88-Channel 8-Degree Optical Cross-Connect System

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1. Introduction

Wavelength division multiplexing (WDM) transmission systems for metro and core networks must allow for higher-capacity communications at higher speed with greater reliability. However, it is also necessary to reduce the ever-increasing capital expenditure/operating expenditure (CAPEX/OPEX) of networks, and to improve network efficiency. An optimal solution to such demand is a multi-degree optical cross-connect system, which allows for high-capacity WDM transmission and supports optical switching. To use this type of system in practice, both multi-degree technology and mesh network management technology are necessary. Using these technologies, Mitsubishi Electric Corporation recently developed a highly extensible 88-channel 8-degree optical cross-connect (OXC) system for metro and core networks.

2. Multi-degree Technology

Conventionally, the use of ring/linear topologies has been the mainstream for metro and core networks. When establishing communication channels in two or more directions, these topologies require the installation of multiple units of WDM equipment in one station building, which makes it harder to secure the requisite equipment space and power supply. Accordingly, there is a trend toward the use of a mesh topology using a multi-degree optical cross-connect system (Fig. 1).

Such multi-degree communication requires wavelength cross-connect technology, which allows the wavelength and direction settings to be remotely changed without affecting existing optical signals. Furthermore, for practical use, it is indispensable to use an ultra-long-haul, high-capacity transmission technology that allows for flexible telecommunication across any route.

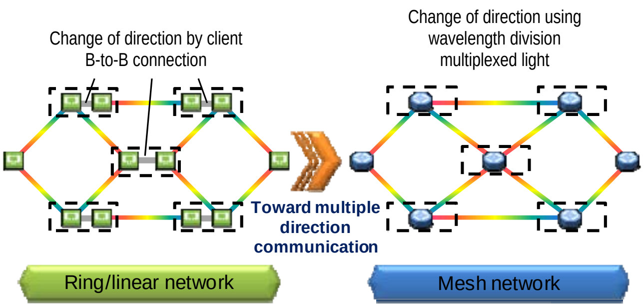

Fig. 1 Migration of the network topology

2.1 Wavelength cross-connect technology

The wavelength cross-connect technology switches to wavelengths in any direction and grouped wavelengths that are in different directions or that are multiplexed/demultiplexed at the station itself.

We have developed an economical wavelength cross-connect technology capable of adding/removing a channel in each direction, using a compact wavelength selective switch (WSS). Figures 2 and 3 show an exterior view and a functional schematic view of the equipment, respectively. The wavelength cross-connect technology is represented by the wavelength cross-connect (WXC) function part equipped with the above WSS. Mesh switching is enabled via multiple WXC function parts, each of which operates in a different direction and is connected using an optical fiber to the equipment inside it.

A configuration like this allows for remote switching of directions, without affecting the quality of signals in directions other than those involved in the switching. This contributes to flexible network building. The key device, the WSS, uses liquid crystal on silicon (LCoS) elements, which can also be used for future flexible-grid switches.

In addition to the wavelength cross-connect technology, we have developed the CDC (colorless, directionless, and contentionless) function, which enables a network to be built flexibly. Conventionally, fibers are reconfigured manually in order to switch the wavelength or direction each time a path is built. The CDC function allows all wavelengths and directions to be switched freely and remotely by simply connecting a fiber to a given port in advance. The MUX/DEMUX function

Fig. 2 Exterior view of the equipment

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parts and MSW function part, which make the CDC function work, are configured to be functionally independent from each other, thereby enhancing the wavelength/directional independence. This configuration has made it possible to suppress physical wavelength interference to secure flexibility, and to prevent the signals affecting other directions when a wavelength/direction is added or removed, or when any failure occurs.

2.2 Ultra-long-haul and high-capacity transmission technology

In a mesh network, there exist multiple channels for an optical signal from its starting point to its end point. If the transmission performance is poor, 3R regeneration that involves photoelectric conversion is necessary, which lessens the advantage of a mesh network: flexible routing. In particular, when a 100 Gbps or faster signal is transmitted using WDM, there is an issue regarding compensation for the narrowing of an optical signal's bandwidth resulting from multistage relaying at OXC nodes on the route, as well as optical signal degradation as a result of a reduction in the optical signal-to-noise ratio (OSNR). We have developed spectral shaping technology for optical signals and forward error correction technology, enabling ultra-long-haul, high-capacity transmission to be put into practical use.

