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Optical-Layer Restoration in a Self-Healing Ring Network Using a Wavelength-Blocker-based Reconfigurable Optical Add/Drop Multiplexer

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Optical-layer restoration has been demonstrated with a wavelength-blocker (WB) -based reconfigurable optical add/drop multiplexer (ROADM). Two 2 × 2 optical switches with a control circuit were placed before and after a WB-based ROADM to provide automatic path restoration under fiber-failure conditions. Using the proposed node configuration, a 3-node self-healing ring (SHR) network has been implemented to demonstrate the feasibility of the automatic optical-layer restoration. From the results, the restoration time was measured to be ~4 ms under fiber-failure conditions, without any additional power penalty in receiver sensitivity.

Keywords : Self-healing ring network, Reconfigurable optical add/drop multiplexer, Optical-layer restoration
OCIS codes : (060.0060) Fiber optics and optical communications; (060.2330) Fiber optics communications

I. INTRODUCTION

Reconfigurable optical add/drop multiplexers (ROADMs) with wavelength-division multiplexed (WDM) technology could provide a lot of flexibility in optical transport networks [1-5]. Among various types of ROADMs, wavelength-selective switch (WSS) -based ROADMs could support mesh and multi-ring configurations, to maximize utilization of existing network infrastructure, and thus efficiently reduce both capital expenditure (CAPEX) and operational expenditure (OPEX) [1-3]. Even though WSS-based ROADMs would be suitable for the deployment of multi-ring network (> degree 2) architectures, simple ring (degree 2) networks do not need this type of third-generation ROADM. For cost-effective deployment of systems, a simple ring architecture could still be used widely in metro and access network configurations [4-6]. A wavelength-blocker (WB) -based ROADM might be well suited to cost-effective deployment of metro or access networks. Previously, we have demonstrated transmission and flexible add/drop multiplexing of WDM signals with a slightly modified WB-based ROADM [7]. In addition to flexible add/drop multiplexing of WDM signals, an optical-layer restoration feature should be demonstrated for efficient implementation of a simple ring network [4-6, 8]. Thus, in this paper, we have proposed and demonstrated a node configuration with a WB-based ROADM, which could provide an optical-layer restoration feature. 2 × 2 optical switches were used to re-route the transmission path from a working fiber to a protection fiber automatically when fiber failure was detected. A 3-node self-healing ring (SHR) network has been also implemented, to demonstrate the feasibility of optical-layer restoration with the proposed node configuration. In our demonstration, a fiber cut has been restored automatically within ~4 ms. In addition, the performance of signal transmission was evaluated with measurements of the bit-error rate (BER). From the results, no additional power penalty was observed for signal transmission through a restored path.

II. PROPOSED NODE CONFIGURATION

Figure 1(a) shows the proposed node configuration with a WB-based ROADM. The WDM signals launched into a node were first amplified with an erbium-doped fiber amplifier (EDFA). A small portion of the amplified signal

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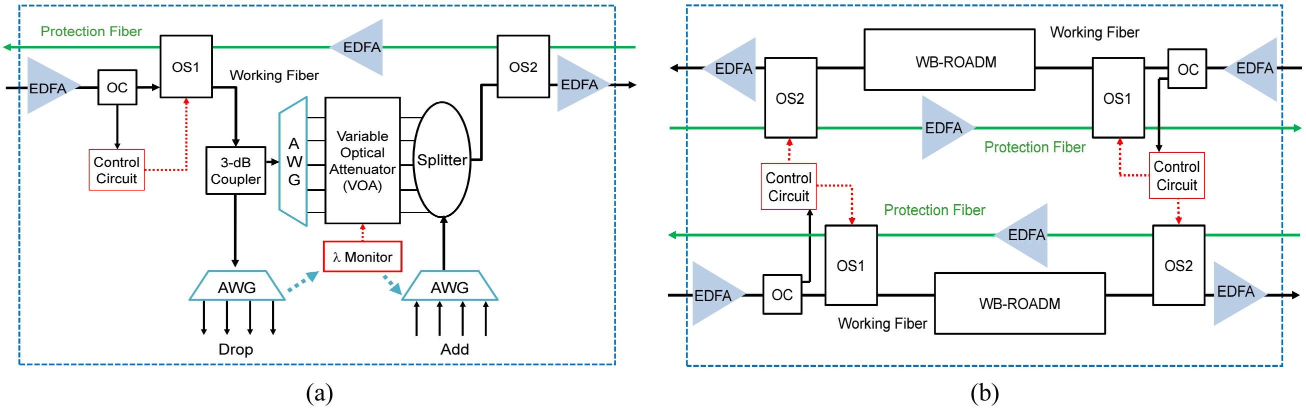


