Nonlinearity-Tolerant In-band OSNR Monitoring for Synchronous Traffic Using Gated-Signal RF Spectral Analysis

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Abstract: We demonstrate a new in-band OSNR monitoring scheme using RF spectral analysis of gated framing-signal of synchronous traffic. The proposed technique is simple and robust to fiber-nonlinearity induced polarization rotation in WDM systems.

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1. Introduction

Optical signal-to-noise ratio (OSNR) monitoring is a critical function in performance monitoring of re-configurable wavelength-division-multiplexing (WDM) networks [1]. Due to the use of dynamic filters in such networks, the OSNR measurement must be performed within the filter bandwidth, rather than using the traditional linear interpolation method. Previously a number of in-band OSNR monitoring schemes have been proposed, which are mostly based on polarization-assisted techniques such as polarization-nulling method [2-4] and degree of polarization (DOP) correlation approach [5]. These schemes are based on the assumption that the optical signal has well-defined polarization and the amplified spontaneous emission (ASE) noise is fully randomly polarized. However, the assumption is not always valid in practice, especially in the presence of inter-channel cross-phase modulation (XPM) induced polarization scattering effect [2, 6], which refers to the randomization process of the polarization states of a signal channel caused by the intensity-related nonlinear polarization rotation. In [6], large OSNR monitoring errors were observed when the signals experienced polarization scattering in a WDM system.

Beat-noise measurement method [7] is an alternative in-band OSNR monitoring technique, which measures the signal-ASE beat noise power density after the photo-detection to reconstruct the OSNR. Since the photo-detectors perform optical-to-electrical conversion regardless of the polarization of the optical input, this method is immune to the polarization scattering effect. However, the previously proposed method does not work for pseudo random bit sequences (PRBS) longer than 2^{15}-1 or truly random data due to the limited resolution of the RF spectrum analyzer prohibiting the distinction between the signal tones and the noise. In addition, the performance of such monitoring scheme has not been examined in a WDM transmission system in the presence of XPM-induced polarization scattering effect.

In this paper, we propose and demonstrate a gated-signal RF spectral-analysis technique, which takes advantage of the periodic nature of the frame header of synchronous traffic. The gating function ensures that only the repetitive short patterns in the frame header are analyzed so that their discrete tones in the frequency domain are distinguishable regardless of the payload pattern length. This technique possesses a number of attractive features: it is insensitive to polarization scattering; the monitoring setup is simple and does not require high-speed receiver at the line rate; it works for any modulation formats, and is in principle also robust to polarization mode dispersion (PMD). We have experimentally demonstrated the proposed OSNR monitoring technique in the presence of strong polarization scattering for a SONET-like synchronous traffic with repetitive header structure and a payload of 2^{23}-1 PRBS. For comparison we also carried out DOP measurements. Results show that monitoring errors can be significantly reduced by employing the proposed scheme.

2. Principle and Experimental setup

Fig.1 shows the frame structure and the nominal spectrum of a synchronous traffic, which consists of repetitive short patterns in the header and PRBS in the payload. The discrete spectral tones due to the periodic nature of the traffic are shown in Fig.1 (b). However, for payloads with PRBS pattern length of 2^{23}-1, the spectral tone spacing is 1.2 kHz for a 10-Gb/s NRZ signal ($\Delta f = 1/(2^n-1)\,T_b$), which cannot be resolved by the spectrum analyzer because of the limited resolution. In order for the noise spectrum to be revealed for beat noise measurement, the payload must be suppressed in spectral analysis. This can be achieved by gating the synchronous traffic so that only the header is let through, as shown in Fig. 1 (c). The corresponding spectrum is provided in Fig. 1 (d).

Fig.2 shows the experimental setup of our proposed OSNR monitoring scheme. Four WDM channels from 1558.16 nm to 1560.56 nm with 100-GHz channel spacing are modulated by a SONET-like data stream programmed by an Anritsu's MX176401A SDH/SONET pattern editor. The combined WDM signals are then amplified and sent to a 50-km single mode fiber (SMF). The input power is kept at 14 dBm/channel to generate significant nonlinear effects in the SMF fiber. After transmission, an ASE source is added to the signal to change the OSNR levels. A small portion of the multiplexed signal is directed to an optical spectrum analyzer (OSA), while the other part is sent to an arrayed waveguide grating (AWG) filter. The signal centered at 1559.76 nm is filtered and sent to the OSNR monitoring module. The OSNR monitoring setup consists of an intensity modulator to perform the gating function, a photo-detector followed by a RF spectrum analyzer to measure the spectral components, and a power meter to measure the total optical power. The intensity modulator, which is modulated by the gating signal, only passes

