Technical Improvements in Photonic Networks for Constructing Next-generation Networks

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Abstract

A massive infrastructure for IP networks should be developed to handle the rapid increase in Internet traffic. This requires interworking technologies between IP routers and the underlying transport equipment, so photonic networking technologies urgently need to be improved. This paper describes optical switching technologies for flexibly changing optical connections, control technologies for photonic networks such as ASON (automatic switched optical network) and GMPLS (generalized multi protocol label switching) to improve connection control, and new restoration techniques to enhance network robustness. It also introduces research on optical burst switching to enable fast connection control for dynamic traffic engineering.

1. Introduction

The rapid increase in the volume of Internet traffic is overtaking the improvements in electrical processing technologies predicted by Moore's law. As an example, Fig. 1 shows the traffic volume measured at an Internet exchange in Japan [1]. We need to rapidly increase the network's traffic carrying capacity and simultaneously reduce costs.

Here, we consider two examples of constructing large-scale IP (Internet protocol) networks. The first configuration uses large-scale IP router connections as shown in Fig. 2(a) and the second uses a lower-layer (e.g., Ethernet, SDH/SONET (synchronous digital hierarchy, synchronous optical network), or photonic network) switch and a relatively low-capacity IP router as shown in Fig. 2(b). In the future, by using a cluster configuration combined with multiple IP routers, we expect a massive router configuration and router ports to be used for that interconnection.

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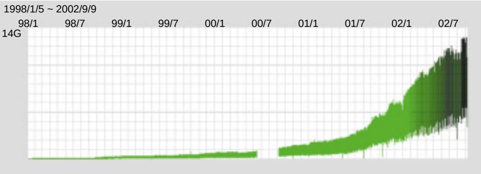

*The maximum and minimum daily traffic volume on the Internet exchange backplane in bits per second (http://www.jpix.ad.jp/en/techncal/traffic.html)

Fig. 1. Increase in traffic.

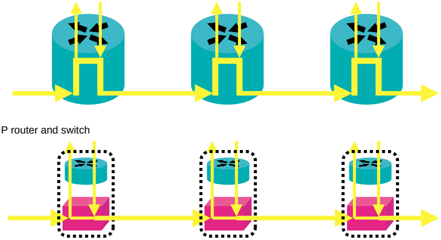

Fig. 2. Configuration for high-capacity IP networks.

Considering the degradation in efficiency that accompanies the cluster configuration and the evaluation results of the ratio of the through-traffic to the processing traffic, etc., the second configuration is superior for high-capacity nodes. It was reported that, under specific conditions, the number of IP routers could be reduced to 1/5 [2].

Constructing a combined network of IP and lower layers requires close cooperation among the layers. For this reason, the speed of the lower-layer control technology must be increased to flexibly support requests from the upper IP layer. Thus, steps are being taken to increase the speed of control functions, for example, in the areas of SDH/SONET, wavelength division multiplexing (WDM) networks, and multiprotocol label switching (MPLS).

First, as one step towards increasing the capacity of SDH/SONET, next-generation SDH/SONET technology is being developed to address the existing problem of a bandwidth-flexible setup by using technologies such as the link capacity adjustment scheme (LCAS) [3], virtual concatenation [4], and generic framing procedure (GFP) [5].

Photonic networking technology [6], based on WDM link technology, is a design technology that increases the capacity of a network by setting up optical paths over different wavelengths. ITU-T initially established the OTN (optical transport network) [7], [8] as a static network standard. Subsequently, this was expanded to ASON (automatic switched optical network) [9], [10], which can be dynamically controlled based on signaling technology. Because of the enhanced controllability, the photonic network must achieve not only higher capacity and more economical operation, but also greater functionality.

MPLS [11] was originally proposed to increase the capacity of IP routers; however, it is currently used for traffic engineering and constructing virtual private networks. It focuses on cells and frames. In the photonic network, it is extended to multi-protocol lambda switching (MPλS, where lambda is the symbol used to represent wavelength), and for general-purpose trunk networks such as OTN and SDH/SONET, it is further expanded to generalized MPLS (GMPLS) [12], [13]. The Internet Engineering Task Force (IETF) is conducting successful standardization activities on MPLS and GMPLS technology not only for path setup signaling, but also as a technology with various functions and protocol suites for routing and link management, for example.

