Optical Path Restoration Method for Mesh Networks

Authors: *Noriaki Nakamura** and *Sota Yoshida***

1. Introduction

Internet connection lines and mobile devices are increasingly using broadband channels, causing traffic volumes to surge. For optical access, there is the 10 Gigabit Ethernet Passive Optical Network (10G-EPON) which provides high-speed lines at reasonable prices. For mobile devices, the spread of high-speed communication services (e.g., Long Term Evolution (LTE)) and 5G services may increase the capacity in the future. Recently, with the spread of social networking services (SNSs), most users collect information for daily life via the Internet, making communication services essential for modern life and society.[2] A failure in the optical transmission networks that underpin such services would greatly affect society, and so there is increasing demand to make such networks more reliable. Accordingly, optical cross-connect systems that can establish mesh networks with multiple routes that can be used as restoration routes in case of failure have been introduced.

Mitsubishi Electric Corporation has developed an optical cross-connect system with the following functions:[1] a colorless, directionless, and contentionless (CDC) function for which the independence of wavelengths and directions is high and that is suitable for establishing flexible mesh networks; a supervisory function; and a pre-planned restoration (optical path restoration) function that switches signals to predetermined restoration routes when a failure occurs.

In recent years, the scale of mesh networks has been expanded to cope with the expected growth in communication traffic. This has driven demand for economic optical path restoration technologies to cope with simultaneous failures at multiple points due to a natural disaster or other reasons and an unexpected failure over a wide area. To satisfy such needs, Mitsubishi Electric has additionally developed optical cross-connect systems. The new system has a PCE function that automatically designs an optimum restoration route from complicated routes in a large-scale network and a dynamic restoration function for switching signals to restoration routes calculated based on the resource status when a failure occurs.

This paper describes the advantages of the CDC, supervisory, and pre-planned restoration functions of Mitsubishi Electric's conventional optical cross-connect system in Section 2, and the additionally developed PCE and dynamic restoration functions in Section 3.

2. Mitsubishi Electric's Optical Cross-connect System

For optical transmission networks, mesh networks are increasingly being used instead of conventional ring/linear networks. To realize highly reliable optical cross-connect systems suitable for mesh networks, the following functions are essential: a CDC function that can change the settings of wavelengths and directions remotely without affecting the existing optical signals; a highly resilient supervisory function; and a pre-planned restoration function for switching signals to predetermined restoration routes through remote control when a failure occurs.

2.1 CDC function

The CDC function enables optical path switching without affecting the existing optical signals. Conventionally, every time an optical path is established, the fibers are manually reconnected and the wavelengths and directions are changed. In contrast, the CDC function can be realized by connecting a fiber to a port in advance, and allowing all wavelengths and directions to be freely switched remotely. In addition, the optical multiplex/de-multiplex (MUX/DEMUX) function section and mesh-switch (MSW) function section, which form the CDC function, are configured as shown in Fig. 1 such that each function is physically independent. This configuration increases the independence of wavelengths and directions and can reduce physical wavelength interference. These advantages realize a highly reliable system that can reduce the influence of main signals on other directions when wavelengths and directions are expanded or reduced or when a failure occurs.

2.2 Supervisory function

One task in mesh networks is to ensure network management that can continue supervision even when multiple failures occur. We have developed such a supervisory technology for mesh networks. As shown in Fig. 2, out-band communications that use the external lines of the devices are combined with in-band communications that use free communication domains between the devices, and each device broadcasts in the configuration. For the out-band communications of the

