Simultaneous Optical Monitoring and Fiber Supervising for WDM Networks Using an OTDR Combined With Concatenated Fiber Gratings

C. C. Lee, T. C. Kao, and S. Chi

***Abstract*—We have proposed a new optical monitoring technique that employs an optical time-domain reflectometer combined with an acoustooptic switch and concatenated fiber Bragg gratings to achieve simultaneous optical monitoring and fiber surveillance for wavelength-division-multiplexed (WDM) networks. The optical power monitoring with dynamic range of 26 dB and accuracy $\leq \pm$ 0.1 dB for each WDM channel and the feasibility of simultaneous optical monitoring and fiber surveillance in WDM networks have also been demonstrated by using this technique.**

***Index Terms*—Fiber Bragg grating, optical time domain reflectometer, WDM networks.**

I. INTRODUCTION

WAVELENGTH-DIVISION-MULTIPLEXED (WDM) technique has been intensively employed to raise transport capacity in all optical networks. This evolution also brings new requirements for optical surveillance of channel characteristics and system performance. Conventional grating spectrometers, wavemeters, and scanning fiber Fabry–Pérot filters can be used for optical monitoring but with the disadvantage of cost, performance and reliability. Recently, several new techniques have been proposed for optical monitoring in WDM systems. In these approaches, the one that utilizes the detection of the transparent point of semiconductor optical amplifier or semiconductor laser diode can provide sub-angstrom wavelength resolution for wavelength monitoring, but is unsuitable to supervise channel optical power [1]. Another techniques that combine an optical delay line such as concatenated fiber Bragg gratings (FBGs) with the optical sampling method [2] or the data correlation detection [3] can accomplish wavelength and channel power monitoring. In this letter, we propose and demonstrate a new optical monitoring technique that employs an optical time-domain reflectometer (OTDR), an acoustooptic switch (AOS), and an optical delay line composed of concatenated FBGs to achieve sampling and wavelength-to-time mapping for the multiwavelength data streams. Compared to the method in [2], this proposed method has the following advantages: 1) the ability to simultaneously measure the linked fiber status and the optical power at each wavelength; 2) higher dynamic range and sensitivity; and 3) the ability to be integrated with OTDR.

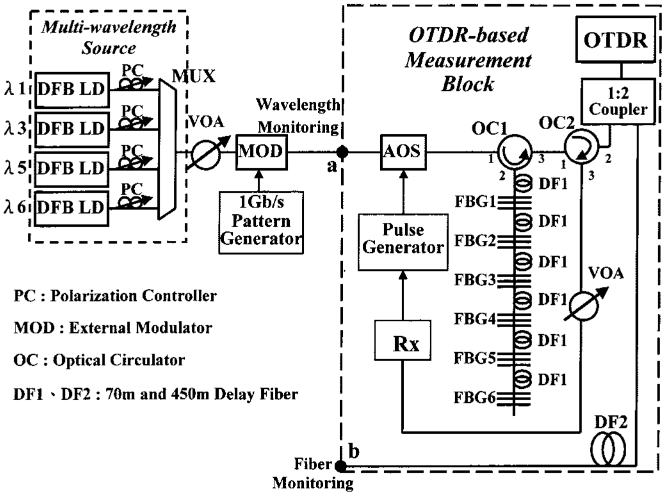

Fig. 1. Experimental setup for the optical monitoring.

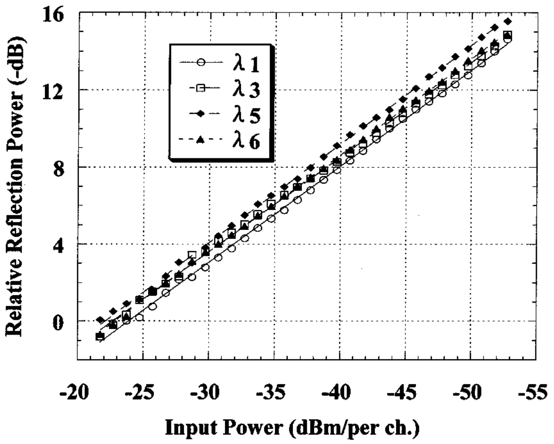

Fig. 2. By using the OTDR-based measurement block, the relative reflection powers versus the input power for the wavelengths of λ_1, λ_3, λ_5, and λ_6.

