Experimental Demonstration of Robustness and Accuracy of an MZI-based OSNR Monitor under Transmitter Drift and Reconfigurable Networking Conditions for Pol-Muxed 25-Gbaud QPSK and 16-QAM Channels

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Abstract: We experimentally demonstrate the robustness of an MZI-based OSNR monitor under reconfigurable network and transmitter drift. The monitor calibration factors for 25 Gbaud PM-QPSK signal are stored after assembly and applied to study the accuracy of the OSNR monitoring unit when different changing scenarios outside the monitor occurred.

OCIS codes: (060.2360) Fiber optics links and subsystems; (060.4257) Networks, network survivability

1. Introduction

Optical performance monitoring has gained much interest for its ability to help determine the relative health of various optical data channels. Such ability can enable: (i) the identification and location of data-degrading effects at different points in the system, and (ii) routing traffic based on the relative "quality" of a given physical route. Such monitoring should optimally be located at many points of the system [1].

A key parameter to measure is the optical signal-to-noise ratio (OSNR), which represents a crucial metric of the health of a data channel at various points around the network. There are different approaches for OSNR monitoring. One method is to measure the noise adjacent to the data channel and interpolating what the noise would be in-band [2]. This approach is not only an approximation, but it also is problematic the many systems that incorporate wavelength filters and (de)muxes that preferentially reduce the out-of-band noise. Another method that does measure the in-band noise is to use polarization nulling, but it is difficult to use this approach for unpolarized optical data channels [3].

There have been reports of using a Mach-Zehnder interferometer (MZI) to achieve OSNR monitoring in which the MZI contains a ¼-bit delay in one arm of the interferometer. In this approach, the data signal experiences coherent interference and the noise does not. By measuring the relative output power at the constructive and destructive ports of the delay-line interferometer (DLI), the OSNR can be measured [4-6].

Although this single-DLI approach has been shown to provide <0.5 dB error for different modulation formats and can operate on pol-muxed data channels, there are still several critical questions that must be answered in order to enable future deployment in systems. For example, the OSNR monitor must be calibrated after assembly so that it accurately measures signal and noise. However, it is unclear if the monitor will indeed still perform accurate measurements if: (a) the transmitter parameters drift or the data channel is modified, (b) if the data channel originates from a different source transmitter due to reconfigurable networking or transmitter replacement, and (c) if the baud rate or modulation format of the data channel is changed. A laudable goal would be to determine if the OSNR monitor would function properly under changing network conditions with requiring servicing, updating or recalibration.

In this paper, we experimentally demonstrate robustness and accuracy of an MZI-based OSNR monitor under transmitter drift and reconfigurable networking conditions for pol-muxed 25-Gbaud QPSK and 16-QAM channels. We initially calibrated the monitor with its signal and noise distribution factors (α and β) once and changed the: (a) error vector magnitude (EVM), (b) baud rate, (c) modulation format, (d) wavelength, and (e) path, to emulate the reconfigurable network and conduct accuracy study (see Fig. 1). We show that the monitor is robust and can achieve <0.5dB error at specific baud rate for most of the cases.

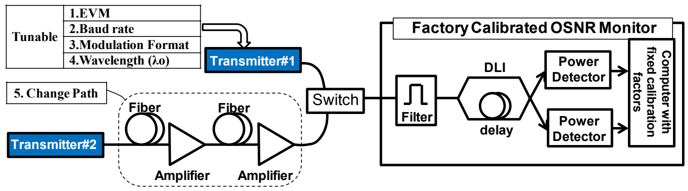

Fig. 1. The conceptual block diagram for an MZI-based one-time calibrated OSNR monitor at reconfigurable networks.

2. Experimental Setup

The experimental setup is depicted in Fig. 2. A tunable-wavelength laser sends a continuous-wave (CW) light at λ_o and is modulated using I/Q modulator driven by a 2^{31}-1 pseudo-random bit sequence (PRBS) with a tunable clock (i.e., tunable baud rate). The modulator is adjusted to transmit an optimal QPSK signal by automatic bias control (ABC) feedback loop on the Mach-Zehnder modulators (MZMs), and by setting the phase modulator bias (V_{Phase}) at $\Phi=\pi/2$. This QPSK signal can feed a higher-order QAM emulator to generate 16-QAM. The modulated signal then passes through a pol-mux emulator, which splits, delays, and combines the orthogonal polarization states using polarization controllers and a polarization beam splitter (PBS). For the noise, an ASE source can be either added directly to the channel or routed through three cascaded EDFA's to imitate the effect of changing the path. Both signal and noise are coupled to the OSNR monitor through variable attenuators Att1 and Att2 for signal and noise, respectively. The OSNR monitoring unit consists of a 0.3 nm fixed-bandwidth tunable-wavelength bandpass filter (BPF) followed by a coupler and a polarization-insensitive 10 ps fixed-delay DLI (i.e., FSR = 100 GH_Z).