*Communication Networks Center **Information Technology R&D Center

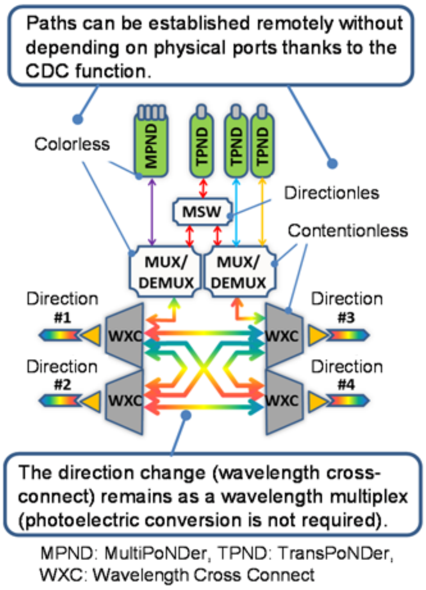

Fig. 1 Structure of CDC function

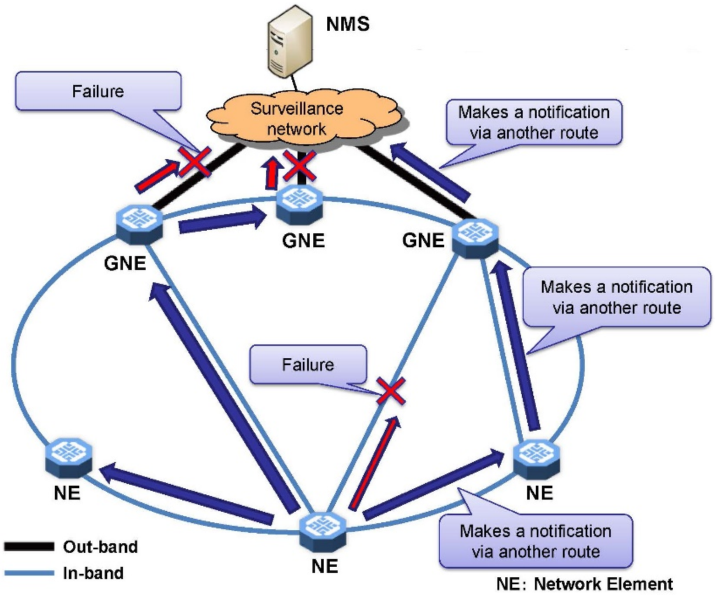

Fig. 2 Mesh supervisory network

devices, three gateway network elements (GNEs) are installed for each arbitrarily definable sub-network and notifications are sent to the NMS via the three routes in the configuration. For the in-band communications, the devices broadcast the same message to each route and the receiving side deletes redundant notifications, which makes the channel redundant configuration robust. This configuration enables continuously controllable supervision without affecting the supervision of optical signals even when multiple failures occur.[3)]

2. 3 Pre-planned restoration function

Figure 3 illustrates the pre-planned restoration function. In the pre-planned type, circuitous routes and wavelengths (pre-planned restoration paths) that will replace the working paths are registered to the NMS in advance; when a failure occurs, the registered spare pre-planned restoration path is established to replace the working path. By registering multiple pre-planned restoration paths for working paths, signals can be restored even if multiple failures occur.[4)] After a failure on a working path is detected, signaling is performed to set the pre-planned restoration path and thereby the resources of the pre-planned restoration paths can be shared between multiple working paths. This makes it possible to effectively use the wavelength resources and allows re-shaping, re-timing, and re-generation (3R). Resource sharing is allowed only when working paths do not pass the same link. This requirement makes restoration from a single failure possible without exception.

3. Optical path Restoration for Large-scale Mesh Networks

In large-scale mesh networks, since many redundant routes can be established, it is important to calculate economic and highly reliable restoration routes and realize optical path restoration that allows the services to be continued even when multiple failures occur.

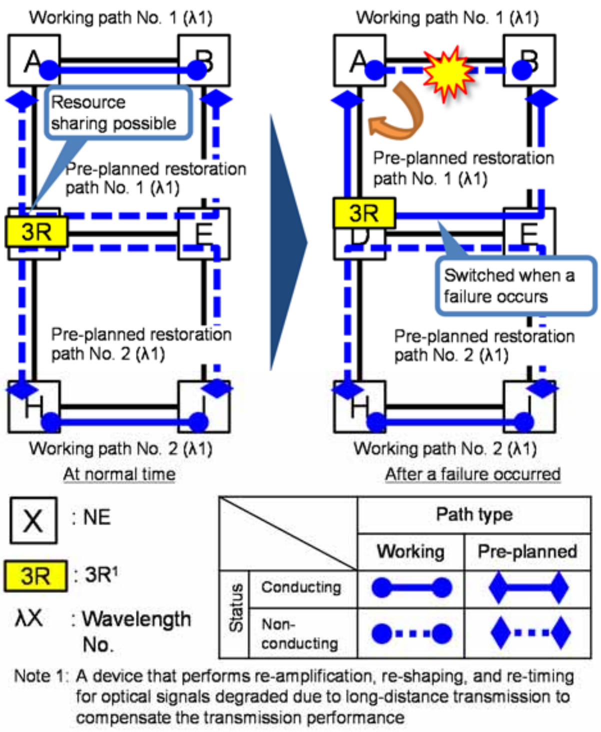

Fig. 3 Pre-planned restoration function

3.1 PCE function

Since a large-scale mesh network has innumerable route patterns from the starting point of optical signals to the end point, it is difficult to select an economic and highly reliable optical path. In the pre-planned restoration method, in particular, the resources of pre-planned restoration paths can be shared between multiple working paths. Therefore, technologies are needed to automatically calculate an optical path group to improve the resource efficiency. We have developed a PCE function[5)] that calculates an optical path group that satisfies the route search requirements entered by operators and that can minimize the allocation of wavelength resources and 3R.