II. EXPERIMENTAL SETUP AND RESULTS

Fig. 1 shows the experimental setup for the optical monitoring. The operating wavelengths from λ_1 to λ_6 represent the optical wavelengths at 1549.32, 1550.12, 1550.92, 1551.72, 1552.52, and 1555.75 nm, respectively. As shown in Fig. 1, an OTDR-based measurement block, which is composed of a commercial OTDR, an AOS, an optical delay line consisting

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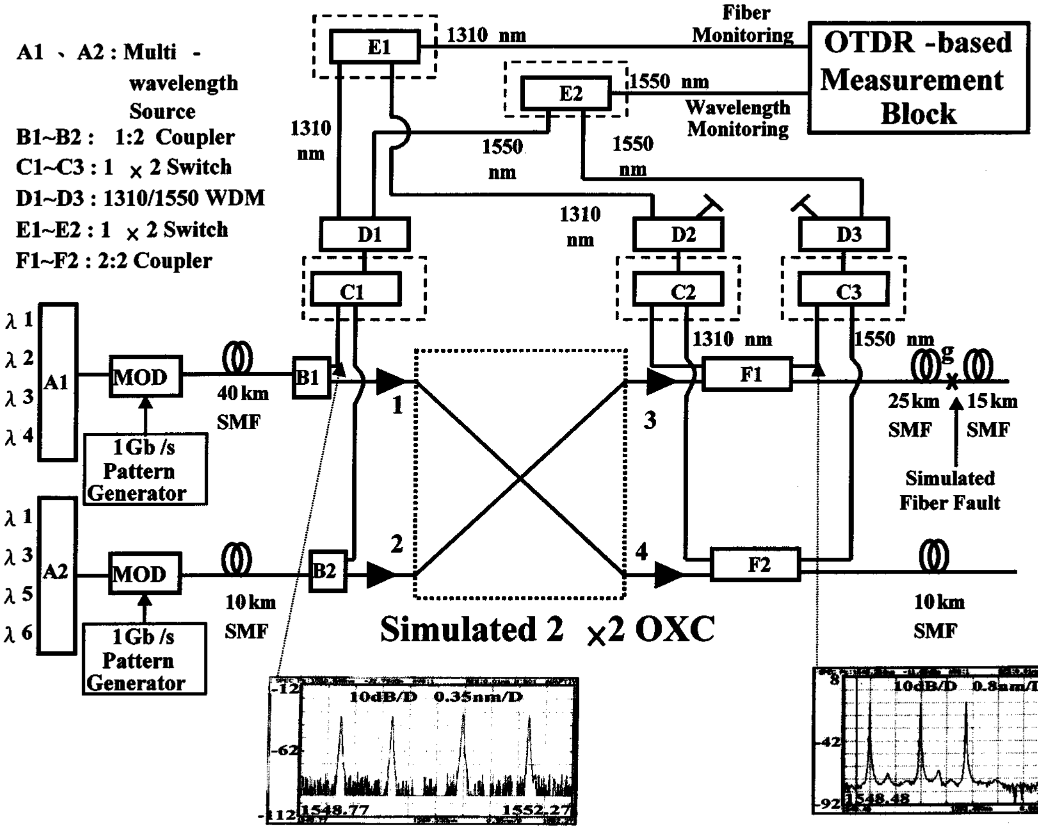
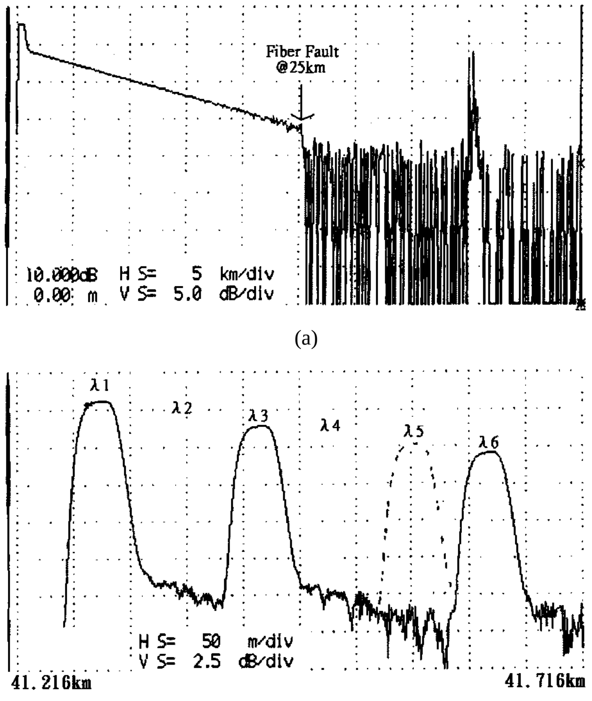


