Bidirectional WDM Self-Healing Ring Network for Hub/Remote Nodes

Sung-Bum Park1, Seung Goo Kang2, Sang Bae Lee3, Chang-Hee Lee1
1 KAIST, Dept. of Electrical Engineering and Computer Science, 373-1 Kusong-dong, Yusong-gu, Daejeon 305-701, Korea
2 Tel: +82-42-869-3463, Fax: +82-42-869-3410, E-mail: chl@ee.kaist.ac.kr
3 Current affiliation: Samsung Electronics Co. Ltd., Suwon, Korea
4 2 XL Photonics, Inc., Daejeon, Korea
5 3 KIST, Seoul, Korea

Abstract
We demonstrate a bidirectional WDM self-healing ring network for hub/remote nodes with one fiber. In this network, self-healing can be achieved within 8 ms. The transmission capacity can be doubled in the operating state.

A self-healing ring (SHR) network has been studied for interoffice networks due to bandwidth sharing and improved flexibility [1, 2]. They also provide survivability against fiber break. The WDM ring networks proposed recently connect a central office (CO) and N remote nodes (RNs) based on unidirectional transmission, which require a protection fiber to ensure network survivability [1, 2]. These architectures are based on unidirectional add/drop multiplexers. In this paper, we demonstrate a bidirectional WDM SHR with one fiber based on bidirectional add/drop multiplexers (BADM). The proposed ring network can double the transmission capacity in the operating state and provide the self-healing function. Thus we can increase the network reliability. We observed the improvement of power penalty due to the spectral filtering effect in the realized network with 2.5-Gb/s directly modulated signals [1].

The schematic diagram of the BADM for the RN is shown in Fig. 1. The proposed BADM consists of two 4-port circulators, two wavelength division demultiplexers (WDDs) and two fiber gratings. The WDDs and fiber gratings are used for drop function and add function, respectively. The odd wavelength signal inputted to 4-port circulator on the left-hand side is dropped by upper WDD, which determines the drop wavelength. The same odd wavelength signal launched into the add port of the other circulator is reflected by the upper fiber grating and transmitted to the counter-clockwise direction. Similarly, the even wavelength signal is dropped and added.

There are two types of intrachannel crosstalk in the node. The first one is induced by the crosstalk between the added and dropped signals. To suppress this crosstalk below ~50 dB level, the required isolation of each WDD filter and fiber grating is 15 dB [3]. These devices can be realized easily. The second crosstalk arises from the relative intensity noise (RIN) induced by optical back reflection. In the proposed network, the crosstalk due to the RIN is 60 dB below the signal power for 30-dB optical back reflection coefficient of the transmission fiber [3]. Thus, the scalability of the proposed ring network is not limited by the RIN induced by the optical back reflections and the imperfect isolation of the fiber gratings and WDD filters.

Fig. 2 shows the experimental setup for the proposed bidirectional WDM SHR network. We used a conventional single mode fiber (SMF) (10 km, 20 km and 20 km) to connect the nodes. At the CO, the odd wavelength signals (λ1:1550.91 nm and λ2:1554.12 nm) and even wavelength signals (λ3:1552.81 nm and λ4:1555.75 nm) were transmitted to the counter-clockwise direction and the clockwise direction, respectively. The λ1 signal was modulated by a LiNbO3 external modulator and the others were directly modulated at 2.5 Gb/s (pattern length: 23-1).

Add/drop wavelengths were assigned as shown in Fig. 2. At the RN1, for example, λ1 signal coming from the counter-clockwise direction and λ3 signal coming from the clockwise direction were dropped by the WDDs and the new λ1 and λ3 signals were added by the fiber gratings. Similarly, λ2 and λ4 signals were dropped and added at RN2.