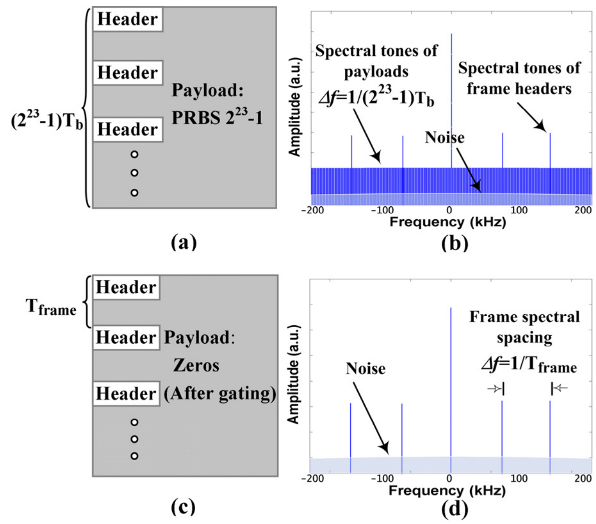


Fig.1. (a) frame structure of a synchronous traffic (b) spectrum of the synchronous traffic (c) gated synchronous traffic with only fixed headers left (d) spectrum of the gated headers

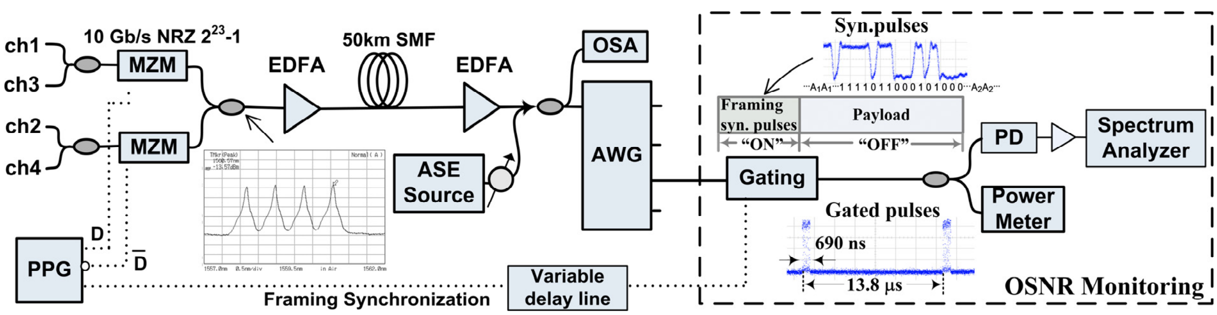


Fig.2. Experimental setup. MZM: Mach-Zehnder Modulator, SMF: Single Mode Fiber, PD: Photon Detector, PPG: Pulse Pattern Generator,

through the repetitive patterns in each header. In our experiment, the length of each frame is set to be 13.8 μs and the total length of the repetitive patterns in each frame is set to be 690 ns. The repetitive patterns can by represented by "A1···A1A1A2A2···A2", where A1 is 0xF6 or "11110110", and A2 is 0x28 or "00101000". The insets in Fig.2 show the repetitive patterns and the gated optical signal. The gated signal repeats itself every 13.8 μs, corresponding to 72.4-kHz frequency span in the frequency domain. This is the minimum frequency spacing between the spectral tones of the gated signal, therefore, the noise becomes visible.

At the receiver, the beat noise power density can be described as follows [7, 8]:

$$N_{beat} = P_{sig}^{2} \cdot \left(A / OSNR + B / OSNR^{2} \right) \qquad (1)$$

where A, B are coefficients determined by the characteristics of the photodiodes, the RF amplifier gain, and the filter properties. The measured total power can be described as:

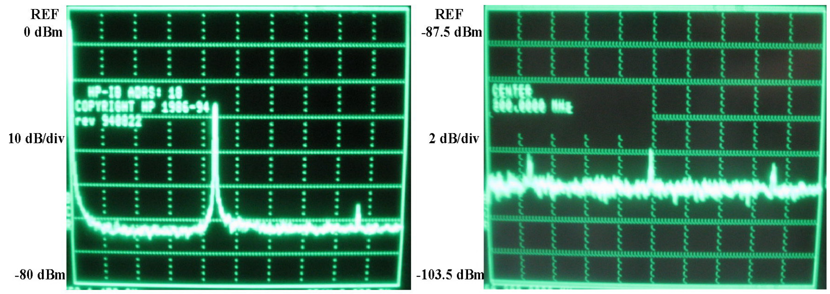
$$P_{total} = P_{sig} \cdot \left(1 + 1 / OSNR \right) \qquad (2)$$

In the above equations, the coefficients of A and B can be calibrated in advance, and the OSNR can be obtained from N_{beat} and P_{total}. Note that the OSNR in these equations is calculated using the bandwidth of the AWG filter.