Fig. 3. The experimental setup for simultaneous optical monitoring and fiber supervising in WDM networks. The insets are the optical spectra of the WDM signals at the port "1" and port "3" of this OXC.

of six concatenated FBGs with a 70-m delay fiber spacing, two optical circulators (OC1 and OC2), a 1 : 2 optical coupler, an variable optical attenuator (VOA), a 155-Mb/s optical receiver (RX), a pulse generator, and another 450-m delay fiber, is used to provide the optical monitoring and fiber supervising. These used FBGs have reflectivity of 99.95%, 0.5-dB bandwidth of ~0.36 nm, and central wavelengths from λ_1 to λ_6. The operating conditions of the OTDR were as follows: output power of 23 dBm, pulsewidth of 100 ns, average times of 100, and spatial resolution of 2 m. Optical probe pulse generated from the commercial OTDR are split by the 1 : 2 optical coupler and injected into two optical paths. One path connecting to the 450-m delay fiber line acts as the fiber supervisory route. In another path, the optical probe pulse passing through OC2 and VOA is received at RX and converted into an electrical trigger signal for the pulse generator. An electrical pulse signal of the pulse generator, which has a tunable delay time and pulsewidth, is used to produce an AOS control signal. A multiwavelength source, which was formed by four DFB laser diodes with the wavelengths of $\lambda_1, \lambda_3, \lambda_5$, and λ_6 combined with an external modulator driven by an electrical signal of 1 Gb/s and $2^{23} - 1$ PRBS data pattern is used to simulate the optical signal in the WDM networks. The optical signal from the external modulator is sampled by the AOS with 300-ns duration and the concatenated FBGs are employed to give a staggered time delay to different wavelengths. To verify the optical monitoring performance of this OTDR-based measurement block, we varied the optical power per channel from the external modulator by adjusting the attenuation loss of VOA for the measurements of the linearity, the dynamic range, and the signal-to-noise ratio (SNR) at the receiver of OTDR. Fig. 2 shows the relative reflection powers on the trace of the OTDR, which is referred to the reflection power at "b" point, versus the input power of this OTDR-based measurement block at "a" point for the wavelengths of $\lambda_1, \lambda_3, \lambda_5$, and λ_6, respectively. From Fig. 2, a good linearity with the error $\leq \pm\, 0.1$ dB can be obtained in the input power range from -49 to -23 dBm. In the input power range from -49 to -23 dBm, the SNRs are larger than 5.4 dB and the standard deviations are less than 0.1 dB for these wavelengths. Therefore, the dynamic range of 26 dB for error $\leq \pm\, 0.1$ dB is achieved by using this method.

