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Performance Evaluation of the Improved Polarization-Nulling Technique for the OSNR Monitoring in Dynamic Optical Networks

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Abstract We report on the performance of the OSNR monitoring technique based on the improved polarization-nulling method. The results show that the performance of this improved technique is not sensitive to the PMD, nonlinear birefringence, modulation formats (such as NRZ, RZ, DPSK, RZ-DPSK, duobinary, RZ-AMI, and DQPSK), modulation speeds, and transmission distance.

Introduction

For the proper operation of a dynamic WDM network, it is essential to monitor the optical signal-to-noise ratio (OSNR) of each channel. Previously, the OSNR has been measured by using the linear interpolation technique, in which the amplified spontaneous emission (ASE) noise was measured in between the channels and then interpolated into the signal's wavelength. However, this technique can be quite erroneous in the modern optical network where WDM signals are added/dropped or cross-connected directly in the optical layer. To solve this problem, the polarization-nulling method has been proposed for monitoring OSNR in a dynamic WDM network [1]-[2]. This technique measures the noise power right at the signal's wavelength by utilizing the different polarization properties of signals and ASE noises. However, the performance of this technique could suffer from the polarization-mode dispersion (PMD) and nonlinear birefringence [1]-[3]. In particular, it has been reported in details that the accuracy of the polarization-nulling method could be deteriorated if the signal is significantly depolarized by the nonlinear birefringence [3]. Several techniques have been developed to overcome this problem [1]-[2], [4]. These techniques either calibrate out the small amount of signal power leaked into the noise in the orthogonal polarization state (due to PMD or nonlinear birefringence) by using an additional optical filter [2] or measured the noise power at the side of the signal's spectrum to mitigate the effect of PMD [4]. Recently, we have developed an improved version of the polarization-nulling technique by using a narrow tunable bandpass filter [2]. It has been already shown that the accuracy of this technique is not sensitive to the PMD and nonlinear birefringence [2]. In this paper, we report that this improved version of the polarization-nulling technique can also monitor the OSNR accurately regardless of the use of advanced modulation formats. In addition, we investigate the effects of higher-order PMD and confirm the possibility of using the proposed technique even in an ultra-long haul transmission link by using a re-circulating loop.

Principle of operation

Fig. 1 shows the operating principle of the improved version of the polarization-nulling technique by using a narrow tunable bandpass filter [2]. A PMD compensator (PMDC) is used at the input of the OSNR monitoring module to negate the effect of PMD. The tunable filter has a bandwidth much narrower than the signal. We adjust this filter to the center and the slope of the optical signal, and measure the signal powers (P_1, P_3) and the ASE noise powers (P_2, P_4) polarized orthogonal to the signal, as shown in Fig. 1(c) and 1(d). However, if the optical signal is slightly depolarized after the transmission due to the nonlinear birefringence, there could be a small portion of optical signal in addition to the polarized ASE noise in P_2 and P_4. Thus, if we define this small portion of optical signal as ε, P_2 and P_4 are expressed as,

$$P_2 = \frac{1}{2}P_{ASE} + (P_1 - P_{ASE})\varepsilon \,,\quad P_4 = \frac{1}{2}P_{ASE} + (P_3 - P_{ASE})\varepsilon \qquad (1)$$

where P_{ASE} is the power of the ASE noise located within the bandwidth of the tunable optical filter. Since P_3 is smaller than P_1, the depolarized portion of the signal power transferred into P_4 (due to nonlinear birefringence) is also smaller than the portion transferred into P_2. As a result, in case the signal is depolarized due to the nonlinear birefringence (i.e., $\varepsilon \neq 0$), the OSNR derived from P_4 becomes more accurate than the OSNR obtained by using P_2 [4]. However, if ε were large, this technique could still suffer from large errors since the portion of P_3 transferred into P_4 cannot be neglected. To solve this problem, we subtract these portions of the optical signal from the measured noises, and estimate the power of ASE noise and OSNR by using equation (2).

$$P_{ASE} = \frac{2(P_1P_4 - P_2P_3)}{P_1 - P_3 - 2P_2 + 2P_4} \,,\quad OSNR = \frac{P_t - P_{ASE}B_s / B_t}{P_{ASE}B_r / B_t} \qquad (2)$$

where P_t is the total power of the optical signal (measured by scanning the tunable filter over the entire bandwidth of the optical signal), B_s is the bandwidth of the optical signal, B_r is the resolution bandwidth of OSNR (i.e., 0.1 nm), and B_t is the bandwidth of the tunable bandpass filter [2].