FIG. 1. (a) Proposed node configuration with a wavelength-blocker (WB) -based reconfigurable optical add/drop multiplexer (ROADM). (b) Node configuration for a four-fiber bidirectional self-healing ring network. Acronyms are erbium-doped fiber amplifier, EDFA; optical coupler, OC; optical switch, OS; and arrayed waveguide grating, AWG.

was then monitored with an optical coupler (OC) and a control circuit for an optical switch (OS1). The control circuit was implemented with a photo-diode and an electric circuit for the state change of the optical switch. Two 2 × 2 optical switches (OS1 and OS2) were used for optical-layer restoration when fiber failure was detected. After passing through the OC and OS1, WDM signals were split into two paths, one for the dropped signals and the other for the passing-through signals. Any WDM signal channels could be dropped, after demultiplexing with an arrayed waveguide grating (AWG). The passing-through signals were also demultiplexed with the other AWG; then the dropped channels could be blocked with a WB, which was implemented with an array of variable optical attenuators (VOAs). Next the passing-through signals and added signals were wavelength-multiplexed with a combiner (splitter). To implement signal add/drop multiplexing without any collisions, the wavelengths of the dropped channels should be monitored, and the monitored wavelengths of the dropped channels should be shared properly with the controllers for the VOAs and the signal addition. These WDM signals could be transmitted to another node after passing through OS2 and an EDFA. For the optical-layer restoration, a protection fiber was also deployed and connected to two optical switches and another EDFA (which was placed for signal amplification when the WDM signal would be restored through a protection fiber). To implement a SHR network, four-fiber configuration would be widely used for efficient bidirectional signal transmission [8]; thus Fig. 1(b) shows a node configuration suited to automatic optical-layer restoration for bidirectional signal transmission. Four optical switches should be used for the bidirectional signal transmission and the path restoration. However, the states of two optical switches (OS1 for one direction and OS2 for the other direction) could be adjusted with a single control signal in our node configuration, as shown in Fig. 1(b).

III. RESULTS AND DISCUSSION

First, we measured the switching response of an optical switch, as shown in Fig. 2. The upper trace represents the driving electrical voltage for the optical switch used in our experiment. The optical power of one output port of the 2 × 2 switch was measured, as shown in the lower trace of Fig. 2. From the response of the optical switch, the rise and fall times were measured to be ~1 ms and ~6 ms, respectively. Thus we found that it would be better to use the rise-time response for the path restoration in demonstrating a SHR network.

To demonstrate the feasibility of automatic optical-layer restoration with the proposed node configuration, we have implemented a 3-node ring network, as shown in Fig. 3(a). Due to the limited numbers of optical components in our laboratory, only signal transmission in one direction with two fibers (one working fiber and one protection fiber) has been demonstrated, at the moment. Under the normal conditions shown in Fig. 3(a), four WDM signals were added to the ring network at Node 1 in our demonstration.

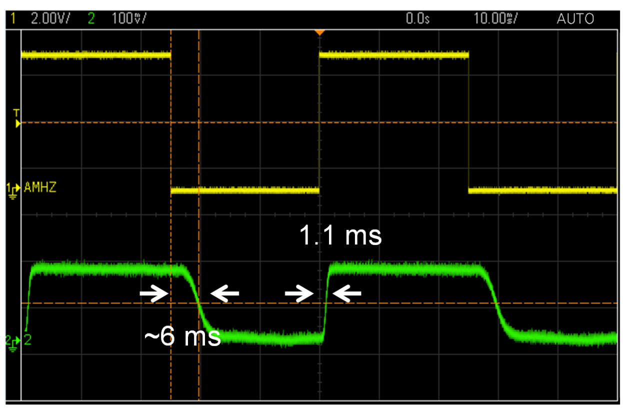


FIG. 2. Measured switching response of an optical switch. Upper and lower traces represent respectively the driving electrical voltage and optical power of one output port.

