Optical-Signal-to-Noise Ratio monitoring for packet switched networks

X. Yi, W. Chen and W. Shieh
ARC Special Research Centre for Ultra-Broadband Information Networks and National ICT Australia
Department of Electrical and Electronics Engineering
The University of Melbourne, Melbourne, VIC 3010, Australia, e-mail: x.yi@ee.unimelb.edu.au

Abstract We present the first experimental demonstration of direct optical-signal-noise-ratio (OSNR) monitoring on the packet basis. The OSNR monitoring error is found to be < 0.6 dB in a dynamic range from 10 dB to 30 dB.

Introduction

There has been tremendous research interest into performance monitoring of various optical parameters, including the channel power, wavelength, OSNR, chromatic dispersion [1]. Furthermore, all-optical label switching holds the promise to bypass the electronic bottleneck and introduce flexibility and efficiency into the data-centric internet network [2]. However, the concept of all-optical networks generates a host of new challenges in terms of efficient network monitoring and maintenance. The performance monitoring for packet switched networks adds a new dimension to the research topics of performance monitoring. Incoming packets at a switching node in a packet switched network could originate from diverse sources and traverse different optical links, which therefore results in vast wide dynamic range of optical parameters on the short time span of one packet. Optical-signal-to-noise ratio is one of the critical parameters to monitor. Previous approaches based on the polarization-nulling [3], or signal-to-ASE beat noise at low frequency [4] cannot be applied to performance monitoring for a packet varying at a rate in the order of 'nanosecond'. Another approach using uncorrelated signal-to-ASE beat noise requires precise matching of the receiver pair and may need more calibration procedures [4]. Indirect OSNR monitoring by measuring bit errors for the purpose of determining Time-to-Live is only sensitive around the 'threshold' OSNR and may not provide enough dynamic range for general purpose network maintenance [5]. In this paper, we propose a novel approach of direct OSNR measurement based on RF noise. We find out the measurement is repeatable and reliable on the packet basis. The OSNR measurement error is found to be less than 0.6 dB for OSNR from 10 dB to 30 dB.

Principle of the OSNR monitor for the packet

Fig. 1 shows the principle of the technique. The packet capable of performance monitor (PM) contains an additional performance mentoring segment (PM segment). In this paper, the PM segment consists of about 10 ns of consecutive '1' bits. At the packet switching node, a part of the input signal power is tapped and the PM segment is extracted from the entire packet by using a Mach-Zenhder modulator. The pulse after the PM extractor is fed into a photodetector. Because the pulse is relatively broad compared to the payload date rate, the data modulation RF is absent at high frequency. The detected RF spectral density at high frequency can be expressed as [6]:

$$P(f) = A_1 \frac{P_S^2}{OSNR} + B_1 \frac{P_S^2}{OSNR^2} + C_1 P_S^2 \qquad (1)$$

where $P(f)$ is the RF power density P_S is the input signal power *OSNR* is the optical-signal-to-noise ratio measured in 0.1 nm noise bandwidth, *A* , *B,* and *C* are constants related to various detection parameters, which can be obtained empirically. The three terms at the right side of (1) consist of the signal-ASE beat noise, the ASE-ASE beat noise and the RIN noise. Without loss of generality, we assume the flat response of the detection system, the RF power *P* integrated in a bandwidth B_e can be expressed as:

$$P = \int_{B_e} p(f) \cdot df = A \frac{P_S^2}{OSNR} + B \frac{P_S^2}{OSNR^2} + C P_S^2 \qquad (2)$$

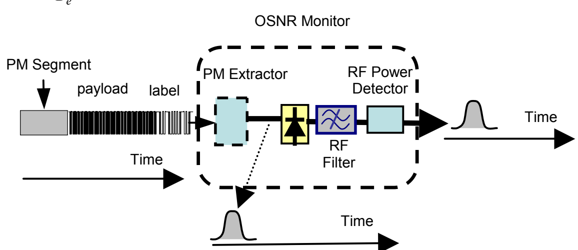

Fig. 1: Conceptual diagram of OSNR monitor.

(2) sums up the underlying principle for the OSNR measurement. If the *A, B, C* coefficients are known and signal power P_s is measured, the OSNR can be evaluated by measuring the RF power *P* using a RF power detector for the extracted PM segment. The advantages of this technique are (i) good immunity to the crosstalk from the payload/label modulation because the PM segment is serial with the regular packet and therefore devoid of high frequency data modulation components; (ii) high sensitivity because of large chunk of noise spectrum about a few GHz can be integrated to provide reliable and repeatable measurement. The ~10 ns of time duration of PM segment will be a large overhead for high speed transmission and therefore, may not be feasible for every packet. However, there may be a need to monitor the OSNR on the time scale of millisecond to second. Because the incoming packets originate

from diverse sources, the OSNR monitoring needs to be performed on a per-packet basis.