NTT is conducting R&D to improve the functionality and controllability of photonic networks to increase the speed and capacity of node processing technologies, make highly functional networks through traffic engineering, which increases the efficiency of overall network resources, improve the fault tolerance, and enable rapid deployment of new services. As a part of this R&D, NTT was one of the driving forces behind the standardization of OTN and ASON. Moreover, NTT proposed photonic MPLS, as an extension of MPLS control technology, at the January 2001 OIF (Optical Internetworking Forum) meeting as a control technology for photonic networks [14]. This proposal along with many similar proposals was successful in creating a technological trend toward MPλS as a photonic network control technology. On the other hand, experimental research was conducted at the same time, and we conducted

R&D on the photonic MPLS router and its demonstration for GMPLS, which effectively utilizes cooperation between optical and electronic technologies.

2. Improving the functionalities of optical networks

Recent developments in optical switching have rapidly improved the functionality of optical networks. Figure 3 shows the progress of optical network technology based on optical switching technology. Photonic network technology, which began as a way to establish a simple connection between two points as a WDM transmission system, was accompanied by the development of optical switching technology. A ring system employing optical add/drop multiplexers (OADMs) [15], [16] and an optical cross-connect (OXC) system [17] that supports a mesh network were developed. Furthermore, the MPLS router [18]-[20], in which IP and photonic networks cooperate, was developed, and the next target is considered to be an optical burst switching node employing high-level and high-speed optical processing technology.

Technologies for enhancing the functionalities of optical networks include optical switching, wavelength conversion, and optical transmission.

2.1 Optical switching technology

Figure 4 shows the evolution of the OADM system as an example of the improvement in optical network functionality based on optical switching technology. In contrast to the fixed-type OADM, a reconfigurable one (R-OADM), which uses optical switches, supports remote path setup, enables operational expenditures related to path provisioning to be reduced, and at the same time can efficiently decrease the provisioning time. These improvements allow optical paths to be provided to customers in a more timely and simpler manner. Table 1 compares the features of these systems. In R-OADM, the optical switch implemented in the node is controlled by the path setup command from the operations system, and ADM switching is performed from the remote operation center. Since this is simpler to do from a remote center than on site, it enables rapid optical path provi-

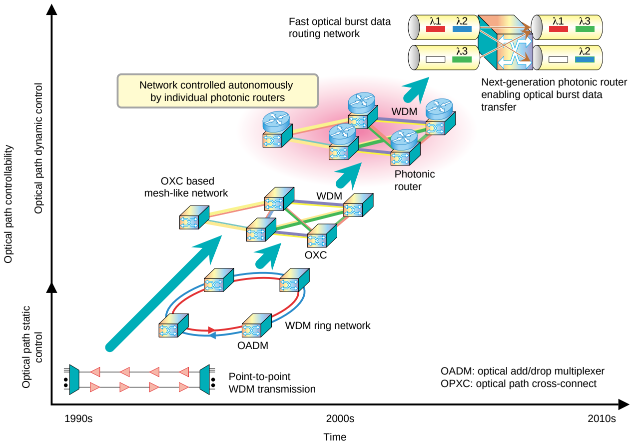

Fig. 3. Development of photonic network technology.

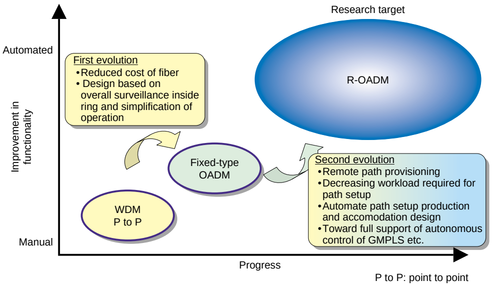

Fig. 4. Progress in functions of OADM system.

Table 1. Advantages of R-OADM ring system.

	Fixed-Type OADM	R-OADM
ADM setup	Setup on site Static configuration	Setup remotely Dynamically reconfigurable (enable support unscheduled demand)
Influence on existing path when new path is set up	Yes	No (OpS-based control)
Time required to set up path	Long (limited by preparation time of UNI-IF and add/drop filters)	Short (limited by preparation time of IFs)

UNI-IF: User network interface
OpS: operation system

sioning in response to new unscheduled requests.