Figure 4 shows the flow of route search by the PCE function when optical paths are added to an existing mesh network in designing. Network information (e.g., node-element (NE) layout, optical transmission section (OTS) link connection, and existing path information) and transmission line information (e.g., transmission distance and transmission loss parameter) obtained from the NMS are sent to the PCE. The PCE calculates the optical signal to noise ratio (OSNR) based on the route search requirements (e.g., path type, passing nodes/links, and number of pre-planned restoration paths) entered by the operator and transmission line information. If the transmission performance needs to be compensated, the PCE function automatically designs passing routes and the layout of 3R such that the number of 3R becomes the minimum necessary in the entire mesh network and calculates the optimum optical path group. The searched optical path group is output as path design information, which makes it easier for the operator to add optical paths based on the output information.

When the working paths are completely different routes, it is possible to set to share the wavelength resources of pre-planned restoration paths and 3R as much as possible. Thanks to this, the PCE function has a route search algorithm that ensures a restoration rate of 100% at the time of a single failure and that improves the resource efficiency. In designing pre-planned restoration paths, multiple pre-planned restoration paths can be designated as search targets for a single working path, which secures multiple pre-planned restoration paths depending on the importance of a working path and enhances the resilience.

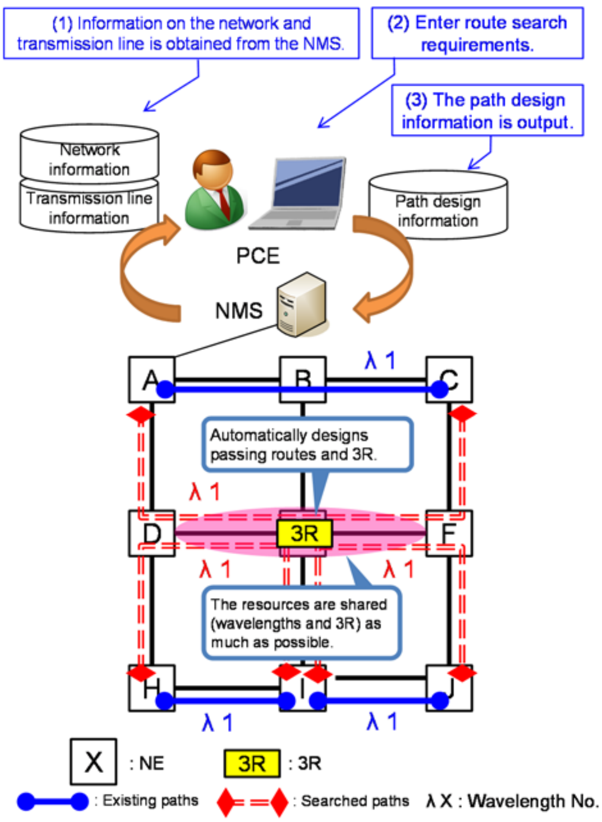

Fig. 4 Route search flow by PCE function

Furthermore, as networks are becoming more complicated, we have developed a graphical user interface (GUI) for the PCE function that operators can intuitively use. Figure 5 shows an example PCE screen. The PCE imports the network information obtained from the NMS and lists the NE layout, OTS link connection, existing path information, and other information. The imported existing paths and new paths designed by the PCE can be listed on the optical path display section. By clicking a path, its passing route can be visually checked.

3.2 Dynamic restoration function

By providing the PCE function on NMS, we have developed a dynamic restoration function. When a failure occurs, the dynamic restoration function calculates restoration routes in real time based on the latest network status and switches the signals to them. In the dynamic type, when a failure occurs the NMS calculates usable circuitous routes in real time to determine circuitous routes and wavelengths (dynamic restoration paths) and to use the circuitous routes instead of the working optical paths. As is the case with the pre-planned type, signaling is performed after a failure is detected on a working path and thereby the spare resources can be used in an efficient way. Figure 6 shows an example of dynamic restoration switching. Thanks to the combination of the dynamic type and pre-planned type, when switching to all pre-planned restoration paths fails, the NMS with the PCE function calculates a dynamic restoration path and switches signals to it. For failures that can be expected, pre-

