in the middle and lower reaches of Changjiang River is another example. Thanks to the CMS algorithm, the transmission distance is improved by over 30%. The number of regeneration sites on the live network is reduced by 10%, greatly reducing the network construction cost.

3.2.2 Case 2: Low Power Consumption Reduces OPEX

With the continuous growth of network traffic, power consumption has become another challenge for carriers. Huawei's new-generation power efficient oDSP provides in-depth optimization for pluggable modules. It not only supports high-performance 100G/200G transmission, but also supports 50 GHz channel spacing, making it perfectly compatible with traditional networks.

Huawei's high-performance 200G CFP modules use the new-generation power efficient oDSP and the most advanced silicon photonics technology. The modules not only improve the performance of 200G transmission, it also greatly reduces power consumption, relieves board heat dissipation, and upgrades the board capability from 2x200G to 5x200G, increasing the board capacity by 2.5 times, and reducing the per-bit power consumption by 60%.



Take a typical site where three cabinets (OSN 9800 U32) are deployed as an example. Based on the per-slot capability of 400G, the capacity of each cabinet is 10T, and that of the entire site is 30T. If the CFP modules empowered by the new-generation power efficient oDSP are used, one cabinet can have a capacity 30T, reducing the number of cabinets by two thirds and the overall power consumption by 50%. Each year, the power consumption of the site can be reduced by 100,000 kWh. In addition, the equipment room space is saved and heat dissipation pressure is relieved, thereby reducing maintenance costs.

3.2.3 Case 3: Adaptive Algorithm Helps Improve System Reliability

In a coherent optical transmission system, phase modulation is used, and the receive end must continuously trace the phase of the signal to ensure that the demodulated phase information is correct. However, in some extreme environments, the live-network signals are negatively impacted. In this case, whether the signal phase can be effectively traced is a key indicator for measuring the oDSP capability and transmission system performance.

Huawei has deployed over three hundred 100G coherent networks around the world and have encountered such extreme scenarios. For example, in the wilderness of northern Asia, the optical fiber of a carrier is routed overhead along the railway. Whenever a train passes over the railway, the signal phase changes sharply in the optical fiber, which is often hundreds of times that in a normal situation. Another example is that in a tropical country, frequent thunderstorms often cause bit errors on the link, because the ionization effect of lightning causes the state of polarization (SOP) of the signals in the optical fiber to change at a very fast speed. As a result, the signals of the receive section are unlocked.

To deal with various extreme conditions, Huawei has established a dedicated reliability lab to simulate extreme conditions, such as lightning strikes, to ensure that the new design meets the requirements of various adverse conditions. In the new generation oDSP CMS algorithm, the compensation and tracking capabilities of related algorithms are enhanced based on the possible abnormal impact of the channel. Taking the speed of tracking the signal polarization status of a 200G 16QAM signal as an example, the SOP capability of Huawei's new-generation oDSP has been improved by 100% compared with the last design. It helps to provide a more reliable system and migrate almost all the impact, like vibration and bad weather, in real environments.

4 Outlook: Has the Limit Been Reached?

History of optical network development:

- It takes only about seven years for the single wavelength to develop from 100G to an ultra-high-speed transmission rate of 600G.
- The 200G transmission performance of a single wavelength has increased by about 50% over a two year period.
- The power consumption of 100G transmission in a single wavelength has decreased by at least 50% in two years.

Huawei believes that the transmission limit of optical fibers is still far away. Especially in real networks, the capacity, distance, and power consumption have great potentials. As a key factor, the oDSP algorithm still needs substantial improvements. In the future, Huawei will use more advanced chip manufacturing techniques and continuously optimize the CMS algorithm to further improve the transmission capability of real networks and reduce the power consumption of transmission links. In addition, many advanced technologies based on the oDSP algorithm have yet to be fully developed. For example, hitless rate adjustment, dynamic bandwidth adjustment, and chip-level AI functions. In the future, oDSP will become an important part of the intent-driven network or intelligent optical network. Also, oDSP will play an increasingly important role in the optical network system and become one of the most critical core capabilities of optical network vendors.