2.2 Wavelength conversion technology

Wavelength conversion also improves the functionality of photonic networks. Figure 5 classifies wavelength conversion functions into wavelength assignment and wavelength interchange [21]. At the photonic network input point, the wavelength assignment function assigns the wavelength as a wavelength-multiplexing signal when the optical path accommodates the photonic network client signal. Inside the photonic network, the wavelength interchange function converts the wavelength of the optical path signal at a node if necessary to avoid wavelength collision in the WDM link. The wavelength assignment function is effective at simplifying the provisioning. Namely, since an interface that has a random wavelength assignment function can remove the limitation based on the wavelength at the accommodation point, automatic operation is promoted, and the reduced number of operational mistakes improves the provisioning functionality. At the same time, because fewer different interfaces are accommodated, it also significantly reduces the number of prepared packages to be deployed. The second function is the wavelength interchange function. In a semi-fixed connection system such as a cross-connect system, this function improves the accommodation efficiency [22] and simplifies the accommodation design of a virtual wavelength path network. In dynamic control systems, such as GMPLS, it increases the availability in label selection with label switching technology and increases the reachability. Figure 6 shows the relationship between wavelength conversion and GMPLS. As shown in Figs. 6(a) and 6(b), a wavelength is assigned as an MPLS label, and the control plane architecture can conform to MPLS. The GMPLS technology enhances the operation conformity in multiple layers and aims to improve cooperation among layers.

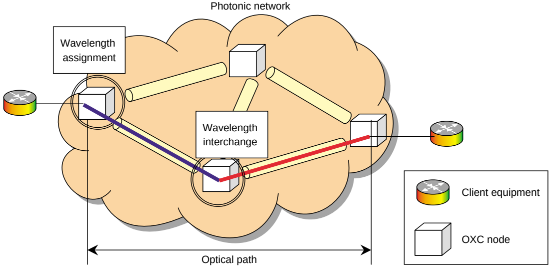

Fig. 5. Classification of wavelength conversion functions.

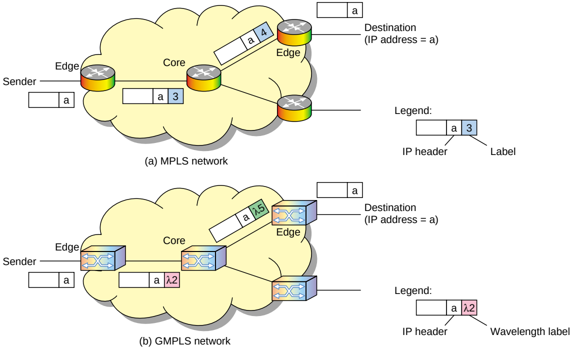

Fig. 6. Wavelength conversion and GMPLS.

2.3 Optical transmission technology

Steady development of optical transmission technology also helps to improve the functionality of optical networks. Based on the development of forward error correction (FEC) [23], Raman amplification technology, dispersion compensation technology, and new optical modulation schemes [24] etc., we can omit the 3R relay (converting light to electricity, amplifying it, and converting it back to electricity), which makes the optical network independent of the signal bit rate and format. This type of advancement in optical network transparency stimulates the offered usage of shared prepared resources and the degree of freedom in optical path routing. This results in better functionality of optical networks. Figure 7(a) shows a network configuration example based on point-to-point and OXC systems. In order to maintain the signal quality in the OXC system, electronic regenera-

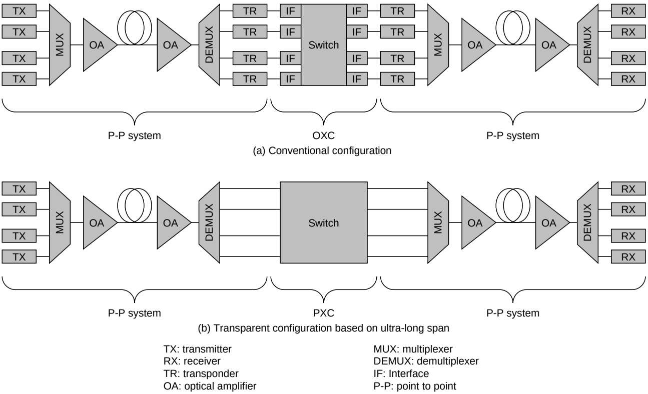

Fig. 7. Decrease in number of transponders based on transparency.

tive repeater-type transponders are used. These transponders are a major factor limiting the signal bit rate and format. They are also a major contribution to the cost of photonic networks. By achieving ultralong spans based on the development of optical transmission technology, a transparent configuration, as shown in Fig. 7(b), becomes possible and peripheral OXC transponders become unnecessary. Therefore, it should be possible to construct an economical photonic network having a high degree of transparency whose signal bit rate and signal format depend only on the accommodation interface. Considering the merits of this type of optical switching technology, and to distinguish it from the so-called O-E-O (optical-electrical-optical conversion) type of OXC, we call one that uses only optical switching technology a photonic cross-connect (PXC).