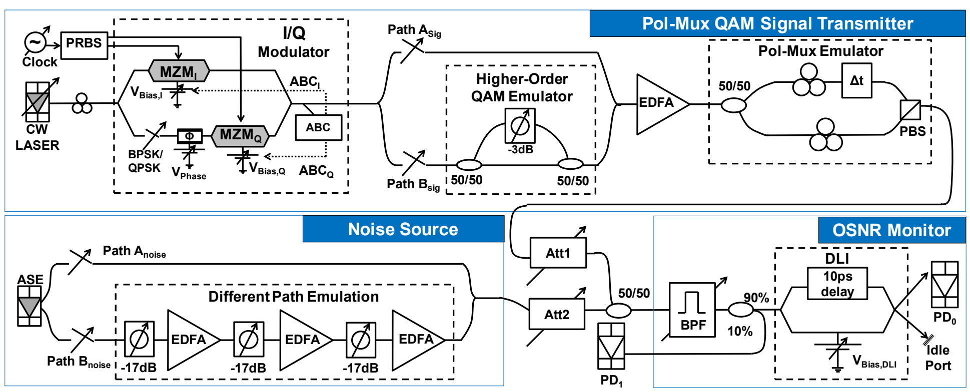

Fig. 2. Experimental setup for OSNR monitor under changing transmitter and noise in reconfigurable networking conditions.

To perform the OSNR measurement, one of the DLI output ports was connected to a low-speed photodiode PD_0. Because filters are linear systems, the computations of output signal and noise powers at that DLI port yield to :

$$\text{OSNR (dB)} \triangleq 10\log_{10}\left(\frac{(\alpha+1).(\delta-\beta)}{(\beta+1).(\alpha-\delta)} \cdot \frac{\text{NEB}}{0.1\text{ nm}}\right);\ \text{where: } \alpha = \frac{P_{Const,Sig}}{P_{Dest,Sig}},\ \beta = \frac{P_{Const,Noise}}{P_{Dest,Noise}},\ \text{and } \delta = \frac{P_{Const,Ch}}{P_{Dest,Ch}}.$$

In the above equation, α, β, and δ are the signal, noise, and channel under test distribution factors, respectively. We also define NEB as the noise equivalent bandwidth for the filter. The constructive ($P_{Const,Sig}$, $P_{Const,Noise}$, $P_{const,Ch}$) and destructive ($P_{Dest,Sig}$, $P_{Dest,Noise}$, $P_{Dest,Ch}$) power levels for signal, noise and channel are measured by sweeping the DLI phase bias ($V_{Bias,DLI}$) over a full cycle. The OSNR monitor should follow a calibration procedure to measure α and β before starting the accurate OSNR measurements. Calibrating α is conducted by sending signal and blocking the noise. Similarly, the signal should be blocked to measure the noise's β. As a result, only δ remains unknown to determine the OSNR. Here, we initially calibrated the monitor with α_{ref} for an optimally biased 25 Gbaud pol-muxed QPSK (PM-QPSK) signal, and then β_{ref} was calibrated for ASE noise sent through path A_{noise}. Afterwards, at the transmitter, we varied the signal's (a) EVM (b) baud rate, (d) modulation format, and (d) wavelength, and tested the accuracy based on the previously stored α_{ref}. We also measured the error due to applying a stored noise calibration factor β_{ref} to a different noise. In order to compare the results, the actual OSNR in every experiment was found by sending the signal and noise separately and measuring the tap power on PD_1

3. Results

In Fig. 3, ABC was switched off and $V_{Bias,I}$ was tuned manually from optimal point by >50% V_{Pi} to give 13.4% EVM. In Fig. 4, we measured the OSNR and observe that up to 10.2% EVM (i.e., 22% V_{Pi} of drifting), the monitor showed less than 0.5 dB error. Fig. 5 shows the OSNR error at various EVM values resulting from random independent biasing of both I/Q modulator arms with permitting <43% V_{Pi} drift. Fig. 6 and Fig. 7 depict the effects of turning the ABC on and changing the phase modulator bias on the EVM and the error. The OSNR monitor showed independence of changes in phase modulator bias although EVM severely degraded.

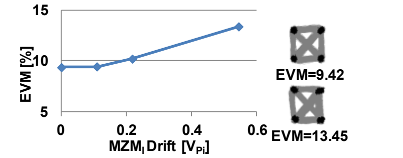

Fig. 3. Experimental results of EVM vs. MZM_I bias drifting.

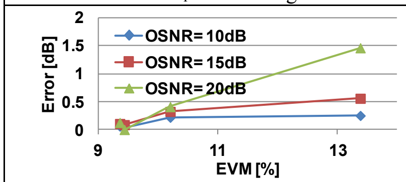

Fig. 4. OSNR error with respect to EVM for MZM_I drifting experiment.

