Reliable Self-Healing WDM Mesh Network Structure

Ching-Hung Chang, Peng-Chun Peng, Yi-Tzai Lin, Jen-Wei Sun, Hai-Han Lu

Department of Electro-Optical Engineering, National Taipei University of Technology, Taipei, Taiwan, R. O. C.

hhlu@ntut.edu.tw; pcpeng@ntut.edu.tw

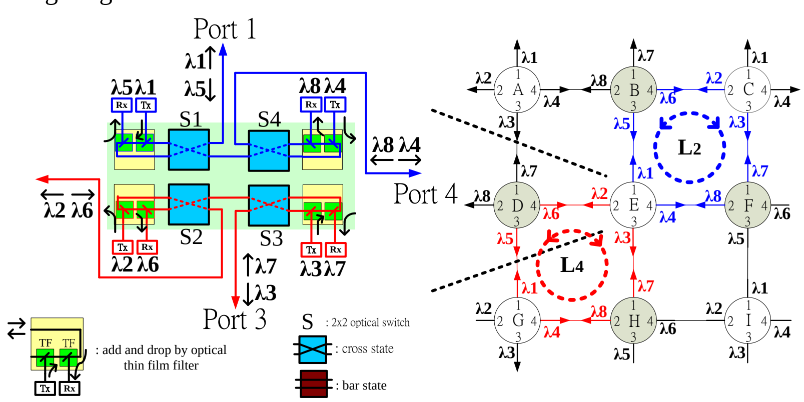
Abstract: A novel self-healing WDM mesh network structure is proposed with economic self-healing functionality. Without the need of wavelength conversion or backup fiber links, 77-channels CATV traffic is successfully restored under single or multiple failure-links happened.

OCIS codes: (060.4510) Optical communications; (060.4250) Networks.

1. Introduction

Based on the rapid growth of optical broadband services, an increasing number of people are using optical multimedia broadband services, resulting in a considerable increase in bandwidth demand in mesh networks. The optical wavelength division multiplexing (WDM) mesh-network has attracted global considerable support for the future provision of the required capacity in the foreseeable future [1]. However, a larger-scale network is associated with a higher probability of multi-link failure, which disconnects many multimedia services from many subscribers. So that integrating the survivability into WDM mesh-networks becomes necessary to guarantee quality of services (QoS) for clients [2-3]. Conventionally, deploying a backup fiber or resetting Internet routing protocol which needs to convert failure-link wavelength along the traffic pathway and to rearrange the bandwidth by protocol management, have been demonstrated as efficient anti-failure schemes [4]. However, the increased capital expenditure and complicated protocol management associated with such schemes have seriously retarded the implantation of optical WDM mesh networks.

A single-fiber bidirectional self-healing WDM mesh network with novel network node design and all-optical deflection routing scheme has been developed [5]. Each network node consists of two arrayed waveguide gratings, four optical switches, four optical circulators, and three optical couplers. Bidirectional fiber link restoration can be realized without centralized control or conversion of the wavelength in the affected channels. However, the network node design is complex and is not cost-effective. This paper is then presenting a simple and powerful self-healing node structure to protect data transmission in WDM mesh-networks without using any backup fiber or complicated protocol management. By resourcefully assigning wavelengths among the proposed network and utilizing the characteristics of optical switches and thin-film filters in each node, a single or multiple blocked traffics can be efficiently restored through logical connections.



(a) (b)

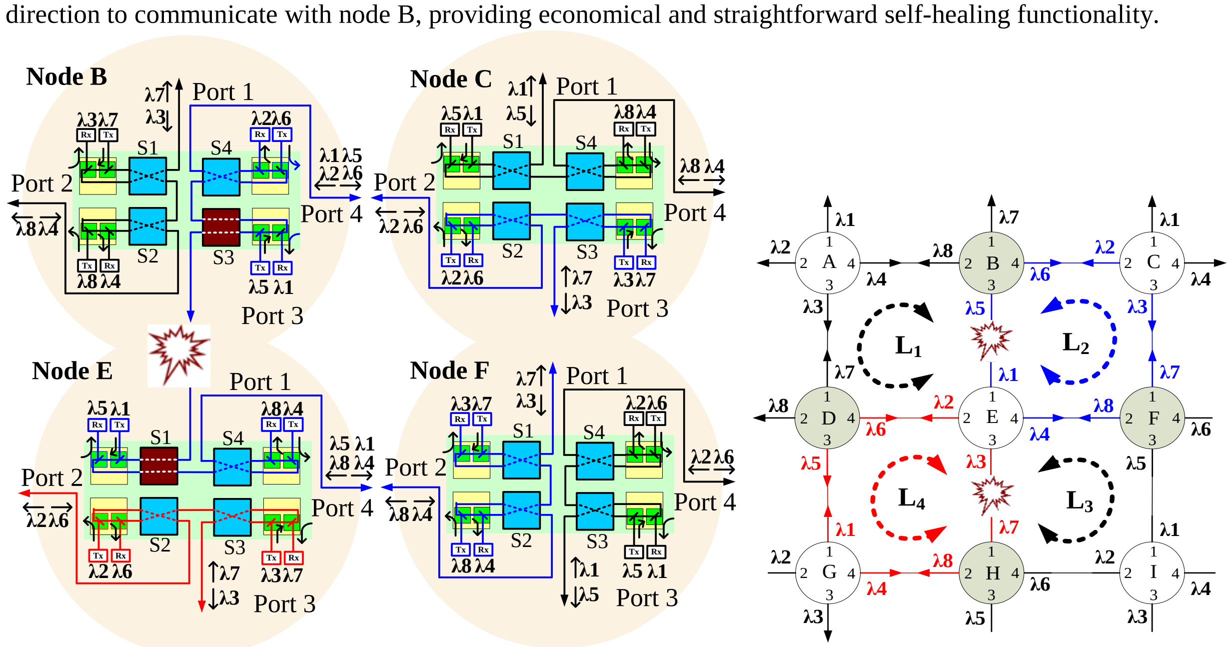
Fig. 1 (a) Self-healing WDM mesh network node configuration and (b) the relative wavelength assignment plan.