Experimental results and discussion

Fig. 2 shows the experimental setup. The transmitter consists of Mach-Zehnder modulator at 10 Gb/s. The details of payload /label are not relevant for this paper. The first EDFA is used to boost the output power for the transmitter. The output of the transmitter is combined with the second EDFA to simulate the link noise. The EDFA noise level is controlled by adjusting the pump bias current. The 1545 nm optical signal contaminated with the noise passes through a 1 nm optical filter and split into two branches for the OSNR measurements. One uses an optical spectrum analyzer as reference and the other has the proposed OSNR monitor. Inside the OSNR monitor, the PM segment is first extracted by using a Mach-Zehnder modulator MZ3, optically detected, and amplified with a 6-12 GHz bandpass RF amplifier. The output from the RF amplifier is fed into a crystal detector (CD, Agilent 8473C) for RF power detection.

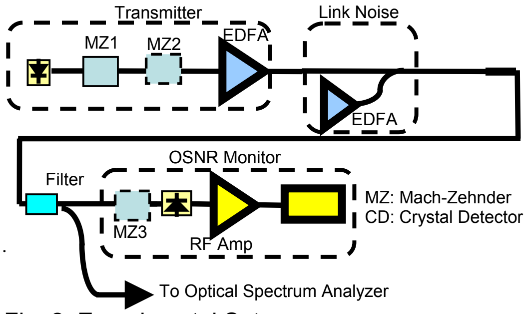

Fig. 2: Experimental Setup

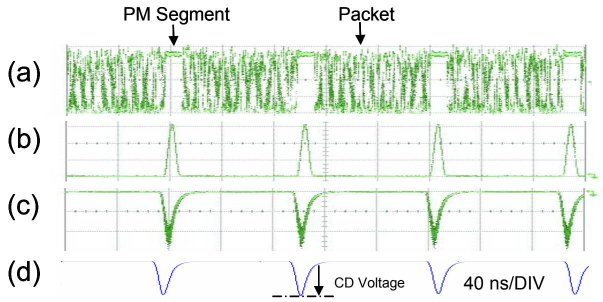

Fig. 3: Oscilloscope traces for (a) original packets, (b) extracted performance monitoring pulse, (c) output from the crystal detector, (d) the same as c after a 100 MHz filter.

We first use one uniform packet to provide a baseline for the monitor and obtain *A, B, C* coefficients. The optical power into the photodetector is ~ -15dBm and the output of CD changes from -80mV to -623mV when OSNR varies. Fig. 3(a) shows the oscilloscope trace for the transmitted packets. Fig. 3(b) shows the extracted pulse after the MZ3. Fig. 3(c) shows the output pulse of the CD. The pulse is relatively noisy due to the leakage of the high frequency components from its input. But if a 100 MHz filter is used, the output is smoothed as shown in Fig. 3(d). We also note the oscilloscope traces in Fig. 3 (a), (b) and (c) are trace measurement without averaging. The repeatable values of the CD voltages for consecutive packets in Fig. 3(d) show the reliability of the OSNR monitor. The CD non-linearity response is calibrated in the experiment.

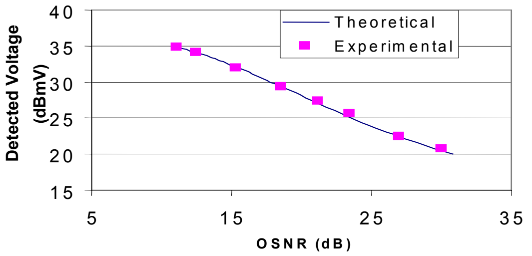

Fig. 4: The detector voltage at the output of the crystal detector as a function of the OSNR.

We used (2) to perform second-order fit of the CD voltage as a function of packet OSNR. The theoretical curve fit is also shown in Fig. 4. The maximum fitting error of the measurement data points from the curve is 0.6 dB.

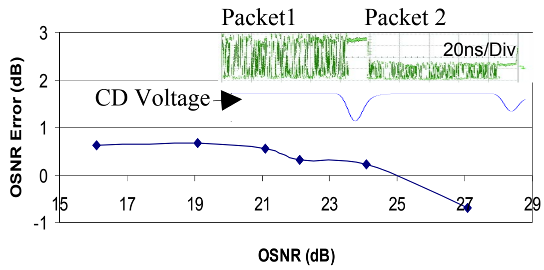

Fig. 5: The OSNR error as a function of OSNR for two dissimilar packets. The inset shows the oscilloscope traces for the two dissimilar packets.

Two dissimilar packets are generated by additional envelope modulation using MZ2 as shown in Fig. 2. The two packets have different OSNRs. The power level P_s and noise level P at the output of the CD are recorded for both packets, and then (2) is used to calculate the predicated OSNRs. Fig. 5 shows the OSNR errors as we vary the OSNR for both packets and the inset CD voltage pulses clearly demonstrate the real time noise measurement. The plot includes the data points for both packets. The maximum OSNR measurement error is found to be 0.6 dB.

References

1 Y.C. Chung, ECOC'2004, paper Tu.6.3.1.
2 D. J. Blumenthal, et al., J. of Lightwave Tech., vol. 18, pp. 2058-2075, 2000.
3 J. H. Lee et al, Electronics Letters, 37 (2001), pp. 972-973.
4 W. Chen, et. al, ATNAC'2004, pp. 150-152
5 J. Yang, ECOC'2004, paper Th. 3.6.5.
6 N. A. Olsson, J. of Lightwave Tech. vol. 7, no. 7, pp. 1071-1082,1989.