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Photonic Network Management

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The deployment of point-to-point WDM systems has just begun in core networks to accommodate the explosive growth in bandwidth demands of Internet traffic and data communications. Now that the basic technologies for wavelength division multiplexing and optical amplifiers have been established, wavelength path management is the key to full exploitation of the advantages of meshed photonic networks by improving the reliability and efficiency of networks. After describing the photonic network layer model, this paper describes photonic network management architecture and a flexible optical path management. Then, a new distributed restoration technique and a spare capacity design method are proposed. The applicability of the proposed technique is discussed based on the results of prototyping of an optical crossconnect management system.

1. Introduction

Network service providers are now planning to deploy point-to-point WDM systems to accommodate the explosive growth in bandwidth demands of IP traffic and data communications. Meshed photonic networks are also gaining wide acceptance as a vehicle for removing bottlenecks in existing networks and for accommodating IP traffic, and thus provide an infrastructure for the global-scale high-capacity networks of the future.

The advent of wavelength division multiplexing and optical amplifier technologies makes it possible to economically integrate a range of telecommunication services by accommodating different SDH, ATM, and IP signals into format and rate transparent optical paths. A mesh network consisting of Optical Crossconnect Systems has a better network architecture than a ring network since it enables extensive sharing of spare capacity when a new service is requested from the client layers and when a failure occurs in the network. Through its efficient path manipulation capabilities, combined with non-intrusive OAM capabilities, it will facilitate flexible, reliable, and economical network construction.

Unlike in SDH/ATM deployment strategies, the optical layer will create multiple virtual fibers under those client layers. Therefore, it is necessary to provide those client layers a consistent, transparent management view and to maximize the usage of virtual fibers. Optical path management involves configuring an optical path layer network which reflects the physical wavelength assignment constraints and configuring efficient wavelength routing schemes on such a network.

Network survivability has also been recognized to be a crucial concern from the point of view of reliability enhancement by network management systems. Therefore it is necessary to be able to recover a photonic layer network from various kinds of failures, for example, multiple link failures and node failures, as fast as possible.

This paper first overviews the photonic net-

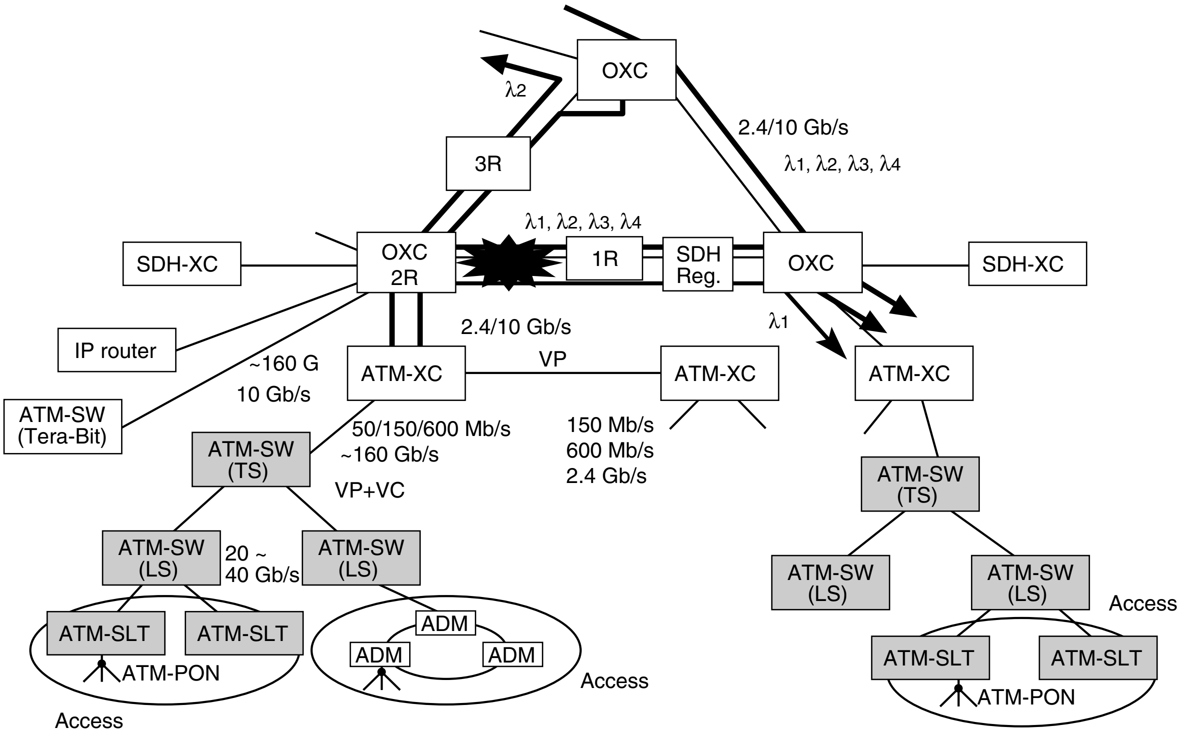


Figure 1
Configuration of photonic network.

work layer model and then focuses on the network management architecture for building a flexible and reliable network that fully exploits the capabilities inherent in photonic networks. This paper then proposes a distributed restoration algorithm and a spare capacity allocation algorithm and describes the prototyping of Optical Crossconnect Management Systems.

