IP Routing Reconfiguration in IP-over-WDM Networks with Bi-Directional ROADMs

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***Abstract*—Temporary static-route adding procedures have been proposed to remove transmission breaks caused in the lightpath reconfiguration processes. It has been clarified experimentally that the transmission breaks could be removed successfully by the proposed procedures.**

I. Introduction

Optical networks have been introduced commonly to satisfy the rapid increase of traffic demands. The WDM (Wavelength-Division Multiplexing) technologies provide more bandwidth per fiber, and are used in core backbone networks, metropolitan area networks (MANs), and regional area networks. The regional area networks include local networks to connect government departments, or local communities, enterprise networks, university campus networks, and so on. We investigated scalable optical IP networks for regional area and large-scale LAN applications [1]. The issues for such optical IP networks were addressed as follows: The technologies should be native IP base, which are used in standardized LANs. The networks should be managed and controlled effectively by a few network administrators, when the traffic changes occur. For the control purpose, suitable technologies are necessary for the reconfiguration of the lightpaths. We developed an effective design and control system [2] for such regional networks. A reconfigurable optical add/drop multiplexer (ROADM) was also developed [3], and could be controlled by the developed system. In the network with the ROADMs, the IP routings could be reconfigured dynamically by OSPF (Open Shortest Path First), when the physical layer lightpaths were reconfigured by the ROADMs. However, the IP reconfigurations caused breaks for several seconds in the IP transmissions due to the dynamic routing table changes by OSPF in the layer-3 switches (L3SWs). In this paper, we propose effective routing reconfiguration procedures without breaks. The procedures and the experimental results are described.

II. Transmission Break Removing Procedures in Lightpath Reconfiguration

An experimental network is shown in Fig.1, which was constructed to show the new procedures. Four sets of the bidirectional ROADMs (B-ROADMs) were prepared, and installed in the nodes except Node 4. Each B-ROADM contains wavelength-dependent couplers and splitters to mux/demux wavelengths, and optical switches (SWs). It is possible to have 3 types of configurations for each wavelength in the B-ROADMs, depending on the SW numbers and the connections. Type-1 reconfigures both point-to-point (P2P) lightpaths connecting 2 nodes and one-by-one (O-O) lightpaths among nodes. Types-2 and -3 reconfigure O-O and P2P lightpaths, respectively. Refer [4] for the structures in details. The B-ROADM configurations in the network are shown by symbols schematically in Fig.1: e.g. when λ_1 is configured by Type-1, it is denoted as λ_1/T1 symbolically, and no precise SW configurations are shown. Each B-ROADM had two Type-1 configurations, one Type-3 configuration, and one simple passing-through (PT) connection. In Node 4, 2 sets of coupler and splitter were installed to add/drop λ_1 - λ_3 simply, which are denoted by λ_x/AD symbolically, and to pass λ_4 through Node 4. As a result, each node has 3 pairs of optical transceivers (OTRs) with different wavelengths. By this configuration, the 5 nodes are connected by more lightpaths than the full-mesh connections. The 4 wavelengths λ_1 - λ_4 of 1530, 1550, 1570 and 1590 nm of the CWDM standard values were adopted, respectively. To control the B-ROADMs, a control system (CS) was connected to the L3SW in Node 1. A LAN analyzer (LA) was also connected to the L3SW to monitor packet changes, when lightpaths are reconfigured. A personal computer (PC) is connected in each node to send and receive packets between nodes.

The lightpaths were reconfigured from the full-mesh to ring connections, i.e. from (a) to (d) shown in Fig.2. To evaluate the performance, ICMP (Internet Control Message Protocol) echo requests were sent continuously from PC1 to other 4 PCs in the full-mesh network, and the packets were monitored. The results are shown in Fig.3.

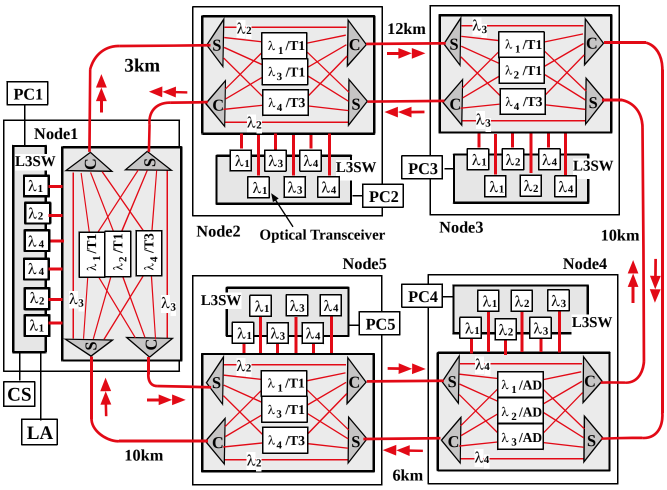

Figure 1 Experimental network configuration

The request and reply packets were observed by the direct lightpaths between Node 1 and other 4 nodes, before the reconfiguration. After the control signals were detected, the packets disappeared between Node 1 and Nodes 3 and 4, respectively, and the packets re-appeared in 5.8 s between Nodes 1 and 3 via Node 2, and between Nodes 1 and 4 via Node 5. Thus, transmission breaks were observed. This is because OSPF detected that the 2 direct paths disappeared, tried to find other routing paths, and found the possible route from Nodes 1 to 3 via Node 2, and from Nodes 1 to 4 via Node 5, taking 5.8s to complete the processes on the packet detection base.

