# Demonstration of a Scalable Fault Surveillance Scheme for WDM Transmission Links

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## Introduction

In long haul WDM transmission systems, some kinds of surveillance schemes are needed for the status monitoring of the in-line erbium-doped fiber amplifiers (EDFAs)[1] and the identification of fiber breaks to guarantee the quality of service. Previous surveillance schemes that based on using the combination of fiber Bragg gratings (FBGs) and amplified spontaneous emission (ASE) as monitoring source were proposed[2,3]. In these schemes, FBGs of various distinct wavelengths are inserted at the inputs of all in-line EDFAs to reflect selectively the ASE for monitoring purpose. These schemes, however, are not scalable and can only be applied to long-haul transmission systems with limited distances, as each FBG's wavelength has to be unique. Here, we propose a scalable surveillance scheme, which is based on a novel monitoring-wavelength reuse concept. The proposed scheme was demonstrated experimentally.

## Proposed Scheme

We divide a long-haul transmission system into $N$ sections as shown in Fig. 1(a). For the $i$-th section, it consists of $m$ EDFAs ($EDFA_{i,1}$ to $EDFA_{i,m}$), $m$ fiber segments ($L_{i,1}$ to $L_{i,m}$), and $m$ FBGs ($FBG_{i,1}$ to $FBG_{i,m}$) of $m$ distinct center wavelengths. Each FBG can monitor the health statuses of the corresponding EDFA and the fiber segment upstream. Any failure in the EDFA or the fiber segment will result in a power surge at the wavelength corresponding to the FBG's center wavelength[3] at the monitor. For reuse of monitoring wavelengths, we further divide the EDFA spectra into red, middle and blue bands (1529-1542 nm, 1547-1556 nm, 1557-1566 nm). The flat middle-band is reserved for data channels. The two side bands, the red and the blue bands, are dedicated as the sources for monitoring function and are used alternately in consecutive sections. At the end of each section, a WDM demultiplexer (WDD) is used to filter off the monitoring band. The power levels of the monitoring channels are then detected and forwarded to the central office.

## Experiments

The experimental setup is shown in Fig. 1(b), consisting of a total of three sections. The data-channel band is 1547-1556 nm, and the red and blue monitoring bands are 1529-1542 nm and 1557-1566 nm, respectively. The setup consists of one power EDFA at the transmitter and five in-line EDFAs ($EDFA_{1,1}$, $EDFA_{1,2}$, $EDFA_{2,1}$, $EDFA_{2,2}$, and $EDFA_{3,1}$), five standard (non dispersion-shift) fiber links ($L_{1,1}$= 23 km, $L_{1,2}$= 50 km, $L_{2,1}$= 31 km, $L_{2,2}$= 50 km, $L_{3,1}$= 50 km), four FBGs providing four monitoring channels at $\lambda_{1,1}$= 1536.27 nm, $\lambda_{1,2}$= 1532.74 nm, $\lambda_{2,2}$=1557.55 nm, $\lambda_{3,1}$=1531.99 nm, and one WDM demultiplexer (JDS-WD1515RB) splitting input spectra into 1547.72-1558.98 nm and 1531.94-1542.94 nm. As our focus dwells on the monitoring-wavelength reuse performed by the two FBGs with close center wavelengths, $FBG_{1,2}$ (monitoring $EDFA_{1,1}$ and $L_{1,2}$ at $\lambda_{1,2}$) and $FBG_{3,1}$ (monitoring $EDFA_{2,2}$ and $L_{3,1}$ at $\lambda_{3,1}$) in section 1 and 3, respectively. The section-2 health statuses are left unmonitored. Four data channels at λ=1548.71, 1551.41, 1553.48, and 1555.50 nm are modulated at 2.5 Gbit/s with $2^9$-1 PRBS NRZ data. An optical receiver (ORX) with optical pre-amplifier was used to detect the data channel at 1548.71nm.

The status monitoring of EDFAs was demonstrated in Fig. 2. We consider the case of simultaneous partial failure of two EDFAs in two separate sections. Comparing the power spectra in Fig. 2(a) and 2(b) with Fig. 2(c) and 2(d), partial failures of $EDFA_{1,1}$ and $EDFA_{2,2}$ can be detected correspondingly at $Monitor_1$ and $Monitor_3$. There are total changes of 16.5 dB and 14.0 dB at the monitoring channels $\lambda_{1,2}$ and $\lambda_{3,1}$, respectively. The considerable power change at the two similar monitoring wavelengths but from two separate sections demonstrates wavelength reuse of the EDFA-status monitoring. To compare the system performances with and without the monitoring scheme, BER measurements were taken (Fig. 3) with reference to the back-to-back data measurements. Overall, the monitoring scheme shows a 0.6 dB system penalty at a bit-error rate of $10^{-9}$ compared with the measurements without the monitoring scheme.