2. Photonic network architecture

2.1 Photonic network

Figure 1 shows an example of a photonic network which is composed of Optical Cross-Connect Systems (OXCs) that provide mesh networks. Regenerators such as 1R (Amplifier), 2R (Transponder), and 3R are used to make long-distance transmission possible. SDH regenerators may be used for client-specific regeneration.

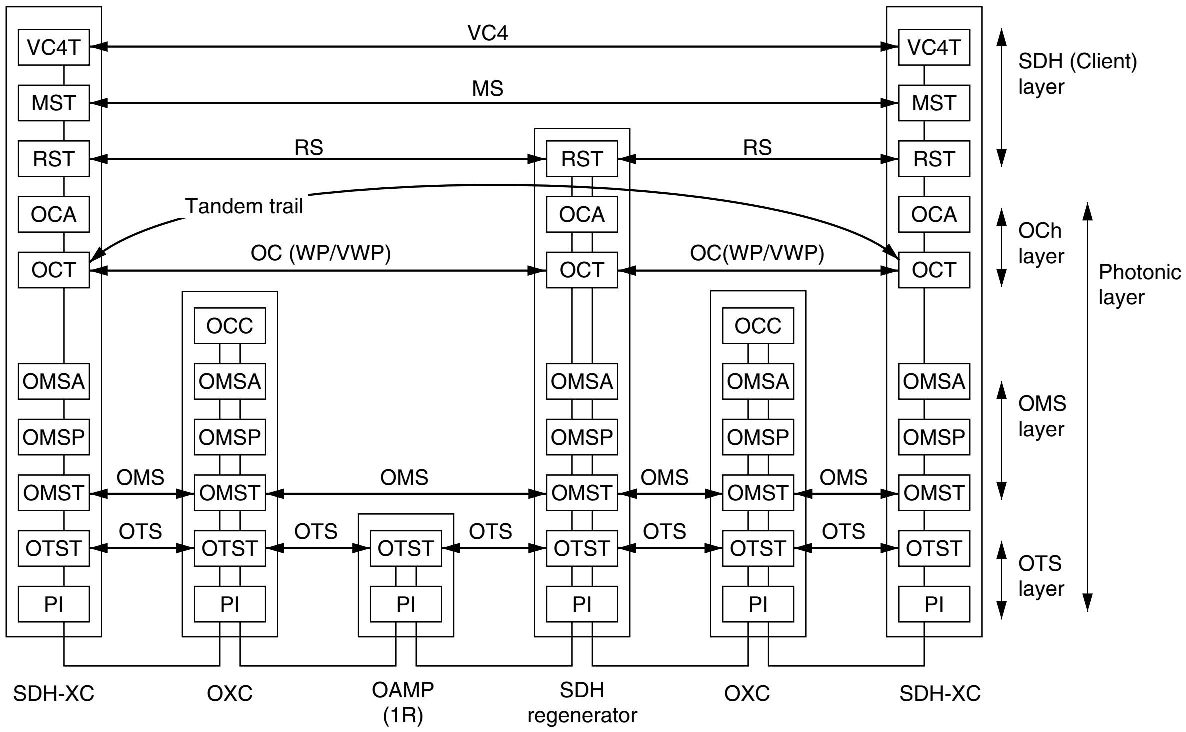
The photonic network will be introduced as the backbone network of an SDH, ATM, or IP network.

Moreover, the photonic network provides a configuration function that changes the connectivity flexibly between ATM switches and IP routers unless new fiber is laid. Therefore, the coordinator system between the photonic NMS and client NMS are important.

2.2 Photonic network layer model

The architecture model for the photonic network is shown in **Figure 2**. The photonic layer consists of three layers: the Optical Channel Layer, which manages the optical wavelength, the Optical Multiplex Section Layer, which manages the optical wavelength multiplexing and demultiplexing function, and the Optical Transmission Section Layer, which provides the capability of transmission between OXCs.

When the SONET regenerator is introduced between OXCs, if a failure occurs between the regenerator and an OXC, the failed path cannot be restored in the SDH layer and the failed path is restored in the photonic layer to find an alternative route between the OXCs. For this restoration,



SDH-XC : SDH Cross Connect
OXC : Optical Cross Connect
OAMP : Optical Amplifier
MS : Multiplex Section
RS : Regenerator Section
OC : Optical Channel
OMS : Optical Multiplex Section
OAS : Optical Amplifier Section
OCA : Optical Channel Adaptation
OCT : Optical Channel Termination
OCC : Optical Channel Connection
OMSA : Optical Multiplex Section Adaptation
OMSP : Optical Multiplex Section Protection
OMST : Optical Multiplex Section Termination
OTST : Optical Transmission Section Termination
PI : Physical Interface
RST : SDH Regenerator Section Termination
MST : SDH Multiplex Section Termination
VC4T : SDH VC4 Termination

Figure 2
Photonic network architecture.

two divided optical channel trails must be managed as one optical channel trail.