When a transmission failure occurs between the RN1 and the RN2, the 2 x 2 electrical switches at the CO and RNs were switched to protect the higher priority signals. At the CO, λ1 and λ4 signals modulated by the higher priority data were transmitted to the RN1 and RN2. Then, the RN1 received λ3 signal without changing the switch state, while the RN2 received λ4 signal by changing the switch state. To transmit the higher priority data to the CO, the RN1 changed the switch state and transmitted λ3 signal in clockwise direction. However, the RN2 transmitted λ4 signal to the CO without switching. Consequently, we can maintain survivability of the ring network for higher priority signals without protection switches in the transmission paths. The electrical switches at receivers of both the CO and RNs may be replaced by 2 x 2 optical switches.

To evaluate the performance of the proposed network, we measured bit error rate (BER) characteristics. The measured BER curves for odd wavelength signals and even wavelength signals are shown in Fig. 3 (a) and (b), respectively. Here, W
stands for the working state and \( p \) stands for the protection state. The \( \lambda_1 \) signal has no power penalty since it is the signal modulated by external modulator. For \( \lambda_2 \) and \( \lambda_3 \) signals dropped at RNs, the measured power penalties (at BER = 10\(^{-9}\)) were < 0.5 dB. These penalties arise from the chirp induced in the directly modulated laser diode. The amount of power penalties depends on the characteristics of the laser diode and the transmission distance.

For the signals received at the CO, we observed negative power penalty, although we use the directly modulated lasers. It can be compared with the received signals at the RNs. These results can be explained by the spectral filtering effect in directly modulated transmission systems. We do not expect the spectral filtering effect for the receivers located at the RNs, since the WDD filter bandwidth of 135 GHz is larger than spectral width of the directly modulated signal. However, at CO, we used optical filters with a 60 GHz bandwidth for \( \lambda_2 \) and \( \lambda_3 \) signals and observed about 0.5 ~ 0.7 dB power penalty reduction. To enhance spectral filtering effect, we used the optical filter with a 30-GHz bandwidth for \( \lambda_1 \) signal. Then, power penalty was improved about 1.2 dB. It may be noted that the simulation predicts optimum filter bandwidth of 8 GHz to maximize the spectral filtering effect.

To demonstrate the self-healing function, we simulated a transmission failure on the path between the RN1 and the RN2 by using a 1 x 2 electro-mechanical switch. The measured BER curves at the CO, RN1 and RN2 show no power penalty as shown in Figs 3(a) and (b). Fig. 4 shows the protection characteristics of the ring network. The upper trace stands for the state of the 1 x 2 electro-mechanical switch. The lower trace represents the received power at the RN2. The measured protection time was < 8 ms.

We estimated the scalability of the proposed network for node spacing of 15 km (span loss of 3.3 dB). The parameters used in this estimation were as follows: isolations of each WDD and fiber grating = 15 dB, remote node (two circulator, WDD and fiber grating) loss = 2.6 dB, optical reflection coefficient = -30 dB and receiver sensitivity = -30 dBm. Considering the RN and receiver sensitivity, the proposed network could accommodate 6 nodes without optical amplifier at 2.5 Gb/s. To increase the network size, we should use bidirectional optical amplifier. One bidirectional optical amplifier of 12-dB gain could increase the network size by 2 nodes.

We have demonstrated a bidirectional WDM SHR network for hub/remote nodes with a single strand fiber. In this network, the transmission capacity can be doubled in the operating state. The proposed ring network provides the self-healing function without the optical protection switches in the transmission path. The experiment has shown that protection can be achieved within 8 ms. We also improved the power penalty by using the spectral filtering method. We have estimated that the proposed network could accommodate about 6 nodes without optical amplifiers when the node spacing is 15 km.

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**Fig. 1** Configuration of the bidirectional add/drop multiplexer

**Fig. 2** Experimental setup of bidirectional WDM SHR network

**Fig. 3** Measured BER curves: (a) odd wavelength signals, (b) even wavelength signals

**Fig. 4** Measured protection characteristics

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**References**