3. Development of photonic network control technology

NTT has developed prototypes for OADM [16] and OXC [17]. The photonic MPLS router that was developed based on technologies originating from these prototypes was demonstrated at the Summer 2001 SUPERCOMM. This node architecture is shown in Fig.8. The photonic MPLS router is configured with a lambda routing unit (LRU), which provides optical channel routing, a payload assembler/disassembler (PAD) for interface conversion, an IP routing unit (IRU: IP/MPLS controller), and a network element manager (NE-Mgr) for managing the integrated node control software used in GMPLS. The photonic MPLS router utilizes the cut-through effect, and traffic engineering is achieved by using network-configuration information to establish a bypass route through nodes that have low loads. Furthermore, to deal with the increase in IP traffic, the router uses the distributed control devices used in IP networks, enabling high-level and flexible network control to be achieved.

3.1 Multilayer LSP management

Multilayer LSP management, shown in Fig. 9, is a newly implemented function of the photonic MPLS router. It enables network applications to be simplified by linking an electrical label switched path (E-LSP) and optical LSPs (O-LSPs), based on Ethernet and PPP (point-to-point protocol). In Fig. 9, there are two E-LSPs established between nodes 1 and 3: E-LSP 1 uses O-LSPs 1 and 2 to connect node 1 to node 3 via node 2 and E-LSP 2 uses O-LSP 3 in a direct

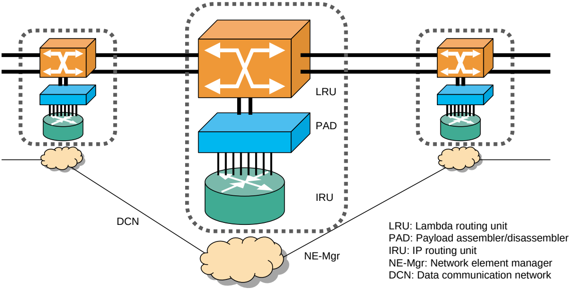

Fig. 8. Overview of photonic MPLS router.

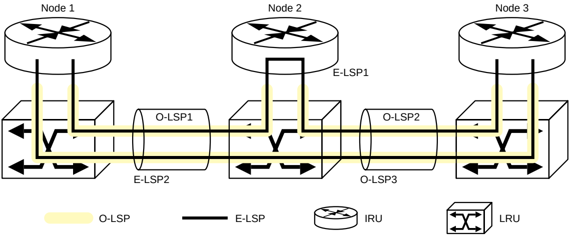

Fig. 9. Multilayer management.

connection from node 1 to node 3. Either E-LSP can be used from node 1 to node 3 according to the network usage state, which increases flexibility for network applications. For example, before existing network application users establish an E-LSP, the accommodation conditions of the O-LSP must be verified. If the capacity of the O-LSP is insufficient, a new O-LSP must be established to accommodate the E-LSP. On the other hand, the network application user of the photonic MPLS router into which the multilayer LSP management function is implemented can control the photonic network just by manually establishing the E-LSP. If, along the E-LSP, the O-LSP capacity becomes insufficient, another O-LSP is automatically established. An example of the setup scheme is given in Fig. 10. Node 1 issues the E-LSP setup requirements, when node 2 detects that there is no O-LSP along the path, node 2 sends a command to node 5 to establish a temporary O-LSP between nodes 2 and 5, and the O-LSP is established between the nodes. Subsequently, a message to establish the E-LSP that transits through the O-LSP is sent to node 6, and an E-LSP is established between nodes 1 and 6.