Therefore, we introduce a tandem trail which is connected to continuous optical channel trails. Also, the tandem trail conceals the regenerator location, so the graph used to search for an optical channel trail becomes smaller and the search time is reduced. With the tandem trail concept, optical paths can be handled without the need for the SDH regenerator and 3R to be aware of them, and they can be configured and rerouted as end-to-end transparent optical paths.

2.3 Photonic network management

The main problems in photonic network management are the transparent path management, wavelength allocation, and cooperation between two layers.

On the transparent path, while an optical path network can support various kinds of client signals, fault detection and performance monitoring must be independent of client signals so as to maintain a transparent network. This can be achieved by monitoring the optical power and the signal-noise ratio.

Moreover, the optical amplifier shuts down the output power when the incoming optical power is lost, so fault isolation is difficult. For example, when a link failure occurs, the adjacent node detects LOS (Loss of signal). However, the amplifier shuts down the output power and LOS is detected by the nodes whose paths failed. There-

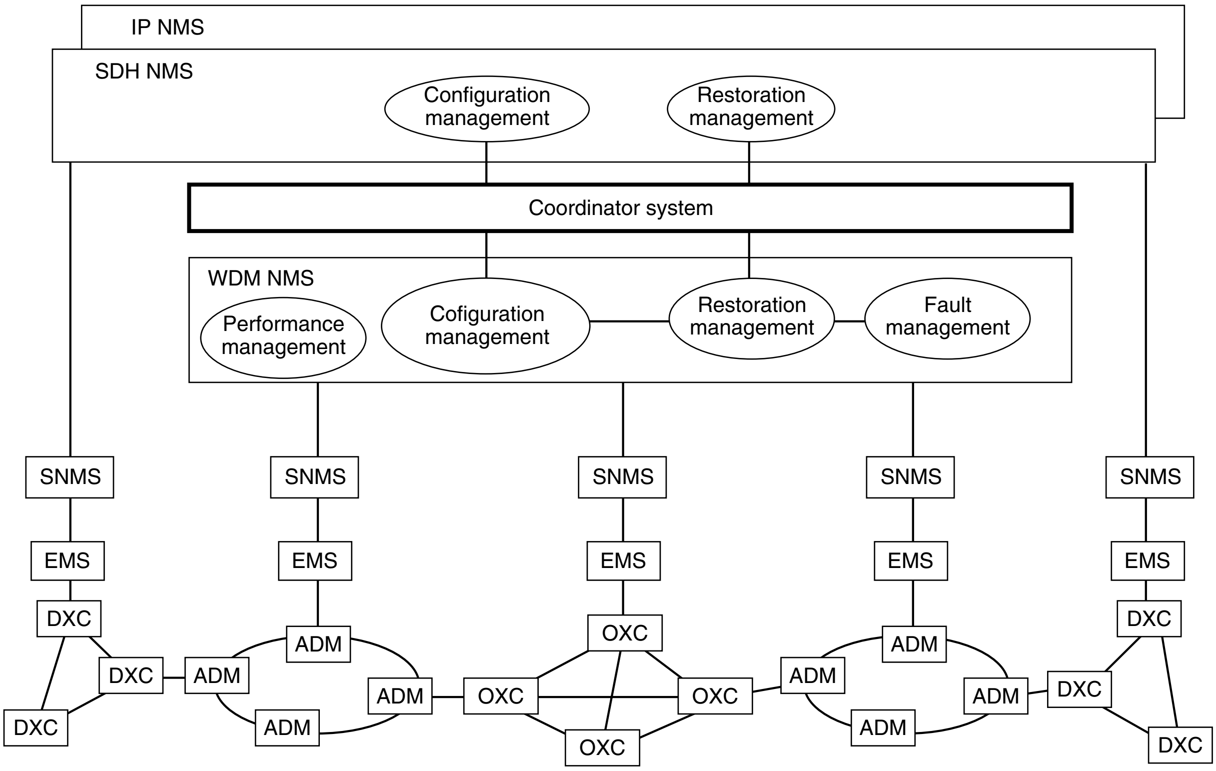


Figure 3
Configuration of NMS.

