Bidirectional WDM Self-Healing Ring Network Based on Simple Bidirectional Add/Drop Amplifier Modules

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I. Introduction: Recently, bidirectional WDM self-healing ring (SHR) networks based on bidirectional transmission have been proposed [1]-[2]. These networks are attractive since they require only two fibers instead of four fibers. However, in a bidirectional network, the relative intensity noise (RIN) due to Rayleigh backscattering, optical reflection and inband crosstalk could degrade the system’s performance and limit the network’s scalability [3]-[4]. In this paper, we demonstrate a bidirectional WDM SHR network by using the recently proposed bidirectional add/drop amplifier (BADA) module [5]. This simple module can be implemented cost-effectively by using only one N x N WDM multiplexer in a fold-back configuration. In addition, the RIN was suppressed efficiently by using two bandpass filters within the module. Accordingly, there was no degradation in the receiver sensitivity caused by RIN when the BADA modules are used in bidirectional networks. Thus, the network’s scalability is limited by the accumulated amplified spontaneous emission (ASE) noise.

II. Node Description: Fig. 1(a) shows the schematic diagram of the network’s node, which consists of a BADA module, two thermo-optic polymer switches, and an additional bidirectional EDFA for the protection ring. Thus, the bidirectional add/drop multiplexer (B-ADM) indicates the BADA module without the EDFA’s at its both ends. The details of the B-ADM are shown in Fig. 1(b). The B-ADM was implemented by using only one N x N arrayed waveguide grating (AWG) multiplexer, two circulators and two optical bandpass filters [5]. These optical bandpass filters were used to prevent the accumulation of RIN generated in the bidirectional transmission and add/drop multiplexing of WDM signals. Thus, the 3-dB bandwidth of these filters should be wide enough (-10 nm in our work) to pass all the signals propagating in one direction (i.e., OBPF1 for clockwise direction and OBPF 2 for counter clockwise direction), while suppress the unwanted signals propagating in the other direction. This node is capable of restoring the transmission failure automatically. In case of fiber-cut, the control circuits detect the transmission failure by monitoring the signals at the inputs of EDFA’s in the working ring and trigger the relevant switches (adjacent to the fiber cut) to transfer the signals from the working ring to the protection ring. The switching times and insertion losses of the thermo-optic polymer switches were about 1.5 ms and 3.5 dB, respectively. The additional bidirectional EDFA located at the protection ring compensates the fiber and component losses.

III. Network Demonstration: Fig. 2 shows the experimental setup of a bidirectional WDM SHR network. The fiber length between nodes was 40 km. In node 1, two DFB lasers transmitted 2.5-Gb/s signals (pattern length: 221-1) in each direction. The signal wavelengths were 1549.32 nm and 1550.92 nm (for counter-clockwise direction), and 1555.75 nm and 1557.36 nm (for clockwise direction), respectively. To demonstrate the bidirectional add/drop capability, the signals at 1549.32 nm and 1557.36 nm were dropped at node 2 and node 3, respectively. The new signals at the same wavelengths were added at the dropped nodes and received at node 1. To evaluate the performance of bidirectional transmission, we transmitted one signal in each direction (1550.92 nm for counter-clockwise and 1555.75 nm for clockwise direction) all the way around the ring, and received at node 1. Thus, these signals passed through 6 bidirectional EDFA’s and 3 B-ADM’s. Fig. 3 shows the measured BER curves of six signals. The maximum power penalty was measured to be less than 0.5 dB at an error rate of 10^-9.

To demonstrate the self-healing capability, we simulated a transmission failure (e.g., due to fiber-cut) between node 1 and 3 by using an acousto-optic modulator (AOM). Fig. 4(a) shows the measured restoration characteristics of the proposed network. The upper trace represents the electrical signal applied to the acousto-
optic modulator. The transition of this signal to lower level indicates the transmission failure. The lower trace represents the signal (at 1550.92 nm) received at node 1 before and after the restoration. Before the transmission failure (normal state), this signal was passing all the way around the working ring (node 1-2-3-1). However, in case of fiber-cut, it was no longer possible to receive this signal at node 1 through the working ring. Thus, this signal was transferred to the protection ring at node 3, and sent back to node 1 through the protection ring (node 1-2-3-2-1). This restoration was achieved within 2 ms, as shown in Fig. 4(a). Fig. 4(b) shows the measured BER curves of the restored signals. The maximum power penalty of the restored signal (i.e., the power penalty of the signal restored by passing through the maximum number of nodes: 3 nodes in the working ring and 3 nodes in the protection ring) was less than 0.5 dB (BER = 10⁻⁶).

To estimate the scalability of the proposed network, we calculated the power penalty of the restored network caused by the accumulation of RIN and ASE noise in bidirectional transmission as shown in Fig. 5 [3]-[4]. We assumed that the signal gain of EDFA was equal to the span loss and the RIN was generated from Rayleigh backscattering. The parameters used in this calculation were as follows: noise figure of EDFA = 5.5 dB, measured Rayleigh reflection coefficient = -28 dB, extinction ratio of bandpass filter = 35 dB, and fiber loss = 0.275 dB/km. Fig. 5 shows the effectiveness of the bandpass filters in reducing the effects of RIN. This is mainly because the signals propagating in unwanted directions within the BADA modules were suppressed effectively by the extinction ratio of these bandpass filters. Without using these filters, the SHR network can not accommodate more than 3 nodes even when the node spacing is as short as 40 km. However, when the bandpass filters are used as in the proposed network, the power penalty caused by RIN becomes negligible and the maximum network size is limited by the accumulation of ASE noise. In this case, the proposed network could accommodate more than 40 nodes. However, the maximum network size would be reduced as the node spacing is increased due to the increased ASE noise of EDFA. When the node spacing is increased to 80 km, the proposed network could accommodate about 14 nodes (considering the signals passing through the protection ring at transmission failure, otherwise the proposed network could accommodate about 28 nodes).

IV. Summary: We have demonstrated a cost-effective bidirectional WDM SHR network using BADA modules. The restoration time was measured to be less than 2 ms. The bandpass filters within the BADA modules are proved to be very effective in reducing the RIN caused by Rayleigh backscattering and optical reflections. In fact, there was no observable degradation in the receiver sensitivity caused by RIN. Thus, the scalability of the proposed network would be limited by the accumulation of ASE. From these results, we have estimated that this network could accommodate about 14 nodes when the node spacing is 80 km.

References

Fig. 1. (a) Node configuration of proposed bidirectional self-healing ring network.
(b) Schematic diagram of bidirectional WDM add/drop multiplexer (B-ADM).
Fig. 2. Experimental setup of 3-node bidirectional WDM SHR network.

Fig. 3. Measured bit-error-rate vs. received power.

Fig. 4. (a) Measured restoration characteristics under transmission failure between node 1 and 3. (b) BER curves for restored signals.

Fig. 5. The calculated power penalty caused by accumulation of RIN and ASE noise.