This type of E-LSP sequence automation is achieved based on protocol technology suites such as the IETF standardized link management protocol (LMP) [25], RSVP-TE (reservation protocol, traffic engineering) [12],[13], and OSPF-TE (open shortest path first traffic engineering) [26]. LMP automatical-

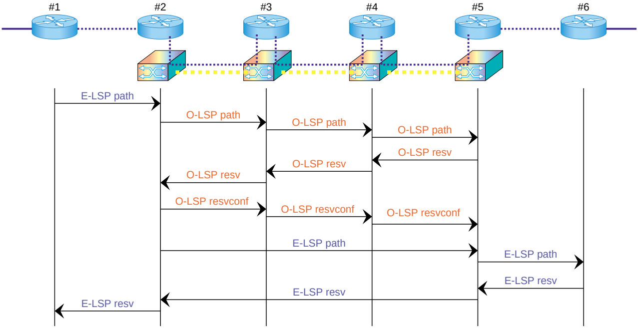

Fig. 10. Multilayer LSP setup sequence.

ly discovers adjacent nodes, recognizes connected link types, and automatically performs tests. As in the IP router network, OSPF-TE autonomously exchanges network topology information, for example, between nodes and automates the LSP count. In the future, it will be necessary not only to improve the basic parts of this type of protocol suite, but also to provide a more refined methodology that includes exception handling that can cope with real applications. Besides theoretical considerations, activities to ensure interoperability among vendors and among devices will also be important.

3.2 Restoration technology

For photonic networks, it is important to measure improvements not only in applicability, but also in the ability to overcome problems. In the case of the photonic MPLS router, distribution-oriented optical path restoration technology was developed and a basic verification test was successfully completed [27], [28]. In network fault recovery technology, there are two schemes: i) the protection scheme in which a signal is copied and transmitted over two branches so that one branch that achieved successful transmission can be selected and ii) the restoration scheme in which a new path is established only after a failure occurs. The protection scheme provides fast recovery from faults, but it must use extra resources, so improving the equipment utilization rate is difficult.

The restoration scheme has the opposite characteristics, but if the switchover time can be improved, we can use it and benefit from its merits. Furthermore, with the existing types of restoration, centralized control is required in many cases; only a few cases deal with the distributed control used in IP networks.

Our current restoration scheme handles distributed control by optimizing the signaling-based protocol and executes a four-point plan to reduce the switchover time. First, prior to a fault, the reserved path should be calculated, and the resources it needs based on a logical path should be reserved. Unlike in the protection scheme, in the restoration scheme multiple reservations can be shared, so even when reservations have been established, we can still attempt to improve the equipment utilization. In the example given in Fig. 11(a), wavelength λa is to be reserved with a logical path identifier, VPa. Second, a switchover message is transmitted via the logical reserved path. Third, we speed up fault detection by optimizing the detection process. Fourth, the switchover function is initiated only at a path termination point as shown in Fig. 11(b). We plan to avoid an complicated fault localization process and to simplify the switchover protocol. A triangular verification network using three nodes is constructed. We conducted a trial and found that the restoration scheme using optical technology could successfully complete a fast switchover in 450 ms (Fig. 12). This switchover time is sufficiently short compared to the typical fault detection time of 1 s for upper layer

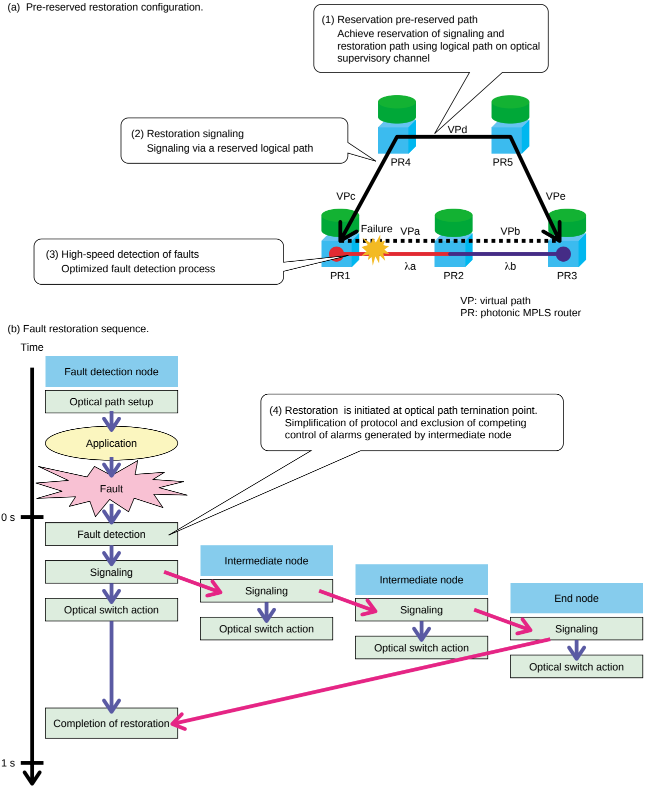

Fig. 11. Distributed control-type optical path high-speed restoration.