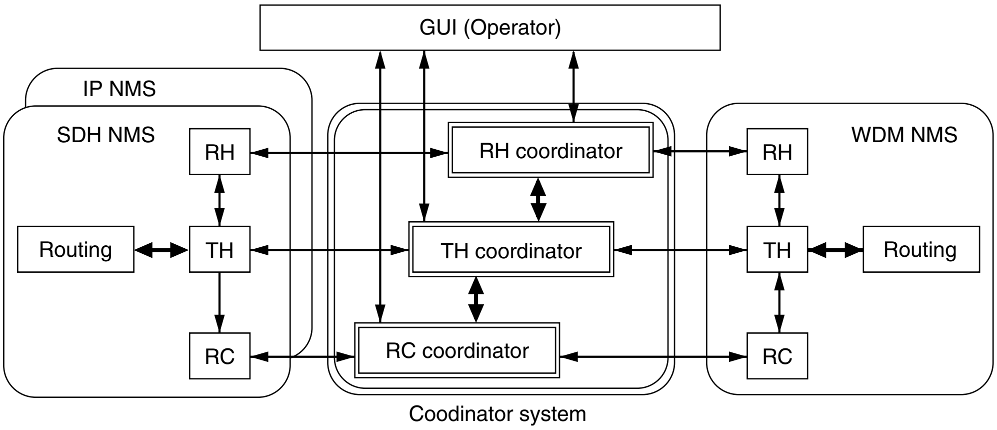
fore, alarm information such as FDI (Forward defect indication) should be transferred downstream from the fault detection point to indicate where the failure occurred.

Regarding the wavelength allocation, the photonic network has a limited number of wavelengths and a limited function for changing wavelengths, so the optical path routing is more difficult than in legacy path routing. For example, existing network design methods for time division multiplex (TDM) networks can assign routes for paths if the links have spare channels. However, such methods cannot be applied for wavelength path (WP) networks in which the wavelength does not change over the length of a path because the same wavelength must be selected throughout its route. Another point is that the wavelength routing function must consider the cooperation between the optical path layer and electric path layer to maximize usage of the server and client layers and to migrate to the existing networks.

2.4 NMS architecture

Legacy NMS manages one technology network and has a loose relationship between another NMS. But, if the cooperation function is introduced between NMSs, spare resources can be shared to restore failed paths in the photonic and client network.

Therefore, we introduce a coordinator system that cooperates between NMSs of the photonic layer and client layers (**Figures 3** and **4**). This coordinator system has a path configuration function, restoration function, and resource configuration management function. The trail handler has a function to set up and release paths, the restoration handler has a function to restore a failed path, and the resource configurator manages the termination point. The trail handler



TH : Trail Handler (Path configuration management)
RC : Resource Configurator (Resource configuration mamagement)
RH : Restoration Handler (Restoration management)

Figure 4
Coordinator system.

coordinator manages the relationship between the server and client paths, the restoration handler coordinator manages transference from server restoration to client restoration, and the resource configurator coordinator manages the relationship between the server termination point and client termination point. The restoration handler requests rerouting of the failed path to the trail handler, and the trail handler gets sub-network model from the resource configuration.

For example, the restoration handler restores traffic when a failure occurs in the network. In addition to restoration in each layer, the restoration handler in the coordinator system restores traffic by executing operations, for example, server trail creation and rerouting of client paths, across layers. **Figure 5** shows an example of coordination. When a failure occurs in the photonic network, the restoration handler in the WDM NMS tries to restore the failed paths. If none of the failed paths can be restored, the restoration handler in the WDM NMS sends an alarm to the coordinator system. Then, the restoration handler coordinator requests retrieval of the failed paths that are accommodated in the failed optical path, and requests rerouting of it to the trail handler coordinator. Also, the trail handler coordinator requests the trail handler in the SDH NMS to perform VC4 trail creation and the trail handler in the WDM NMS to perform optical channel trail creation. In this way, failed paths are restored across layers. Using this coordinator system, we can flexibly manage a multi-domain network. Moreover, network resources can be reduced to use unused client resources by restoring across two layers. This function can restore more traffic in restricted resources; in other words, the cost of spare resources can be reduced.

3. Restoration

WDM technology, which transmits several wavelengths in a single fiber, can make the transmission capacity much higher than before. However, if a failure occurs in the network, much more information will be lost. Therefore, services should be recovered as fast as possible whenever a failure occurs. Furthermore, services should be recovered from various kinds of failures, for example, multiple link failures and node failures.

Many kinds of recovery schemes, for example protection schemes and restoration schemes, have been developed. Protection schemes work fast but they require much spare resources. On the other hand, restoration schemes are a little slow, but they need less spare resources. Moreover, restoration schemes work flexibly in response to various kinds of failures.

The restoration handler manages the configuration information for restoration. When paths are established, the restoration handler tells the element managers the required path configuration information or directs the element managers to start path route monitoring so that the path configuration information can be gathered.