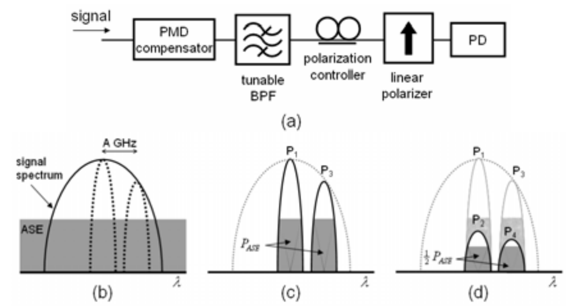

Fig. 1. Operating principle of the proposed technique. (a) OSNR monitoring module, (b) Signal spectrum in the presence of the ASE noise and the measurement positions of the tunable filter, (c) Filtered signals, (d) The ASE noise orthogonally polarized from the signal.

Experiment and Results

Recently, we have reported that the proposed technique could monitor the OSNR accurately even in the presence of the large first-order PMD and nonlinear birefringence [2]. For example, it has been reported that the proposed technique could monitor the OSNR in the range of 14 dB ~ 30 dB with accuracy better than 1 dB even when the first-order PMD was as large as 60 ps. In addition, by using the technique described above, it was possible to monitor the OSNR with accuracy better than 1 dB even when we transmitted the WDM signals spaced at 50 GHz (output power = 3 dBm/channel) over eight spans of 80-km long NZDSF link (total transmission distance = 640 km).

In this paper, we first evaluated the effect of higher-order PMD on the performance of the proposed technique. For this purpose, we implemented a PMD emulator (PMDE) by using eight sections of polarization-maintaining fibers and polarization controllers. This PMDE could emulate the PMD of real fiber including the higher-order PMD [5]. Fig. 2(a) shows the probability density function of the emulated PMD at 1553 nm. The emulated PMD had a Maxwellian probability density function. The average PMD, <Δτ>, was 15.2 ps. To evaluate the effect of higher-order PMD, we sent a 10-Gb/s NRZ signal (OSNR: 20 dB) to this PMDE, and then measured the differential group delay (DGD) and OSNR error by using a commercial polarization analyzer and the proposed polarization-nulling technique, respectively. As expected, Fig. 2(b) shows that no significant error was observed in the measured OSNR. This was due to the PMDC placed in front of the monitoring module and the extremely narrow bandwidth (3 dB bandwidth = 3 GHz) of the tunable filter used in the proposed technique. Thus, the effect of the higher-order PMD on the performance of the proposed OSNR monitoring technique could be neglected.

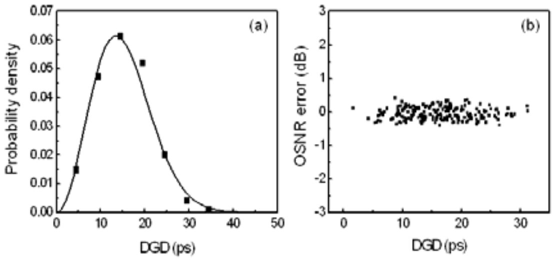

Fig. 2. Effect of all-order PMD (a) Probability distribution of the emulated first-order PMD (<Δτ> = 15.2 ps), (b) Measured OSNR error of the proposed technique (10-Gb/s NRZ signal, OSNR = 20 dB).