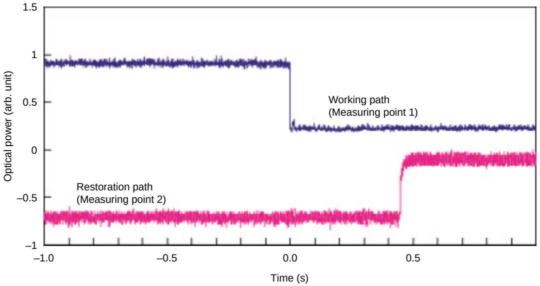

Fig. 12. Experimental results for restoration.

equipment. Before client fault recovery was initiated, fault restoration on the photonic network was completed, so there was almost no effect on the client network.

In the future, we aim to increase the speed to make it faster than the SDH/SONET standard of 50 ms by optimizing the hardware and software. At the same time, by integrating shared risk link group (SRLG) technology, we will further increase the network's ability to overcome problems. SRLG classifies the main cause of a fault and its effects. For example, if a fault occurs along a cable, all the transmission fiber lines accommodated in it may be affected, so the fiber lines are considered to share the same risk and this risk information is shared within the network. A single fault can affect multiple transmission fiber lines, so we are actively investigating how to increase the network's ability to overcome problems such as by avoiding faults that affect both working and recovery paths.

4. Investigation of fast optical path switching

In the future, due to the expansion of dynamic traffic engineering and bandwidth-on-demand services, the demand for high-capacity short-holding-time O-LSPs is expected to increase. For these services, O-LSPs should certainly be established, but at the same time high-speed O-LSP setup and teardown is required. To achieve high-speed control, we must improve not only the hardware response time, but also the signaling speed itself. An optical burst switch network is being considered for such extension. As a related part of the performance test of the photonic MPLS router, we evaluated the O-LSP setup and teardown time. Figure 13 shows the experimental system configuration. We evaluated a three-node photonic MPLS router. In Fig. 13, O-LSPs 1, 2, and 3 are parts of an OC-192 path and they are switched by signaling between NE-Mgrs. Normal O-LSP setup was confirmed by measuring the optical power level and signal transmission was verified using an SDH analyzer. Based on the results of the optical power level measurements, we verified that the O-LSP setup took approximately 200 ms. In these experiments, each O-LSP was maintained for 6 to 10 s, which is equivalent to a transfer capacity of 7.5 to 12.5 GB. These experiments show that this system provides sufficient performance for sending video data such as DVD data based on a bandwidth-on-demand service [29]. In the future, we plan to increase the performance of comparatively small-size data transmissions, and improve the response time to expand the application area.

5. Conclusion

This paper introduced the development of photonic network technology including the OADM ring and OXC, which achieve flexible connection conversion using simple point-to-point optical switches, the photonic MPLS router considering linkage to current IP networks, and future optical burst networks. As the main technologies for development, we described optical switching, wavelength conversion, and optical

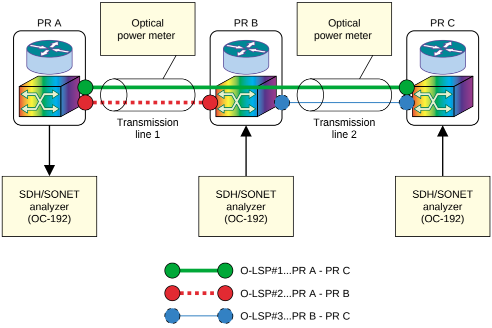

Fig. 13. GMPLS experimental system.

transmission. Furthermore, we presented multilayer LSP management control, application-improvement measures, and ways to better overcome problems. Finally, for future photonic networks, we investigated the optical burst network.

Photonic network technology is expected to develop further as a very economical backbone network construction technology mainly by cost reduction achieved through transparency and inexpensive applications based on a protocol represented by GMPLS. We expect new services such as bandwidth-on-demand and optical virtual private networks to be created as a base technology.

Acknowledgment

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