We developed a restoration scheme for WDM networks, called the self-healing scheme, which reroutes the traffic in a distributed fashion by network nodes. This function corresponds to OCH-RH in Figure 5. The self-healing scheme works faster than the centralized control restoration scheme and works flexibly. This scheme is based on the restoration schemes we developed for SDH networks and ATM networks.[1] The method of searching for and reserving the alternative route is restricted for a wavelength path (WP) based WDM network, in which a path uses a single wavelength. The algorithm uses three restoration phases: the alternative route search phase, the route-reservation and cancellation phase, and the cross connection and confirmation phase (**Figure 6**).

The first phase is the alternative route search phase. When a failure occurs in the network, the node which detects the failure becomes the sender node. The sender node broadcasts an alternative route-search message to all ports. This message contains the number of available wave-

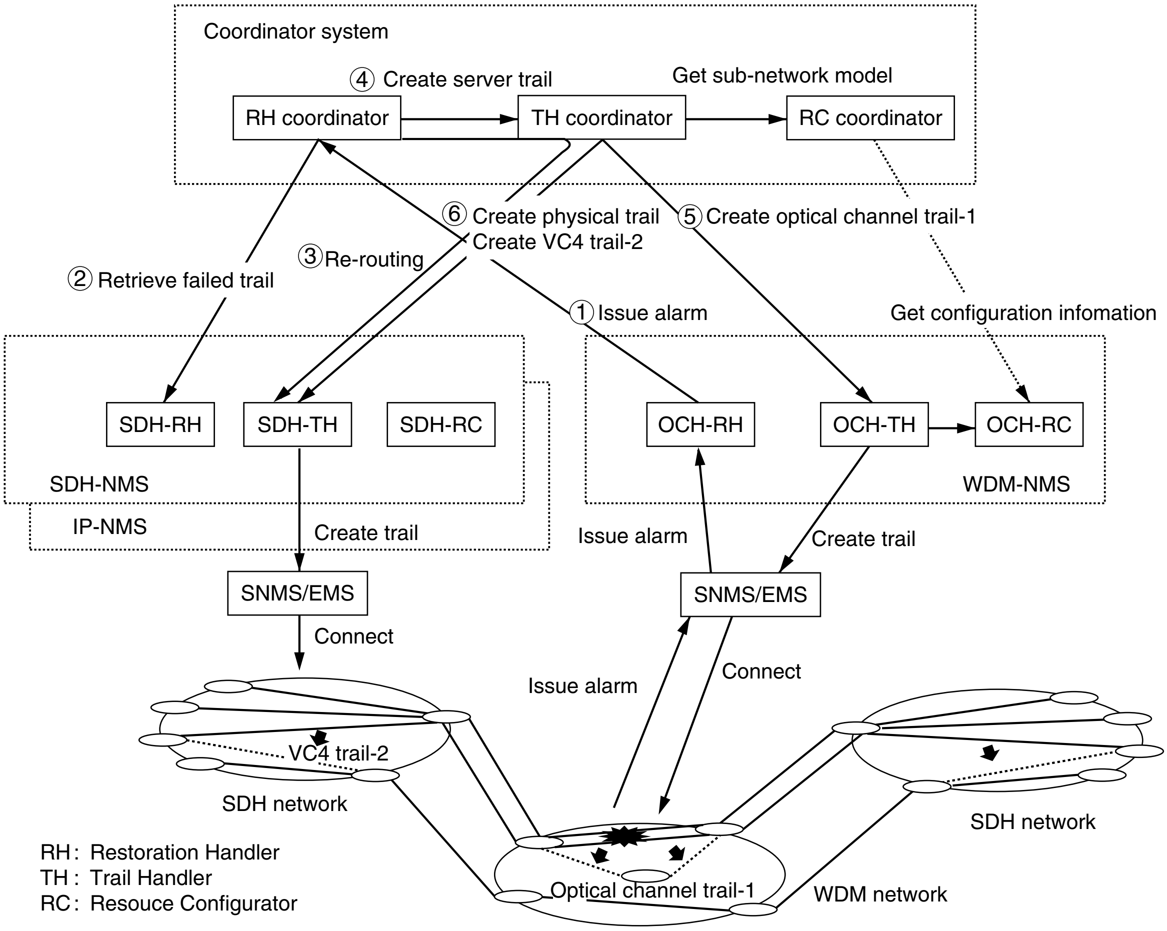


Figure 5
Example of coordination.

lengths and is used for searching for available routes from the sender node to the chooser node which is the destination of the alternative route. The node which receives the alternative route-search message broadcasts it again to all ports after adjusting the information about the number of available wavelengths.

In the second phase, when the chooser node receives the alternative route-search message, the node sends a reservation message back to the receiving port. The reservation message is transferred to the sender node reserving the required capacity.

The third phase is the cross connection and confirmation phase. When the sender node receives the reservation message, the node sends the cross connection message to the chooser node to instruct the nodes along the alternative route to switch to the alternative route. Then, the chooser node sends the confirmation message to confirm the end of switching.