To remove such breaks, we propose temporary static-route adding procedures (TSRAP), which is shown in Fig.2. As a first step, temporary static-route entries are added to the routing table in the L3SWs working by OSPF in the full-mesh configuration shown in Fig.2(a), such that the added routes can be used, after the lightpaths are removed in the reconfigurations: i.e. the temporary routes S12, S23, S34, S45 and S15 are added through the ring lightpaths, as shown in Fig.2(b). The static routes should become bypass routes for the traffic being transmitted through the lightpaths to be removed. Therefore, higher priority is given to the temporary routes than the OSPF routes O13, O14, O24, O25 and O35 to be removed. After the temporary routes are added, the lightpaths are removed by the B-ROADMs as shown in Fig.2(c). This lightpath removing process causes OSPF to re-calculate the routing table dynamically. At the same time, the priority given to the temporary routes is changed to be lower value than the OSPF routes, and the bypassed traffic is transmitted by the OFPF routes. After this, the temporary routes are removed, and all the packets are routed by OSPF, shown in Fig.2(d).

The packets were monitored to examine the performance by the proposed procedures. The results are shown in Fig.4. The packets were observed initially between Node 1 and other 4 nodes in the same way as in Fig.3, and TELNET packets were observed to add the temporary static-routes. After this, echo request packet route was changed from the direct to the bypass routes via Node 5 for the transmission between Nodes 1 and 4. The echo reply packet route was also changed from the direct to the bypass routes via Node 5, leading to the complete change to the bypass route. After this, control packets for the B-ROADM were sent and observed, and the lightpaths were reconfigured in the physical layer to be a ring configuration. This change gave no influence on the packet streams, showing that the transmissions were changed to the bypass route. TELNET packets were observed, again, to remove the static entries in the L3SWs. It is clear that the temporary route removing gave no influence on the transmissions, again. As a result, no transmission breaks were observed in the reconfigurations, showing that the breaks could be removed completely by the proposed procedures.

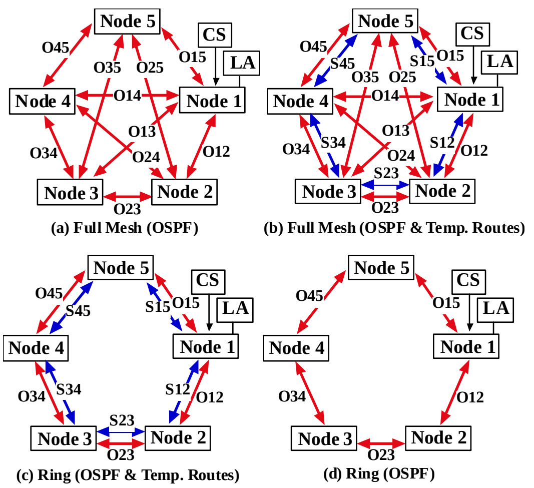

Figure 2 Temporary static-route adding procedures

III. Conclusion

Temporary static-route adding procedures have been proposed to remove transmission breaks caused in the lightpath reconfiguration processes. An experimental network with B-ROADMs was constructed by connecting 5 nodes with bi-directional dual-fibers. It has been clarified experimentally that the transmission breaks could be removed successfully by the proposed procedures.

Acknowledgment

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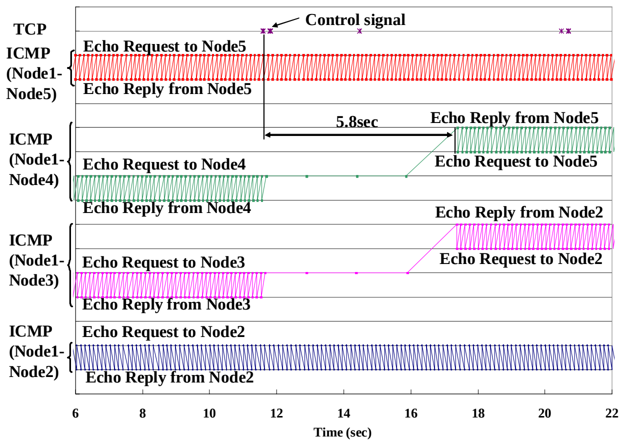

Figure 3 Monitored packets in lightpath reconfiguration

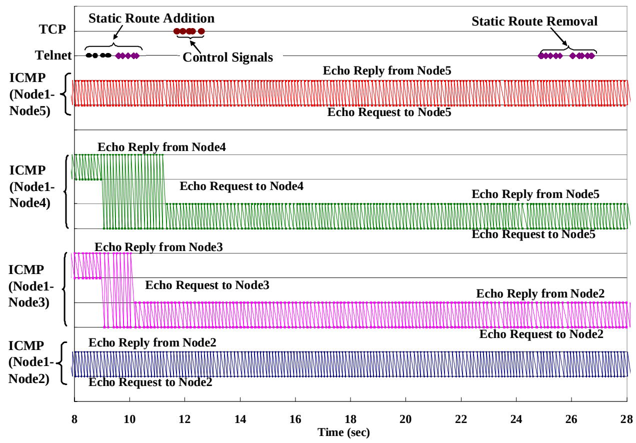

Figure 4 Monitored packets in lightpath reconfiguration with TSRAP