3. Experimental results

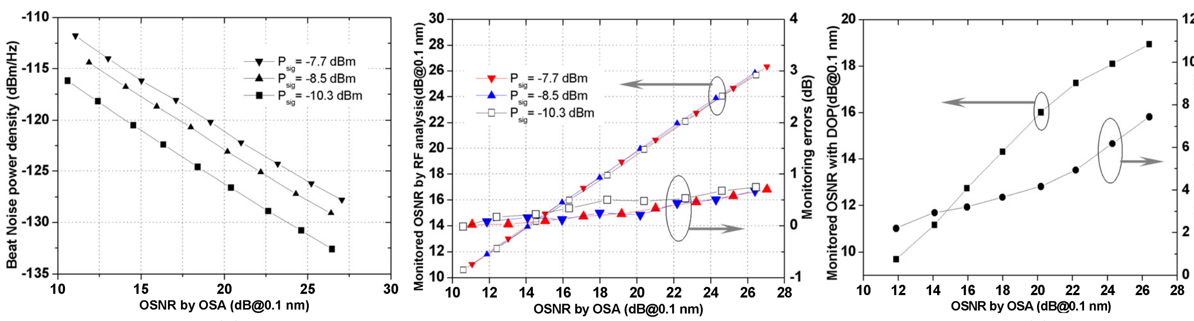
Fig.3 (a) shows the RF spectrum of the gated signal in the frequency span of 0~2.9 GHz, with a resolution bandwidth (RES) of 3 MHz. It can be seen that after the gating operation, the RF spectrum of the random payload is cut off, and only the spectrum of the periodic signal is left. The frequency tone centered at 1.25 GHz corresponds to the repetition of bytes A1 or A2 with a period of 800 ps. Fig.3 (b) shows the zoom-in spectrum at 300 MHz with a frequency span of 200 kHz and a RES of 1 kHz. The spectral tones are spaced by 72.4 kHz, corresponding to the repetition of the frames with the period of 13.8 μs. Between the spectral tones, the noise floor is clearly revealed and can be used for OSNR monitoring.

Fig.4 (a) provides the results of the measured beat noise power density at 300 MHz versus the OSNR measured with the OSA at different signal powers. Fig. 4 (b) shows the measured OSNR values and monitoring errors versus the OSNR values based on OSA measurements. In the OSNR range of 10 - 27 dB, the maximal monitoring error of the proposed method is less than 0.8 dB. For higher OSNR values, the errors are mainly caused by the limited extinction ratio of the modulator, which leads to payload power leakage and result in overestimation of the beat noise. Fig.4 (c) shows the monitored OSNR and the errors using the DOP method. As can be seen, the monitoring errors range from 2 to 7.5 dB when the OSNR changes from 10 to 27 dB, which can be attributed to the XPM induced polarization scattering effect [6].



(a) (b)

Fig.3. RF spectrum of the gated signal (a) Central frequency=1.45 GHz, Span=2.9 GHz, RES=3 MHz (b) Central frequency=300 MHz, Span=200 kHz, RES=1 kHz



(a) (b) (c)

Fig.4. (a) measured beat noise power density (b) OSNRs and monitoring errors by RF spectral analysis at different signal powers. (c) OSNRs and monitoring errors with the DOP method. The X-axis is the measured OSNR by the OSA at 0.1 nm RES

4. Conclusions

We have proposed a novel OSNR monitoring method based on beat noise measurement for the gated header of synchronous traffic. Our proposed method is immune to the XPM-induced polarization scattering effect, which is common in WDM systems. The scheme does not require high speed receivers. In principle, the method is also insensitive to PMD effects. Its advantage over the DOP method in the presence of polarization scattering has been experimentally verified. OSNR monitoring error of less than 0.8 dB is achieved in the OSNR range of 10 - 27 dB in a 4 x 10-Gb/s WDM system, where the XPM induced polarization scattering effect has significantly deteriorated the OSNR measurement based on the DOP method.

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