When the confirmation message reaches the sender node, the sender node reports the end of restoration to the restoration handler. If none of the failed paths are fully restored, the restoration handler tries to restore traffic in other layers, for example, the client layer.

4. WP routing algorithm

We developed a wavelength routing algorithm for the WP scheme to avoid wavelength collision and to maximize the usage of wavelength resources, and have adapted it to our network design method.

The objective of our network design is to minimize the total equipment cost for a given traffic

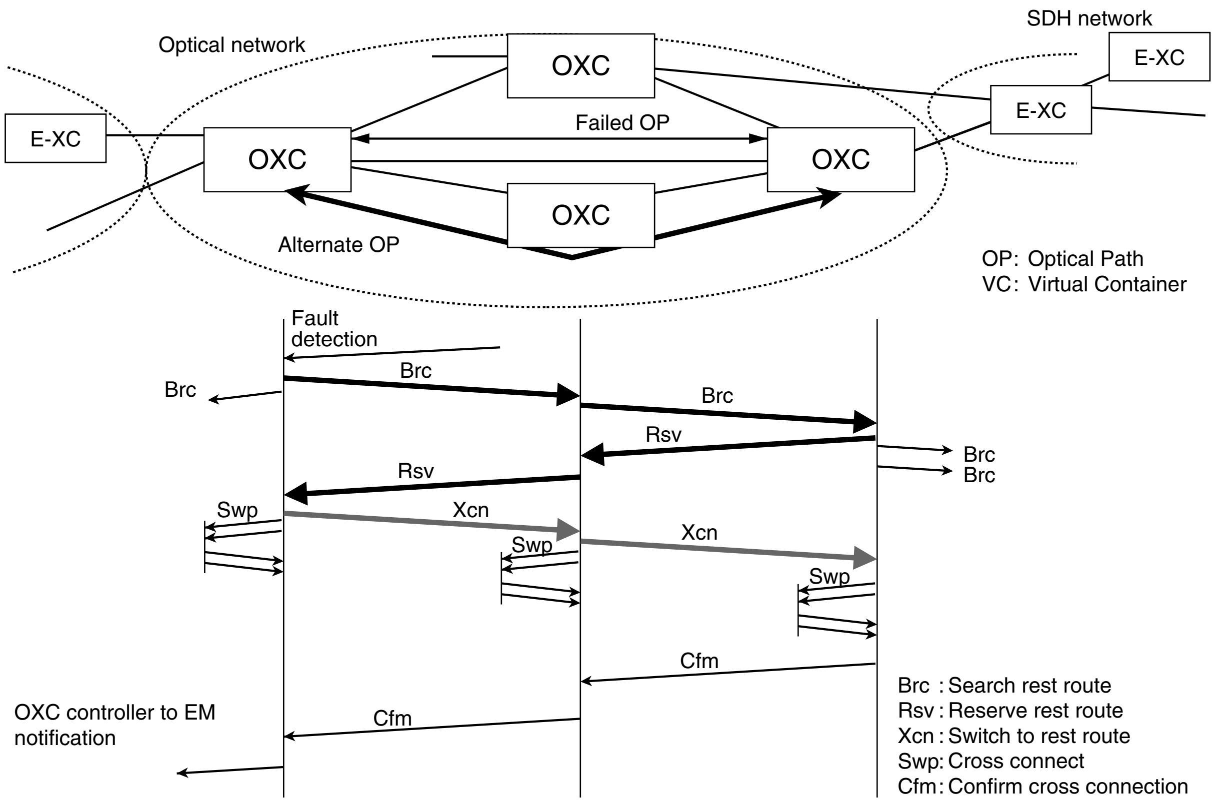


Figure 6
Restoration sequence.

demand. **Figure 7** shows the WP network design method.[2] Because existing design algorithms cannot be used for WP networks in which routing is restricted to using a single wavelength through each path, the optical path routing function is separated from the electric path routing function. Network topology and traffic demand matrixes are used as input data. The electric path routing function chooses the cheapest path by comparing the costs for a 2.5 Gb/s SDH path and an OC-48 path according to the costs for the equipment being used. It then outputs the optical demand for the optical path routing function.

With the optical path routing function, each wavelength is represented by a process graph that has *N* branches for each original link (*N* is the number of wavelengths in a link). This makes it possible to use the minimum-cost equipment routing algorithm regardless of the special restrictions of WP (**Figure 8**). The optical path routing function assigns one capacity unit to each branch in the process graph and searches the route that incurs the minimum cost from source to sink with respect to the first optical demand. For the next demand, the optical path routing function adds one capacity unit to the link to which the previous demand was assigned. It continues this operation for the total optical demand. However, with respect to the division of the network, the usage ratio for the various branches might not be uniform. For this reason, the optical path routing function also uses a dynamic equipment model for the process graph and assigns a low cost to branches with a low usage ratio so as to better balance the usage ratio in the process graph. Finally, to further minimize the total cost of the optical cross connect, the optical path routing function tries to remove fibers with a low usage ratio and reroute paths to alternate routes. We will apply this optical path routing function to the routing function in configuration management.