The fault identifications of fiber break for three individual cases are shown in Fig. 4. Power spectra [Fig. 4(a) and 4(b)] show a 32.0-dB and 3.3-dB power change at the monitoring channels $\lambda_{1,2}$ and $\lambda_{3,1}$ when the fiber segment $L_{1,2}$ in section 1 is broken. The 3.3-dB power change at $\lambda_{3,1}$ represents an error signal induced by the previous section. The small value of 3.3 dB is well below the detecting threshold and will not be considered as fault indication for either fiber segment or EDFA. Similarly, Fig. 4(c) and 4(d) show a 0-dB and 23.6-dB power change at the monitoring channels $\lambda_{1,2}$ and $\lambda_{3,1}$ for a fiber fault in the segment $L_{3,1}$. For the case when both fiber segments $L_{1,2}$ and $L_{3,1}$ are at fault, high power excursion similar to Fig. 4(a) and 4(d) were obtained, demonstrating successful identification of fiber fault in the two links. In addition, by choosing the detecting threshold correctly, it is possible to discriminate between the EDFA's partial failure and the fiber cut, as fiber

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cut causes a much higher power surge and a loss of all data channels. It is concluded that the proposed scalable monitoring scheme is very feasible and has been demonstrated successfully in a 200-km standard-fiber 6-EDFA link with four 2.5-Gbit/s data channels.

**References**


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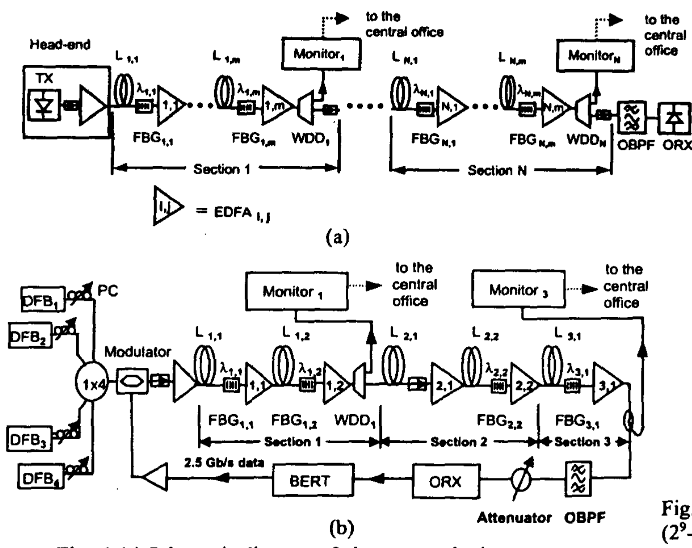


Fig. 1 (a) Schematic diagram of the proposed scheme. (b) Experimental setup. PC : polarization controller. ORX : optical receiver with optical pre-amplifier. OBPF : optical band pass filter.

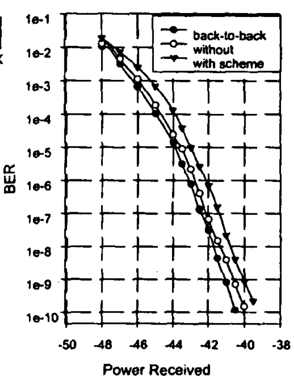


Fig. 3. BER performance of a 2.5 Gbit/s ($2^9$-1 PRBS ) NRZ data channel out of a total 4 channels at 1548.75nm with (▼), and without (o) the surveillance scheme. Back-to-back (•) configuration results are also provided.

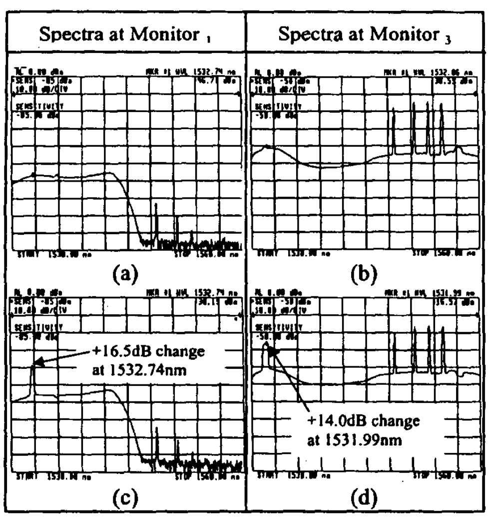


Fig. 2. Power spectra measured at $\text{Monitor}_1$ and $\text{Monitor}_3$ operating under (i) normal condition [ (a) and (b) ], and (ii) the partial failures in $\text{EDFA}_{1,1}$ and $\text{EDFA}_{2,2}$ [ (c) and (d) ].

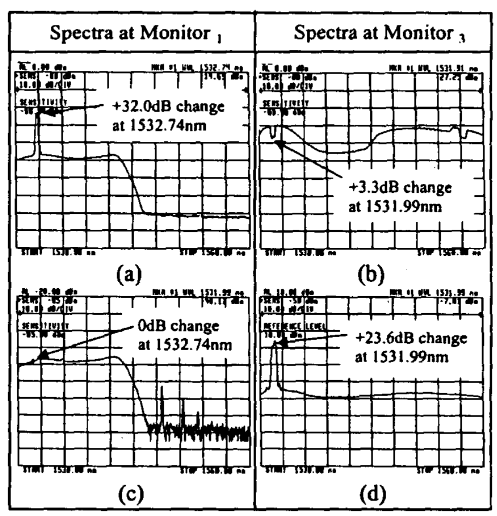


Fig. 4. Power spectra obtained at $\text{Monitor}_1$ and $\text{Monitor}_3$ for fiber break occurring in (i) the fiber link $L_{1,2}$ [ (a) and (b) ], and (ii) the fiber link $L_{3,1}$ [ (c) and (d) ].