2. Network architecture

The novel bidirectional self-healing WDM mesh-network node configuration and the relative wavelength assignment plan are presented in Fig.1 (a) and (b) respectively. In the structure, each node is connected to four other nodes via dedicated fibers and wavelengths, as shown in Fig.1 (b). Unlike a normal node structure in WDM-mesh networks, a 2 × 2 optical switch, S_n, is placed next to each output port to bridge incoming and outputting network traffic, as well as a pair of optical thin-film filters, *TF*, are placed next to each transceiver pair to either add/drop the dedicated wavelengths to/from the network or to enable other traffic to pass.

According to the resourceful wavelength assignment plan, the utilized wavelengths, $\lambda_{1\sim4}$, in the node E for example are totally different with that, $\lambda_{5\sim8}$, in its neighboring nodes but are the same with that in non-adjacent nodes. Therefore, the limited number of wavelengths can be efficiently reused to abound the network scale. Normally, all of the employed optical switches are set to the cross state. The output λ_1 traffic from node E can be guided to the mesh-network by S_1 switch before being dropped and received by the thin film filter and optical receiver in the $port_3$ of node B. Similarly, the λ_5 traffic from $port_3$ of node B can reach node E by the inverse pathway, exhibiting bidirectional single-fiber transmission.

In case of a link-break happening, a backup pathway can be immediately set up by simply switching the optical switches in the affected ports from the cross state to the bar state. As shown in Fig.2(a), if the traffic between the nodes B and E is blocked, a replacement routing pathway for the affected traffic can be established easily by switching the switches, S_3 in node B and S_1 in node E, from the cross state to the bar state. The blocked λ_5 traffic from the $port_3$ of node B can then be firstly routed to the internal $port_4$ by the bar state of S_3 switch. Consequently, the λ_5 traffic can reach its destination through the $port_2$ and $port_3$ of node C, the $port_1$ and $port_2$ of node F and the $port_4$ of node E, since the λ_5 wavelength is not utilized in the backup routing pathway and can always pass through each *TF* in the loop. Inside the node E, the λ_5 traffic can then be forwarded and dropped through the bar state of S_1 switch and the *TF*. Similarly, the λ_1 traffic from the $port_1$ of node E can follow the same pathway but in the opposite direction to communicate with node B, providing economical and straightforward self-healing functionality.



(a) (b)

Fig. 2. (a) Replacement routing pathway for broken single link and (b) replacement routing pathway for broken double link.

In such a reconfigurable structure, even two non-adjacent links in a node are cracked simultaneously; the blocked traffic can still be communicated through logical backup links. As displayed in Fig. 2(b), when the $port_1$ and $port_3$ links of node E are break-down concurrently, the proposed structure can still reconnect the blocked traffics through the $loop_2$ pathway, L_2, and the $loop_4$ pathway, L_4 presenting an economical and easily managed solution for self-healing WDM mesh-networks.

3. Experiment and discussion

To study the performance of the proposed structures, an experiment was set up as displayed in Fig. 3. The solid line in the Fig. 3 represents the connection between two nodes namely nodes J and K. NTSC 77 cable television (CATV) channels ($CH_{2\sim78}$;6 MHz/CH) were simulated using a multiple signal generator (Matrix SX-16). To evaluate the transmission performance, the modulated CATV signals (1558.5 nm) were firstly fed into the node J through an optical thin film filter. Following a single-mode fiber (SMF) transmission, the optical CATV signals were routed, dropped and analyzed by the optical switch, the thin film filter and the CATV analyzer (HP-8591C), respectively. The experimental results are consequently utilized to verify the proposed structure.

