Simple PMD-insensitive OSNR monitoring scheme assisted by transmitter-side polarization scrambling

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Abstract: Recently, degree of polarization (DOP) of light has been utilized as a parameter to monitor optical signal-to-noise-ratio (OSNR). However, in the presence of polarization-mode dispersion (PMD), when using DOP to determine OSNR, OSNR is always underestimated due to the depolarization effect induced by PMD. In this paper, we propose and experimentally demonstrate a simple PMD-insensitive OSNR monitoring technique based on DOP measurement. By the assistance of the transmitter-side polarization scrambling, the in-service OSNR parameter can be accurately derived from the measured maximum DOP value within the polarization scrambling period, which is immune to PMD effect. The monitoring performance is experimentally evaluated by statistical method at OSNR of 25 dB. Experimental results show that OSNR monitoring with about 1-dB standard deviation can be achieved in a 10-Gb/s NRZ-OOK system with DGD varying from 0 to 80 ps.

OCIS codes: (060.2330) Fiber optics communications; (260.5430) Polarization; (999.9999) Optical performance monitoring

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1. Introduction

Optical signal-to-noise-ratio (OSNR) has been vigorously pursued as an important performance parameter in future high-speed (≥10 Gb/s) reconfigurable optical networks. Several polarization-assisted methods have been proposed to monitor OSNR in an in-band manner [1-6]. Among them, the monitoring scheme based on degree of polarization (DOP) measurement offers many noteworthy advantages as it is simple, insensitive to chromatic dispersion, scalable to higher bit-rate systems, and obviates high-speed electronics [1-2]. However, as DOP is affected by both OSNR and polarization-mode dispersion (PMD) [7-8], OSNR will be underestimated in the presence of PMD when DOP is chosen as the monitored parameter for OSNR. It would be highly desirable to develop PMD-insensitive monitoring schemes. Recently, a PMD-insensitive DOP-based OSNR monitoring scheme has been proposed and experimentally demonstrated [7][9]. But intricate data processing and a narrow tunable filter (~0.1 nm) are needed to derive the PMD-induced DOP by spectral state-of-polarization (SOP) measurement, and it is only suitable for high-bit-rate (≥40 Gb/s) or narrow-pulse systems.

In this paper, we demonstrate that, by applying a polarization scrambler at the transmitter side, OSNR can be easily and accurately monitored using a conventional DOP analyzer. This proposed method makes the DOP-based OSNR monitoring technique more practical for deployment in real systems with non-negligible PMD. Using a 10-Gb/s non-return-to-zero on-off keying (NRZ-OOK) system, we demonstrate that, at OSNR=25 dB/0.1nm, OSNR can be accurately monitored irrespective of the PMD varying from 0 to 80 ps with <0.6 dB estimation mean deviation, and about 1-dB standard deviation. The high-order PMD involved in the system is assumed to be negligible in this paper.

2. Operation principle

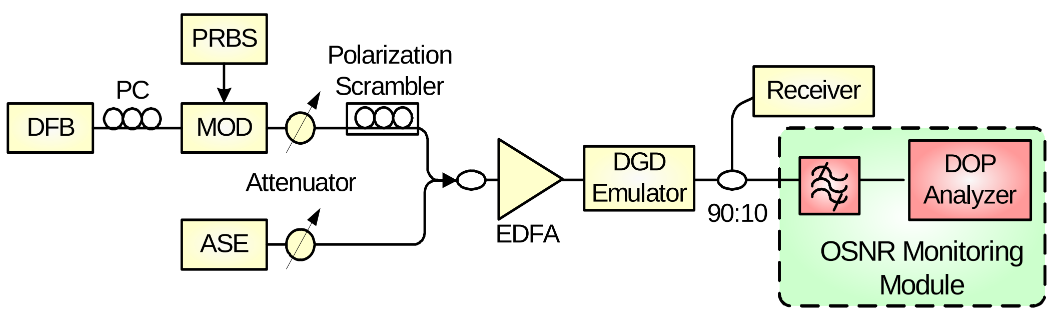

Fig. 1. Experimental configuration for the proposed PMD-insensitive DOP-based OSNR monitoring scheme.

Figure 1 shows the configuration of the PMD-insensitive DOP-based OSNR monitoring scheme. The monitoring module consists of a polarization scrambler at the transmitter side and a DOP analyzer (polarimeter) preceded by an optical band-pass filter at the receiver side. A degradation of OSNR will cause a reduction in DOP. This is because an increase in the unpolarized amplified spontaneous emission (ASE) noise power will decrease the ratio of the polarized portion of the total optical power [6]. However, when the link PMD is introduced, the DOP of the received signal is further reduced. This reduction is dependent on both the differential group delay (DGD) and the power splitting ratio, γ, between the two principal states of polarization (PSPs) of the transmission link. With non-negligible PMD in a system, the DOP measured is affected by both link PMD and OSNR, and the total DOP can be given by [7]