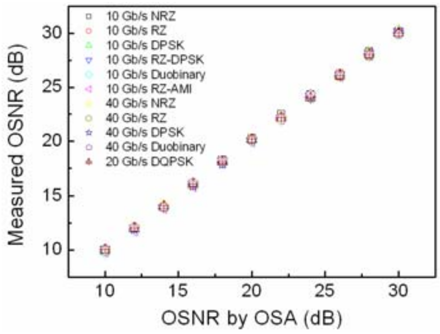

Fig. 3. Modulation format dependency

We also evaluated the effects of using advanced modulation formats on the performance of the proposed technique. In principle, since the proposed technique obtains the noise power to calculate the noise contribution in a part of signal's wavelength, we expect that the proposed technique can monitor the OSNR regardless of spectral shape and width of the signal. For this purpose, we modulated the signal at 10 Gb/s ~ 40 Gb/s in various formats (such as NRZ, RZ, DPSK, RZ-DPSK, duobinary, RZ-AMI, and DQPSK), and then measured their OSNR's. The results in Fig. 3 confirm that the proposed technique could accurately monitor these OSNR's, regardless of their modulation formats and modulation speeds.

Finally, to verify the possibility of using the proposed technique in an ultra long-haul transmission link, we implemented a re-circulation loop made of a 640-km long SMF link shown in Fig. 4. The dispersion of this SMF link was compensated by using a dispersion-compensating fiber (DCF) module. We multiplexed 8 WDM channels (spaced at either 100 GHz or 50 GHz), modulated them with 10-Gb/s NRZ or RZ signal (pattern length = 2^{31}-1), and then launched into this loop. The signal powers incident on the SMF and DCF were 0 dBm/channel and -3 dBm/channel, respectively. Fig. 5 shows the measured OSNR of the center channel by using the proposed technique as a function of the transmission distance for each modulation format and channel spacing. The measured OSNR's agreed well with the values obtained by using an optical spectrum analyzer, regardless of the modulation formats and channel spacing. This figure also shows that the proposed technique could monitor the OSNR accurately, even when the transmission distance was as long as 3200 km.

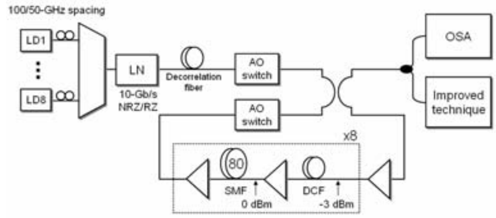

Fig. 4. Experimental setup to verify the possibility of using the proposed technique in an ultra long-haul transmission link.

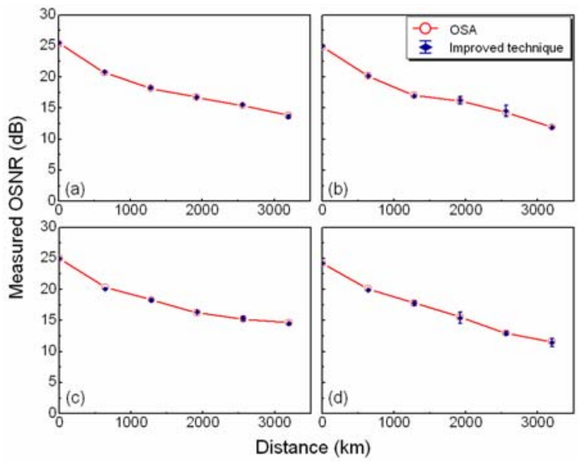

Fig. 5. Measured OSNR by using an OSA and the proposed technique (a) NRZ with 100-GHz spacing, (b) NRZ with 50-GHz spacing, (c) RZ with 100-GHz spacing, (d) RZ with 50-GHz spacing.

Summary

We have investigated the performances of the OSNR monitoring technique based on the improved polarization-nulling method. Previously, it has been reported that this technique is not sensitive to the first-order PMD and nonlinear birefringence. In this paper, we experimentally show that the proposed technique is also insensitive to the higher-order PMD, modulation formats (including NRZ, RZ, DPSK, RZ-DPSK, duobinary, RZ-AMI, and DQPSK), and modulation speeds. In addition, we verified the possibility of using the proposed technique in the ultra long-haul transmission link by using a 64-km long re-circulating loop. The proposed technique could monitor the OSNR accurately even when the transmission link was longer than 3200 km.

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