Figure 9 shows our network design tool

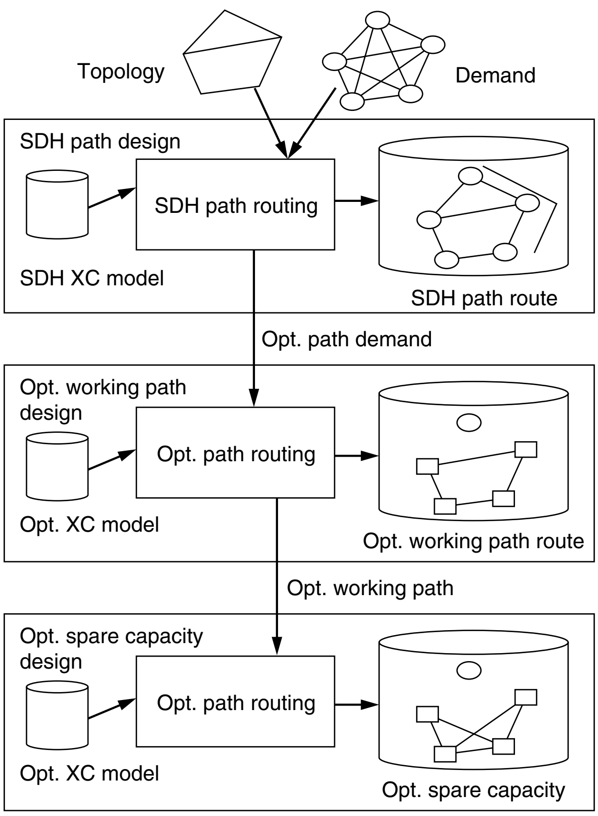


Figure 7
Structure of WP network design method.

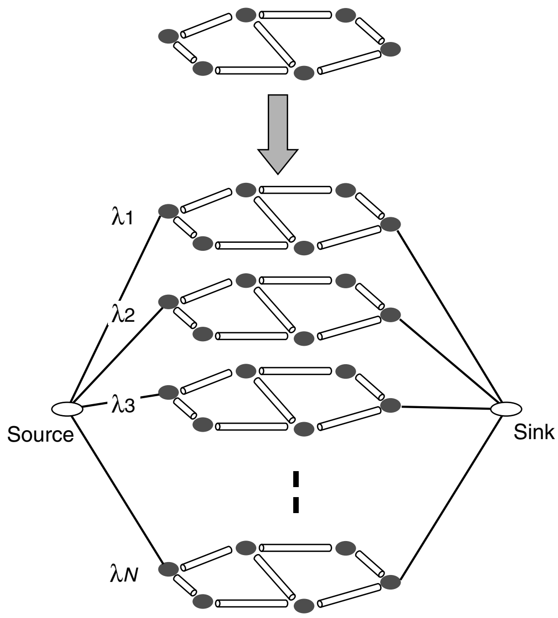


Figure 8
Process graph for optical allocation.

FINDEM (Fujitsu Integrated Network DEsign Method). We can design a working and spare network using this tool.

5. WDM management system prototype

Figure 10 shows the configuration of the WDM network management system prototype, and **Figure 11** shows the GUI interface. The NE controller manages a single network element, and the NE manager manages the entire network. The functions of the NE manager are path configuration, alarm logging, and link status display. The functions of the NE controller are switch control, performance monitoring, alarm indication signal transfer, and restoration.

The performance monitoring of an optical path should be independent of the client signal. Optical spectrum monitors are used for gathering performance information in this prototype system. This information includes the optical power and signal noise ratio for every wavelength. The NE controller gathers this information periodically and watches whether the optical power is higher than the threshold. When the optical power becomes low, the NE controller issues an alarm to the NE manager. If the powers of all wavelengths in a fiber become low, the NE controller starts the restoration process.

If the optical cross-connect equipment does not regenerate the main signal, a loss of the signal is detected on every node downstream of the path. In this case, the NE manager will receive many unnecessary alarms and it will be difficult to identify the original defect. To avoid this situation, an FDI is transferred downstream along the path. The nodes which receive the FDI suppress the issuance of the alarm. FDI is transferred via the outband's supervisory channel, which is multiplexed with the main signal. This channel also carries restoration messages.

6. Conclusion

We described the management functions for a WDM network. Also, we presented a management architecture to manage end-to-end optical paths and coordinate path management processes in different layers for efficient use of network resources. The restoration algorithm that we developed makes WDM networks reliable and robust.