$$DOP = DOP_{OSNR} \times DOP_{PMD} \tag{1}$$

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In our proposed scheme, the use of the transmitter-side polarization scrambler is to make the input SOP of the signal cover the whole Poincaré-sphere within one scrambling period. When the SOP of the signal is launched at 45^o in Jones space (i.e. $\gamma = 0.5$) with respect to the two PSPs of the transmission link, the DOP measured at the receiver will be the minimum. On the other hand, when the SOP of the signal aligns with one of the PSPs (i.e. $\gamma = 0$) of the transmission link, the DOP measured at the receiver will be the maximum and the PMD-induced DOP will approach 1 ($DOP_{PMD} \approx 1$), corresponding to the case when there is no effective DGD. The maximum DOP is dependent on OSNR only ($DOP_{max} \approx DOP_{OSNR}$), while the minimum DOP value is dependent on both the OSNR and PMD. Thus, the OSNR can be derived from the measured maximum DOP value at the receiver side within one scrambling period by the following equation:

$$OSNR(dB/0.1nm) = 10\log[(\frac{DOP_{\max}}{1 - DOP_{\max}})(\frac{NEB_f}{0.1})] \tag{2}$$

where NEB_f is the noise equivalent bandwidth (in nm) of the tunable filter before the DOP analyzer. $DOP_{\max}$ is the maximum DOP measured by the DOP analyzer within the scrambling period. As the maximum DOP is only affected by OSNR, OSNR can be accurately estimated from the measured maximum DOP value in the presence of link PMD. Note that for the DOP-based OSNR monitoring, the monitoring performance will be sensitive to the measure accuracy of DOP when OSNR approaches 25 dB/0.1nm and above [6]. However, better accuracy can be achieved by statistical averaging, as will be shown in the next section.

3. Experiment and results

The proposed monitoring scheme was experimentally demonstrated in a 10-Gb/s NRZ-OOK system using the same configuration as shown in Fig. 1. A CW light source at 1550 nm was externally modulated by a $LiNbO_3$ intensity modulator with 2^{31} -1 PRBS. The modulated signal was then fed into a polarization scrambler. The resolution of the polarization scrambler (Agilent, HP 8169A) is 0.18^o. An ASE noise source was created by cascading two EDFAs. To evaluate the measurement accuracy, the OSNR was fixed at 25 dB/0.1nm, and calibrated by an optical spectrum analyzer (OSA). A PMD emulator (DGD tuning range: 0~80 ps) was inserted in the link to simulate different system DGD values. At the receiver side, a small portion (10%) of the signal power was sent to the monitoring module. Inside the monitoring module, an optical band-pass filter with full-width half-maximum (FWHM) bandwidth of ~0.22 nm (NEB_f: ~0.25 nm) was used before the DOP analyzer. In the proposed scheme, the maximum DOP value measured within the polarization scrambling period (~40 seconds) was used to derive the OSNR using Eq.(2). A control experiment by using the conventional DOP-based monitoring method, i.e., to derive the OSNR from the measured DOP value directly, was also performed for performance comparison.

To demonstrate the PMD-independency of the proposed scheme, at OSNR=25 dB/0.1nm, the OSNR was measured in the presence of different link DGD values (0~80 ps). The histogram, generated from 200 experimental samples, was used to illustrate the measurement performance. Figure 2 shows the histograms for the measured OSNR with DGD of 10 ps, 40 ps and 70 ps by using the conventional method ((a)-(c)) and the proposed method ((d)-(f)), respectively. It clearly shows that in the presence of PMD, as the DOP was affected by both DGD and OSNR, the OSNR was severely underestimated by using the conventional DOP-based method with increased standard deviation (2~3 dB), especially for the large DGD case.

The monitoring performance was also statistically evaluated by examining the "one standard deviation" error bar and estimation mean for the measured OSNR with DGD varying from 0 to 80 ps, which was obtained from 200 experimental samples for each DGD case (Fig. 3). For the conventional DOP-based scheme, with the increase of the link DGD, the estimation mean of measured OSNR deviated further from 25 dB/0.1nm with increased standard deviation. However, by using the proposed scheme, when DGD value varied from 0 ps to 80 ps, the deviation of the estimation mean from 25 dB/0.1nm was less than 0.6 dB, while the standard deviation was around 1 dB. This further verified the effectiveness and PMD-independence of the proposed scheme.