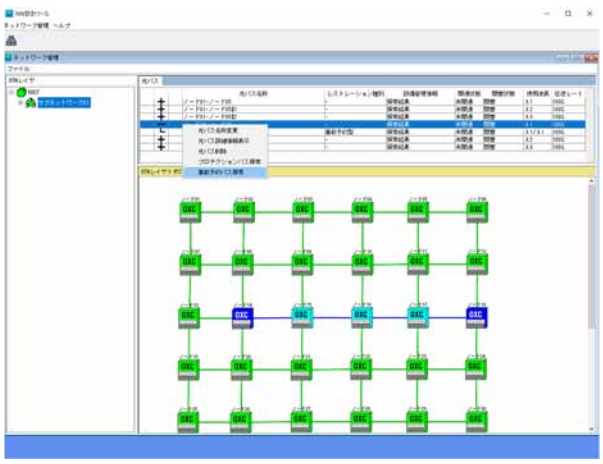

Fig. 5 Example of PCE screen

planned restoration paths are used for restoration as planned, while for unexpected large-scale failures, dynamic restoration paths are used to make it possible to maintain the continuity of optical signals.

3.2.1 Real-time route calculation technology

Figure 7 illustrates dynamic restoration switching by the PCE function. The NMS server updates the network resources (NE connect information, OTS link, wavelength resources, and 3R) in real time successively based on changes in the network topology information and notification (e.g., occurrence of a failure and restoration from a failure). When a failure occurs on the working path, the PCE function section calculates a dynamic restoration path based on the latest network resources and switches signals to the restoration path automatically. Since the NMS server manages route switching control and network resource management in a centralized way, accurate switching control to avoid conflict between the routes is possible. This function makes it possible to use available network resources effectively and allows flexible switching that can cope with unexpected large-scale failures.

In addition, the NMS server has a redundant hot standby configuration (0: ACT, 1: STANDBY), and the two servers always coordinate the data while functioning. Even if a failure occurs in one server, monitoring and control can be continued without interruption. This configuration makes it possible to continue route calculation and optical path switching even if a failure occurs on one server during wavelength restoration switching.