We then described a network design algorithm that includes spare capacity design for restoration and achieves good results in the design of cost-effective networks. Finally, we described a network management system prototype that includes a configuration management function and a fault management function. A restoration function is also implemented in this

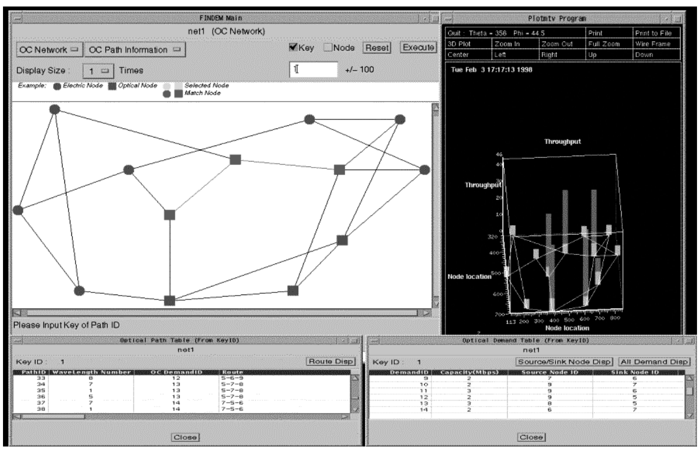


Figure 9
GUI of WDM network design system.

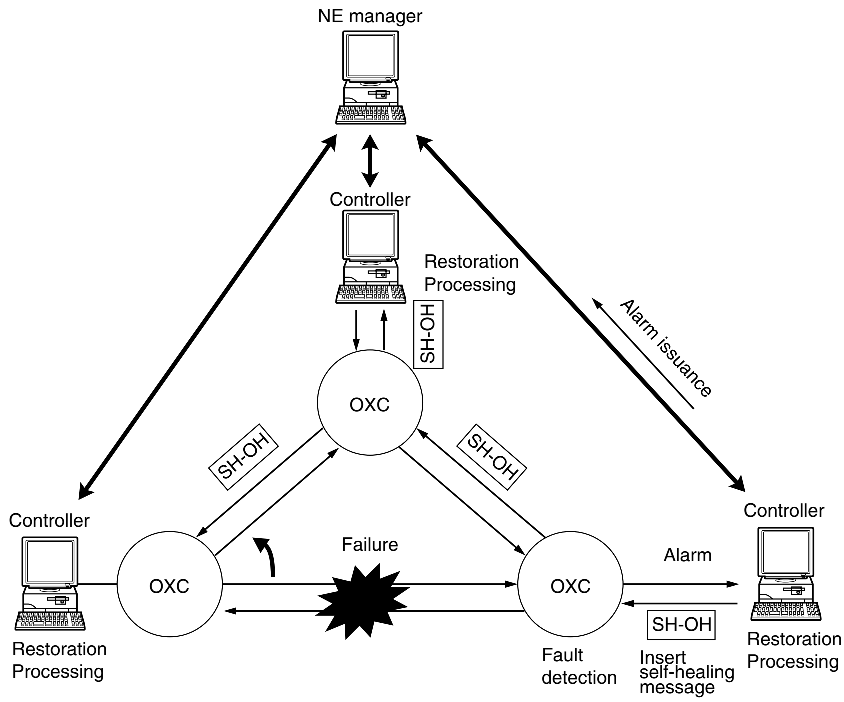


Figure 10
Configuration of optical path network management system.

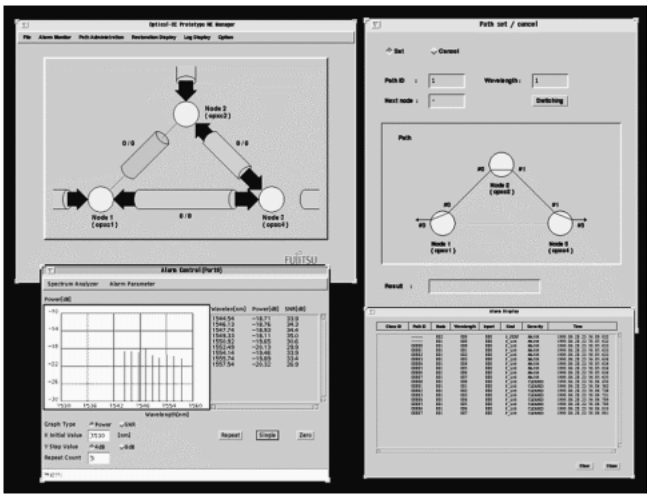


Figure 11
GUI of OXC management system prototype.

prototype system, and traffic can even be restored from failures such as a cable cut.

References

1) M. Azuma, Y. Fujii, Y. Sato, T. Chujo, and K. Murakami: Network Restoration Algorithm for Multimedia Communication Services and Its Performance Characteristics. *IEICE Trans. Commun.*, **E78-B**, 7, pp.987-994 (1995).

2) M. Minoura and K. Miyazaki: A Study of Wavelength Division Multiplex Network Design. Technical Report of IEICE, SAT97-67, CS97-111, 1997, pp.7-12.

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