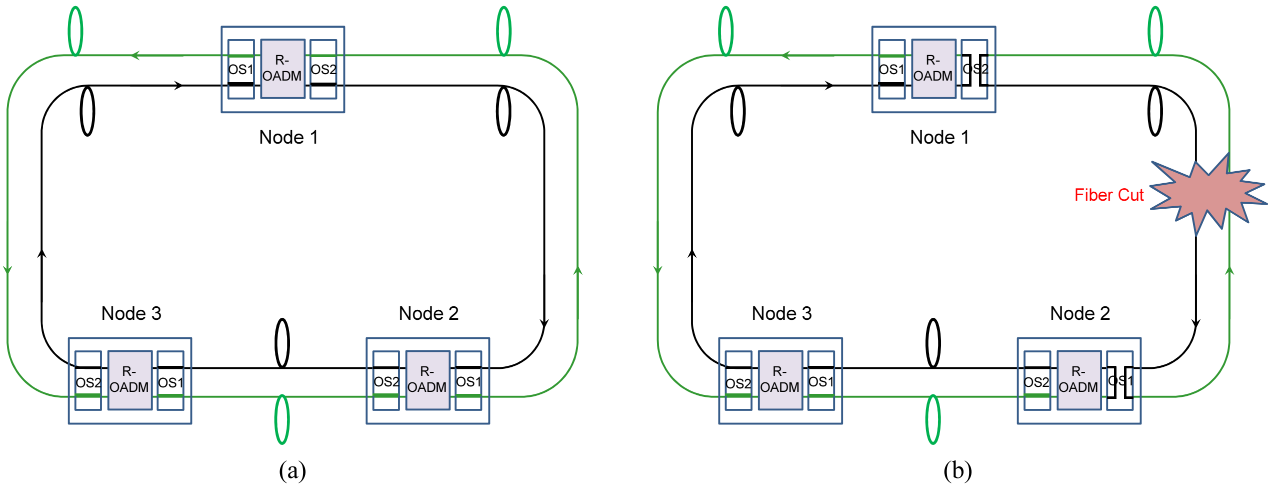


FIG. 3. (a) A 3-node self-healing ring (SHR) network for one-way signal transmission under normal conditions. (b) Optical-layer restoration under fiber-cut conditions between Nodes 1 and 2. Acronyms are optical switch, OS; and reconfigurable optical add/drop multiplexer, ROADM.

Then these added WDM signals were transmitted through Node 2 and dropped at Node 3. However, when both fibers were cut between Nodes 1 and 2, as shown in Fig. 3(b), the states of OS2 at Node 1 and OS1 at Node 2 were automatically changed into a cross state. Then the added WDM signals at Node 1 were transmitted through the protection fiber (Node 1 → Node 3 → Node 2 through the protection fiber via OS2 at Node 1) and back to the working fiber at OS1 at Node 2. Finally, these signals were transmitted from Node 2 to Node 3. In this demonstration, an acousto-optic (AO) modulator was placed between Nodes 1 and 2 to simulate a fiber cut. In a four-fiber SHR network configuration, the state of OS2 at Node 1 would be changed with a control signal from the power monitoring of the signal in the other direction, as explained in Fig. 1(b). However, in our two-fiber SHR network demonstration, the state of OS2 at Node 1 was adjusted with a control signal for OS1 at Node 2. However, we believe that this problem might be fixed simply with a four-fiber SHR network configuration.

Figure 4 shows the measured optical power of one dropped channel at Node 3, before and after a fiber cut. The dropped channel was added at Node 1 and the fiber cut was simulated between Nodes 1 and 2, as shown in Fig. 3. The monitored dropped channel was transmitted through a working fiber under normal conditions, and through both protection and working fibers after a fiber cut. As shown in the figure, the proposed configuration could restore the transmission path properly even after a fiber cut. The restoration time was measured to be ~4 ms, which is shorter than the restoration time in a conventional SHR network [8].