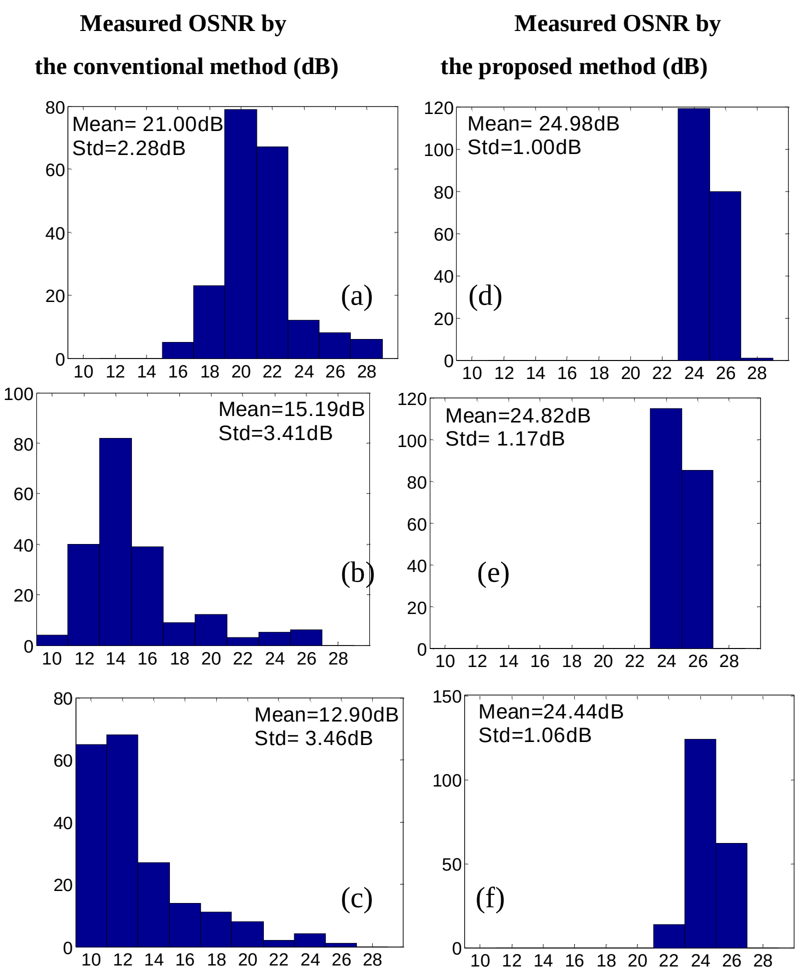

Fig. 2. Histograms for the measured OSNR data with DGD of (a)(d) 10 ps, (b)(e) 40 ps, and (c)(f) 70 ps by the conventional DOP-based method (left) and the proposed DOP-based method (right).

To investigate the PMD in-dependence of the OSNR monitoring under different OSNR conditions, the OSNR measurement was also performed under OSNR of 12, 15, 20 dB/0.1nm, respectively. The estimation means for corresponding OSNR values were plotted in Fig.4. It shows that, under different OSNR conditions, the proposed scheme can accurately measure the system OSNR when link DGD varies from 0 to 80ps with less than 0.6-dB monitoring error.

4. Summary

In this paper, we have successfully demonstrated a DOP-based OSNR monitoring technique that can accurately and simply monitor OSNR even when the link DGD is non-negligible. In a 10-Gb/s NRZ-OOK system, when DGD value varied from 0 to 80 ps, by using the proposed scheme, the variation of the estimation mean was within 0.6 dB, while the standard deviation was around 1 dB. This scheme is simple, insensitive to PMD and chromatic dispersion, scalable to higher bit-rate system, and does not require high-speed electronics.

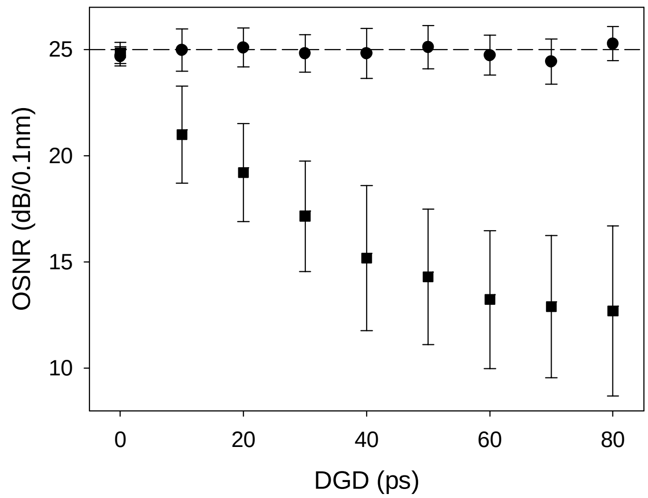

Fig. 3. The measured OSNR by the proposed method (●) and the conventional method (■) with DGD varying from 0 to 80 ps. The measured OSNR values were illustrated by the estimation mean with error bars.

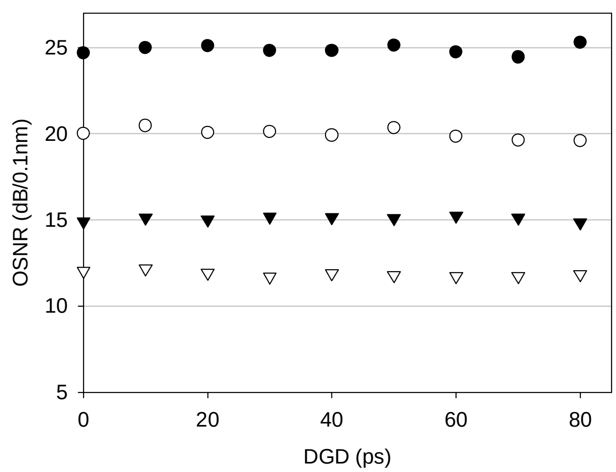

Fig. 4. The measured OSNR by the proposed method under different OSNR conditions with DGD varying from 0 to 80 ps.

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