Figure 4(a), (b) and (c) plot the measured carrier-to-noise ratio (CNR), composite second-order (CSO) and composite triple beat (CTB) performances, for back-to-back (BTB), 10 km normal link transmission and 30 km logical backup link transmission, respectively. A comparison with BTB measurements shows that a power penalty of about 0.5 dB for CNR values and approximately 1 dB for CSO/CTB were presented at the 10 km normal loop transmission, due to fiber chromatic dispersion. In case of fiber failure, the transmission performance degrades in proportion to the increase in the length of the traffic pathway. However, CNR≥ 50 dB and CSO/CTB≥ 62 dB are guaranteed, demonstrating the practical effectiveness of the proposal structures in restoring network traffic. Moreover, the CATV system performance can be improved using an optical filter [6].

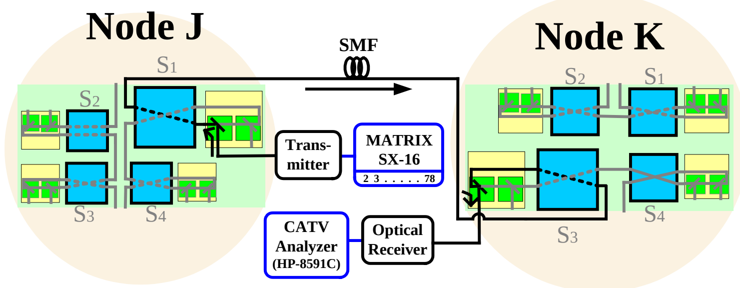
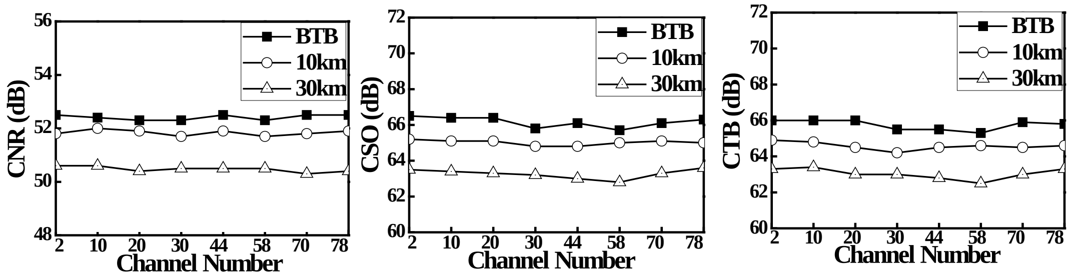


Fig. 3. Experimental setup



(a) (b) (c)

Fig. 4. (a) Measured CNR, (b) CSO and (c) CTB values under NTSC channel number.

The application of additional optical switches in the advanced structure strongly increases the reliability of WDM mesh-networks, but slightly increases the capital cost and power losses. As a trade-off between the self-healing functionality and the capital expenditure, the proposal with non-blocked transmission characteristic will still be an attractive solution for networks that require greater protection at normal cost.

4. Conclusion

This investigation presents and demonstrates a novel self-healing WDM mesh-network node structure based on the characteristics of a thin-film filter and an optical switch. In the proposed structure, a pair of thin-film filters and a 2× 2 optical switch are integrated in each port of a network node to add/drop and to bridge the network traffic between the transceiver and the optical fiber, respectively. In case of link failures happening, logical backup pathways can be built up easily by just modifying the operation state of the deployed optical switches, which can restore the blocked traffics through other internal ports. To achieve the objective, the network traffics are transmitted under a specific wavelength plan, and the blocked traffics can reach their destination through the adjacent nodes. In the proposed structures, no extra fiber link, expensive arrayed waveguide grating or complicated Internet protocol resetting is required, so the capital costs and the operating expense are greatly reduced. To study the functionality of the proposed structures the proposed structure is experimentally accomplished in a physical layer to assist the reliability of WDM-mesh networks. A total of 77 CATV channels were successfully communicated with favorable CNR, CSO and CTB performances. These experimental results show that the proposed structure is an attractive solution for large-scale WDM mesh-networks.

5. References and links

[1] C. Ou, J. Zhang, H. Zang, "New and improved approaches for shared-path protection in WDM mesh networks," J. Lightw. Technol. **22**, 1223-1232 (2004).

[2] L. Guo, "Hybrid survivable configuration for optical wavelength-division-multiplexing mesh networks," Opt. Express **15**, 834-838 (2007)

[3] L. Guo, L. Li, J. Cao, H. Yu, and X. Wei, "On Finding Feasible Solutions With Shared Backup Resources for Surviving Double-Link Failures in Path-Protected WDM Mesh Networks," J. Lightwave Technol. **25**, 287-296 (2007)

[4] E. Bouillet, G. Ellinas, J. F. Labourdette, and R. Ramanurthy, Path Routing in Mesh Optical Networks, (John Wiley and Sons, 2007)

[5] C. M. Lee, X. Sun, C. K. Chan and L. K. Chen, "A Single-Fiber Bidirectional Self-Healing WDM Multihop Mesh Network With All-Optical Cyclic Deflection Routing for Link Restoration," IEEE Photon. Technol. Lett. **17**, 2463-2465 (2005)

[6] H. H. Lu, S. J. Tzeng, C. Y. Chen, and H. C. Peng, "CSO/CTB Performances Improvement by Using Optical SSB Filter at the Receiving Site", IEEE Transactions on Communications **53**, 572-575 (2005).