We have measured the optical spectra of the dropped channels at Node 3, before and after a fiber cut. Under fiber-cut conditions, an additional EDFA was used after signal drop at Node 3, to compensate an additional loss of a protection fiber and set the power levels of dropped channels to be equal before and after a fiber cut. Thus the optical signal-to-noise ratios (OSNRs) of the dropped channels under normal conditions was slightly higher than those under fiber-cut conditions, but in both cases the OSNRs were greater than 20 dB, as shown in Fig. 5(a). To evaluate the transmission performance of a signal channel, bit-error-rate (BER) curves were also measured before and after a fiber cut, as shown in Fig. 5(b). For BER measurements, the added signal was modulated with a 10 Gb/s non-return-to-zero (NRZ) format, which has a pseudo-random bit sequence (PRBS) length of 2^{31}-1. To avoid a dispersion-induced power penalty in these measurements, the fiber lengths between nodes were set to be ~10 km. No significant power penalty was observed before and after a fiber cut, as shown in Fig. 5(b). Thus, we have confirmed that our optical-layer restoration scheme in a SHR network was efficiently implemented with the proposed WB-based ROADM node configuration.

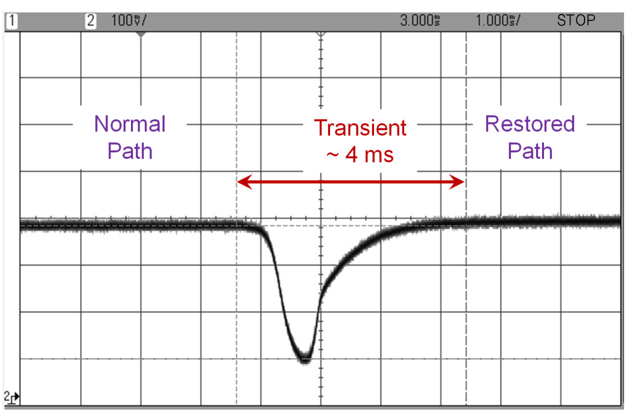
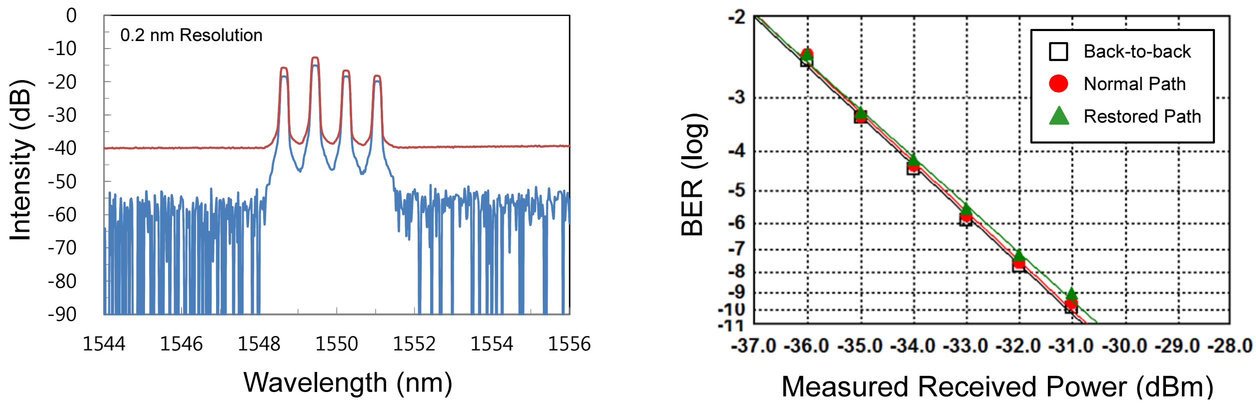


FIG. 4. Measured optical power of one dropped channel at Node 3, before and after a fiber cut.



(a) (b)

FIG. 5. (a) Measured optical spectra of the dropped channels at Node 3, before and after a fiber cut. (b) Measured bit-error-rate curves of one dropped channel at Node 3, transmitted through only working fiber (●) and through both working and protection fibers (▲). In both measurements, the dropped channel at Node 3 was originally added to the network at Node 1.

IV. SUMMARY

We have proposed and demonstrated a WB-based ROADM node configuration suitable for use in optical-layer restoration. Two 2 × 2 optical switches with a control circuit were used to implement the automatic path-restoration under fiber-failure conditions. The switching times of the optical switch were measured to be ~1 ms and ~6 ms for rise and fall respectively. Using the proposed node configuration, a 3-node SHR network was implemented to demonstrate the feasibility of the automatic optical-layer restoration. From the results, the restoration time was measured to be ~4 ms under fiber-failure conditions, without any additional power penalty in receiver sensitivity. Thus, we believe that the proposed scheme might be well suited for use in cost-effective, simple ring network configurations.

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