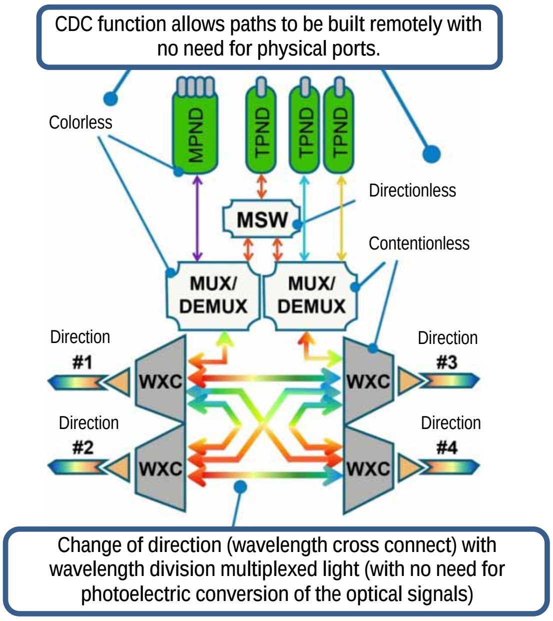
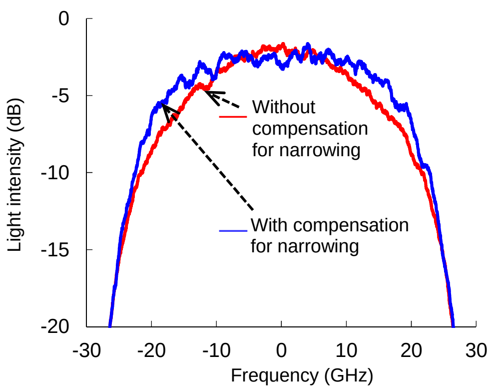


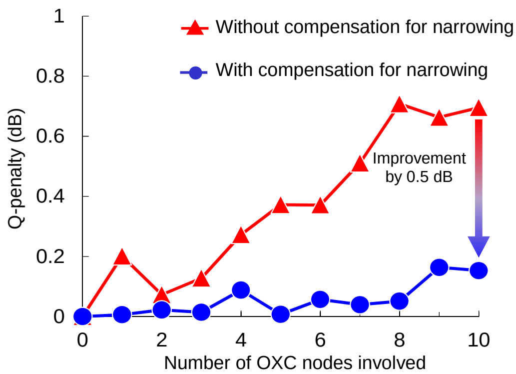
Fig. 3 Wavelength cross-connect configuration

The spectral shaping technology was used to suppress the optical signal degradation caused by the narrowing of an optical signal's bandwidth. By applying pre-emphasis to the high-frequency components of the optical signal using an electrical filter within the transmitter, the spectral narrowing at an OXC node is compensated.[1] Figure 4 shows the difference in the transmission performance during multistage relay with and without compensation for the narrowing. The Q-penalty (Q is a signal quality parameter) was calculated with and without compensation for the narrowing when a DP-QPSK (dual polarization-quadrature shift keying) signal was transmitted through multiple relay stages at a transmission speed of 128 Gbps. The frequency interval of the OXC-node WSS passband was set to 50 GHz. Figure 4(a) shows the effect on the optical spectrum of the waveform. Figure 4(b) shows that as the number of OXC nodes that a signal passes increases, the effect of compensation for the narrowing becomes more evident. When the number of nodes involved is 10, the Q-penalty is expected to be improved by 0.5 dB or more.

We also used the error correction technology with a view to receiving optical signals at a low OSNR. We developed a soft-decision, low-density parity-check code using a multi-spatial combination method. This code is combined with a hard-decision code to form a concatenated forward error correction (FEC) system which achieves high correction performance with a coding gain of 12 dB.[2]



(a) Optical spectrum of the waveform



(b) Q-penalty

Fig. 4 Transmission performance when transmitting a signal through multiple OXC nodes

3. Mesh Network Management Technology

In a conventional ring topology, reliability is ensured by a redundant architecture to provide 1+1 protection. Furthermore, a network management system (NMS), which monitors and controls a network including the equipment, etc., has been a suitable distributed monitoring system for networks that are each independent rings. On the other hand, in a mesh topology in which multiple routes can be configured, services can continue to be provided without a break even if multiple problems occur in the network by using multi-route redundancy. As seamless connections make networks more complex, however, a layer management technique is becoming important to ease the burden of maintenance work.

3.1 Multi-route redundancy

By combining the wavelength restoration technology for sharing backup route resources with the 1+1 protection technology, we have introduced multi-route redundancy to balance reliability and economy.

3.1.1 Wavelength restoration technology

The multi-route redundancy technology supports advance reservation of wavelength resources for restoration as part of the wavelength restoration functions. In the case of advance reservation restoration, a bypass route and bypass wavelength are registered in the NMS in advance for the optical path on the current route. When a failure occurs, the backup optical path is activated on the registered bypass route, and the failed route is switched to the backup path. Thus, by registering optical paths on multiple backup routes for the optical path on the current route, signals can be restored even when there are multiple concurrent problems. In addition, the wavelength restoration function that reserves wavelength resources for restoration signals the failure of the optical path on the route in use, and sets up a reserve optical path. This allows for resource sharing on backup routes for the optical paths on multiple routes in current use, thus improving the efficiency of wavelength resource usage.

3.1.2 3-route protection technology

In addition, we have effected 3-route protection by combining 1+1 protection with advance reservation wavelength restoration. Figure 5 shows a route diagram for 3-route optical path protection. For each optical path on the route in current use and each optical path on the backup route for 1+1 protection, multiple bypass routes are registered in advance in the NMS. If a problem occurs in the optical path on the route in current use or the optical path on the backup route, the 1+1 protection automatically switches the failed optical path. The wavelength restoration function then sets up a preregistered bypass route as a new backup-route optical path. This makes it possible to constantly maintain 1+1 protection even when multiple failures occur concurrently.