This proposed technology can be applied to metro area networks (MANs) for the monitoring of network elements such as optical cross connects (OXCs) or optical add/drop multiplexers (OADMs). The "optical monitoring" means to monitor the optical power and wavelength at each WDM channel. Moreover, the "fiber supervising" means to monitor the related fiber status such as the distributed loss, fault type and fault location in fiber links. To demonstrate that this OTDR-based measurement block has the ability of simultaneous optical monitoring and fiber supervising in WDM networks, the experimental setup in Fig. 3 is employed. As shown in Fig. 3, the optical signals with 1-Gb/s modulation, which are generated from one set of multiwavelength source with wavelengths from λ_1 to λ_4 and from another set of multiwavelength source with wavelengths of $\lambda_1, \lambda_3, \lambda_5$, and λ_6, are used to represent the WDM signals



(a)

(b)

Fig. 4. For the output port of the OXC in Fig. 3, the measured traces of the OTDR-based measurement block in the cases of (a) a simulated fiber cut occurred at “g” position in Fig. 3, and (b) the disappearing of the λ_5 wavelength in the WDM signals.

that enter into a simulated 2×2 OXC through port “1” and “2” individually after passing 40-km and 10-km single-mode fiber (SMF). These WDM signals are cross-connected from port “1” to port “4” and port “2“ to port “3” by the simulated 2×2 OXC. After leaving this OXC, these signals propagate through 40-km and 10-km SMF links to reach the next network elements. The monitoring ports of the simulated OXC were tapped by a $1:2$ optical coupler and a $2:2$ optical coupler for the optical monitoring and fiber supervising. After passing through a 1×2 optical switch, a 1310/1550-nm wavelength-division multiplexer and a 1×2 optical switch, the optical pulse of 1310 nm from the fiber monitoring port of the OTDR-based measurement block can be launched into the selected fiber link to provide the surveillance of the fiber links of the OXC. Besides, the monitoring WDM signals tapped from the 1:2 optical coupler and the 2:2 optical coupler are transmitted through a 1×2 optical switch, a 1310/1550-nm wavelength-division multiplexer and a 1×2 optical switch to reach the wavelength monitoring port of the OTDR-based measurement block. The 1×2 optical switch (E2) in Fig. 3 can select the optical path to provide the monitoring of the WDM signals to enter or leave the OXC. In the same time, the 1×2 optical switches (C1 and C3) in Fig. 3 are used to select the monitoring port of the OXC. The operating conditions of the OTDR for fiber supervising/optical monitoring were set as following: output power of 23 dBm, pulsewidth of 1 μs, average times of 100, and spatial resolution of 2 m. Furthermore, In the operation of zoom-in measurement, the OTDR operating parameter of pulsewidth was set as 100 ns. In addition, the delay time and pulse duration of the pulse generator were set as 400 μs and 300 ns. The optical spectra of the WDM signals at the port “1” and port “3” of this OXC are shown in the insets in Fig. 3. The measured trace can be divided into two parts—the fiber supervising and the optical monitoring sections. If a simulated fiber cut was occurred at “g” position in Fig. 3, this measured trace in the case of the fiber fault is shown as Fig. 4(a). Since the fiber cut was at the location after the OXC about 25-km, it will not affect the detection of WDM signals at port “3” of OXC. Therefore, the WDM signals are still detected as shown in Fig. 4(a). Also from Fig. 4(a), the location and the fault type of this fiber fault can be easily obtained and identified. The wavelength λ_5 of the WDM signals in port “3” of the OXC will disappear due to the failure of the λ_5 laser in A2 of Fig. 3, the wavelength λ_5 routing form port “2” to port “4” or the wavelength λ_5 routing failure by OXC. If this happens, Fig. 4(b) shows the measured zoom-in trace of the OTDR-based measurement block in the optical monitoring section. From Fig. 4(b), it is obvious that the reflected pulse that represents the wavelength λ_5 is missing in port “3” of OXC. As a result, the simultaneous optical monitoring and fiber supervising for WDM networks can be achieved by using this OTDR-based measurement block.

III. CONCLUSION

We have proposed a new optical monitoring technique that employs an OTDR combined with an acoustooptic switch and concatenated FBGs to achieve simultaneous optical monitoring and fiber surveillance for WDM networks. The optical power monitoring with dynamic range of 26 dB and accuracy $\leq \pm 0.1$ dB for each WDM channel and the feasibility of simultaneous optical monitoring and fiber surveillance for WDM networks have also been demonstrated by using this technique.

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