3.2.2 Highly reliable path switching technology based on switching priority

For such a system, multiple pre-planned restoration

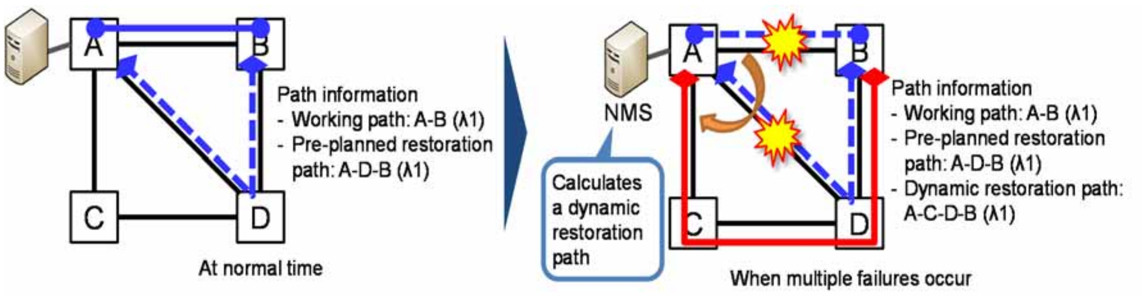

Fig. 6 Example of dynamic restoration switching

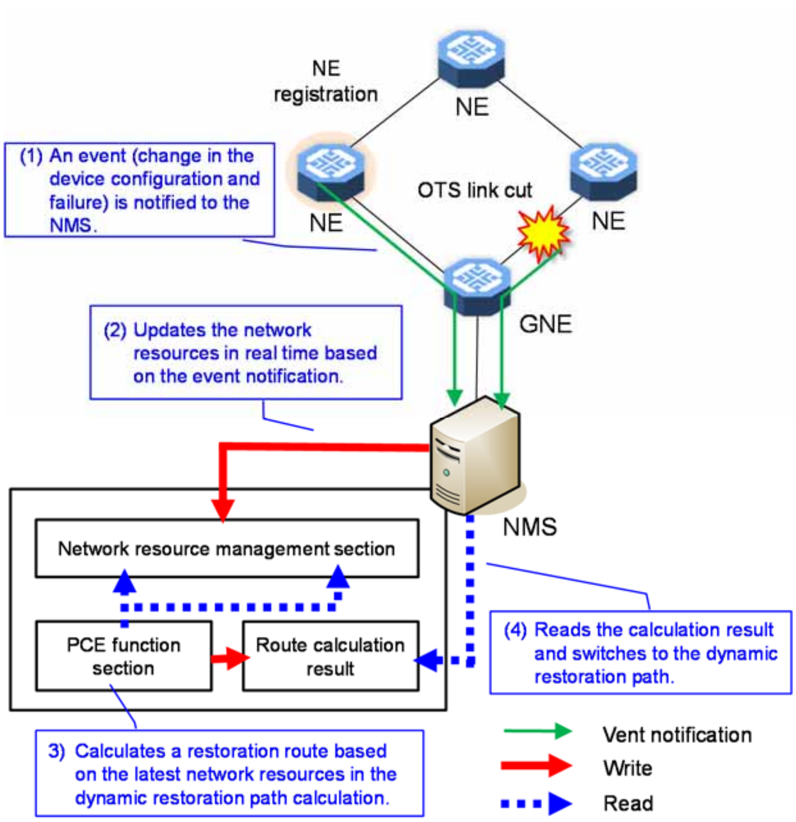

Fig. 7 Dynamic restoration switching by PCE function

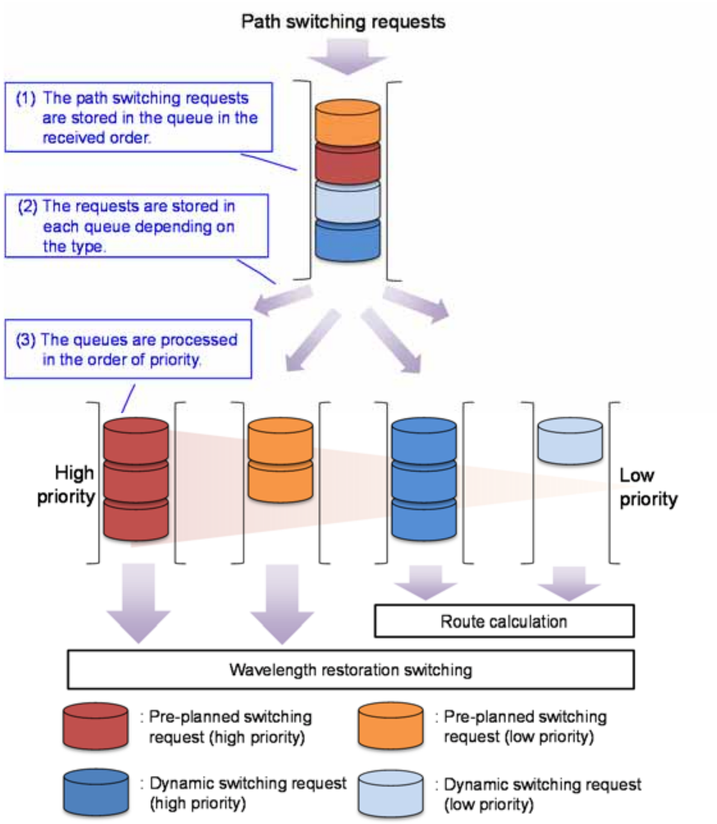

Fig. 8 Dynamic restoration switching by priority

paths and dynamic restoration paths can be set for a single working path. By determining the switching priority for each working path, the working paths can be switched according to the order of priority when wavelength restoration switching is activated. Figure 8 shows wavelength restoration switching in accordance with the switching priority. In the order of notifications received in the NMS, the path switching requests are stored in a queue and then they are stored in other queues based on the switching type (wavelength restoration type and priority). Switching is performed to the queues in the order of priority and thus, even if network resources are not sufficient, important path(s) can be preferentially restored from a failure. If switching fails due to an optical path unblocking failure or other factor, switching requests for unprocessed pre-planned restoration paths or dynamic restoration paths are sent again. This technology realizes both economic and highly reliable restoration that uses fewer resources to establish restoration routes and restoration from multiple failures due to a disaster or unexpected failure.

4. Conclusion

This paper described the PCE function for automating the designing of optimum optical paths in mesh networks and the dynamic restoration function for switching to restoration routes to be calculated in real time when a failure occurs. These technologies make it possible to establish flexible and highly reliable optical transmission networks and are also useful for business continuity planning (BCP) to prepare for the expected Nankai Trough earthquake or an earthquake located directly below a metropolitan area.

We will continue implementing new technologies in the hardware (e.g., network devices) and software including restoration operations to realize highly reliable resilient networks, thus creating safe and secure social infrastructure.

References

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