3.2 Layer management technology

In a ring network, the NMS monitors each ring as an independent network in a distributed manner. In a mesh network, on the other hand, there is no connection gap within a network, which requires seamless monitoring even when the number of devices in the network increases. Given this, we have divided the NMS into two functional parts: the main server in charge of network management and the sub-server in charge of device management. Figure 6 shows the NMS server configuration. This configuration allows the number of sub-servers to be increased as the number of devices in the network increases. As a result, seamless network management can be performed by the main server, achieving large-scale monitoring in a mesh network.

Moreover, as management networks become more complex, it is vital to reduce the operators' workload. We launched the development of an NMS client pursuing the concept of a user-friendly GUI (graphical user interface), which enables intuitive operation of the network by the operators. The equipment in a network and the optical paths passing through the network can be centrally controlled on the network management screen, which is one of the main displays. This centralized operation has been implemented by making

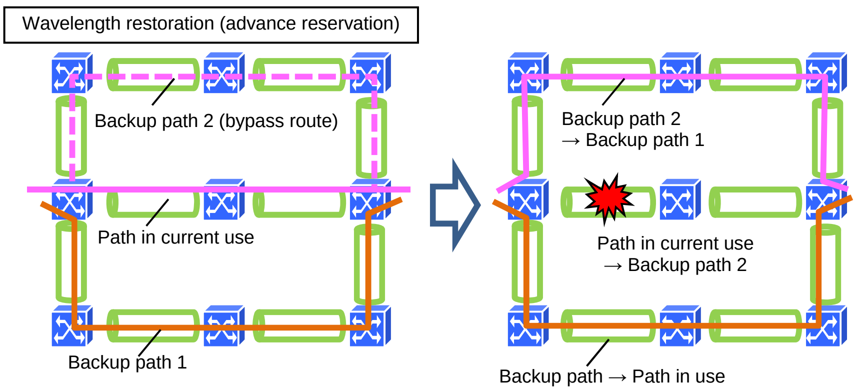


Fig. 5 Overview of the 3-route protection

the NMS perform not only network management but also equipment control handled for it by an EMS (equipment management system).

4. Future Technologies

In order to achieve high-speed, high-capacity transmission at speeds of 400 Gbps or 1 Tbps, we are developing a signal transmission technique using DP-16QAM modulation and multi-subcarrier transmission technology.(3) In addition, we are pursuing an OXC system with higher efficiency to enable a network to accommodate a larger number of routes. This system comes with a path computation element (PCE)(4) function that can derive the optimum combination of modulation format and wavelength grid, and can calculate the optimum optical paths taking the required bandwidths and transmission distances into consideration.

In the future, we will improve the management interface to higher-order devices to achieve integrated monitoring and control of transport network layers including integration packs that use orchestrator functions. Furthermore, discussions are underway on subjects such as online PCE functions to make optimal failure recovery possible over multiple layers of layer-integrated networks, transport SDN usage cases, and interconnection.(5)

5. Conclusion

In this article, we have described the technologies we have developed for wavelength cross-connect and ultra-long-haul, high-capacity transmission to put multi-degree technology into practice for 88-channel 8-degree OXC systems, as well as those for the multi-route redundancy and layer management that constitute the mesh network management technology. It is our hope that these technologies will improve the speed, capacity, and reliability of current metro and core networks, and help reduce CAPEX/OPEX.

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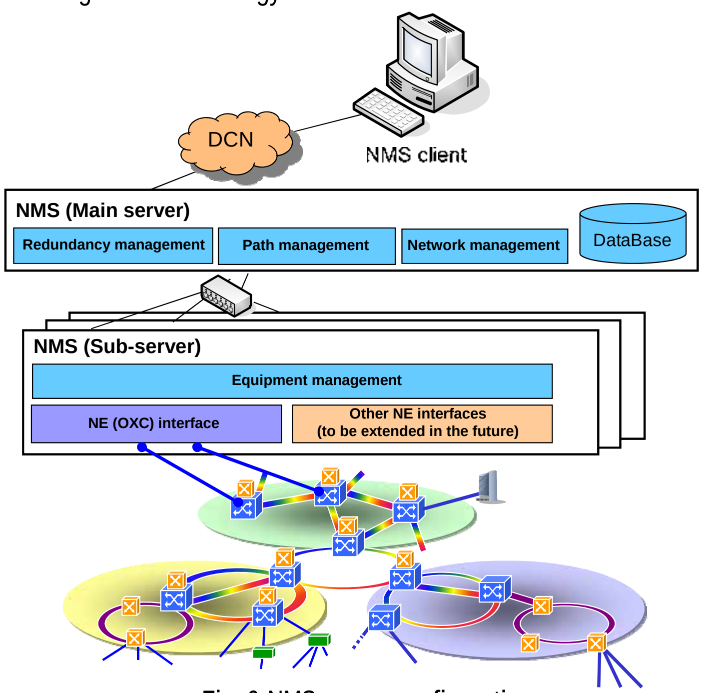

Fig. 6 NMS server configuration