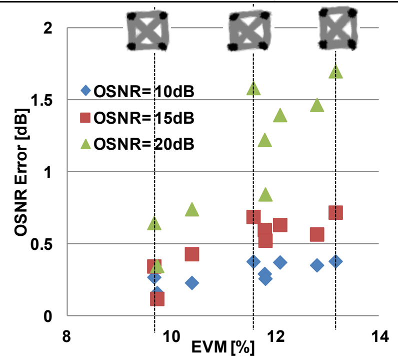

Fig. 5. Experimental error for random scenarios of drifting in both I and Q biases within 43% of V_{Pi}.

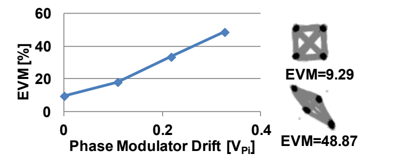

Fig. 6. EVM vs. experimental voltage drifting introduced on the phase modulator

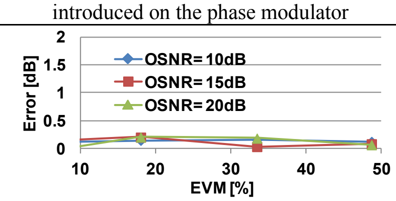

Fig. 7. Experimental resulted error due to the phase modulator drift.

Fig. 8 illustrates effects of changing the baud rate. The monitor showed high error if α_{ref} is used at other baud rates. Fig. 9 indicates the distribution factor for different pol-muxed signals at different baud rates and suggests that α calibration is a baud rate specific. However, at every specific baud rate, different modulation formats had almost the same α factor. We conduct a study on accuracy under changing the modulation format in Fig. 10. We used the PM-QPSK calibration values from Fig. 9 and applied them to PM-BPSK and PM-16-QAM signals at those specific baud rates, and the error stayed within 0.5 dB.

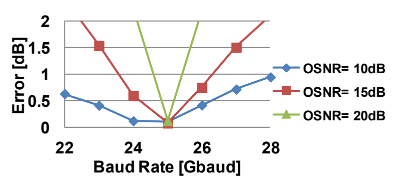

Fig. 8. Experimental OSNR error due to changing baud rate while using a 25 Gbaud signal calibration α_{Ref}.

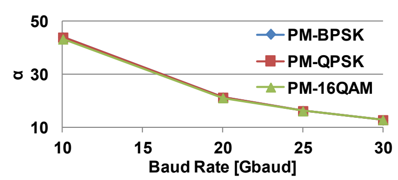

Fig. 9. Experimentally measured α calibration factor value with respect to baud rate for different modulation formats.

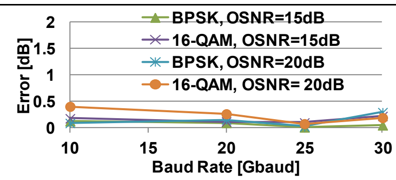

Fig. 10. Error for PM-BPSK and PM-16-QAM at different baud rates when a PM-QPSK calibration factor is measured at each specific baud rate and applied to PM-BPSK and PM-16-QAM.

Fig. 11 indicates the effect of changing the wavelength at the transmitter. The α calibration was taken at 1554.54nm and applied to different ITU WDM channels. We tune the laser wavelength, re-center the filter, recalibrate the noise's β and finally measure the OSNR. The maximum recorded error was 0.67-dB at 1560.61 nm (6.07 nm away from calibrated channel) in the high OSNR case. This suggests that calibration is wavelength insensitive. In Fig. 12, we investigate the effects of changing the path and show the recorded ASE profiles after paths A_{noise} and B_{noise}. The error caused by applying the α_{ref} and β_{ref} to 25 Gbaud PM-QPSK and PM 16-QAM at λ=1552.52 nm changing the path (re-routing) is illustrated in Fig. 13. The monitor remained robust at this condition with <0.5 dB error.

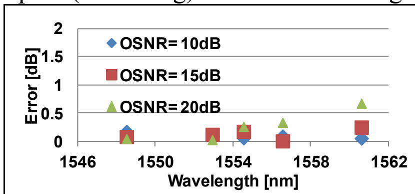

Fig. 11. Experimental error for applying certain α calibration on different wavelengths.

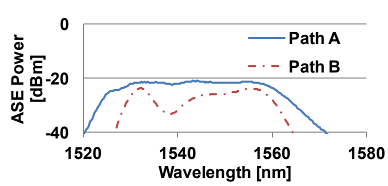

Fig. 12. Recorded ASE profile after paths A_{noise} and B_{noise}.

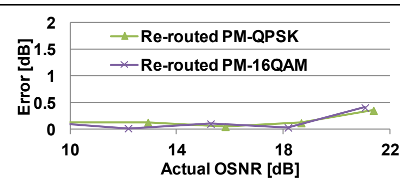

Fig. 13. Measured error for re-routed PM-QPSK and PM-16-QAM signals using α_{ref} and β_{ref}.

3. Acknowledgements

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4. References

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