Joint OSNR and Chromatic Dispersion Monitoring using Empirical Moments of Asynchronously Sampled Signal Amplitudes

F.N. Khan, Alan Pak Tao Lau, Chao Lu and P.K.A. Wai
Photonics Research Centre, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
Phone: (+852)27664094, Fax: (+852)23628439, Email: 08901853R@eie.polyu.edu.hk

Abstract
We propose a technique for simultaneous and independent optical signal-to-noise ratio (OSNR) and chromatic dispersion (CD) monitoring by using the empirical moments of asynchronously sampled signal amplitude. The proposed technique is low-cost and is applicable to various modulation formats and data rates with good accuracy and large monitoring ranges.

1. Introduction
Optical performance monitoring (OPM) is gaining considerable attention as the optical networks are gradually transitioning from fixed point-to-point links to completely dynamic optical networks [1]. The compensation of impairments in dynamic networks must be adaptive in nature which in turn demands continuous information about the extent of these impairments. In particular, monitoring of OSNR and residual CD is of paramount importance as these parameters govern the overall performance of high-speed optical networks. Several techniques have been proposed in recent years for OSNR and CD monitoring [2]. Amongst them, OPM techniques utilizing the statistical properties of received signal are of more significance as they are low-cost and enable multi-impairment monitoring. In this paper, we propose a technique to monitor OSNR and CD simultaneously and independently by analyzing the empirical moments of asynchronously sampled signals and appropriate signal processing. This technique requires simple hardware, demonstrates large CD monitoring ranges, good accuracy and is valid for multiple modulation formats and data rates.

2. Operating principle
Consider a fiber-optic transmission system where the optical signals are degraded by the amplified spontaneous emission (ASE) noise from in-line optical amplifiers and CD as shown in Fig. 1. Other transmission impairments are neglected for simplicity. Let

\[ d(t) = \sum_{k=-\infty}^{\infty} x_k p(t-kT) \]

be the transmitted signal where \( x_k \) are the complex information symbols, \( p(t) \) is the pulse shape and \( T \) is the symbol period. The function \( h(t) \) is the impulse response of the dispersive fiber, \( w(t) \) is an additive white Gaussian noise (AWGN) process modelling the collective effect of ASE noise and \( h(t) \) is the impulse response of optical filter. The received optical signal \( q(t) \) is detected by a photodetector and then asynchronously sampled to collect amplitude samples. For a given bit sequence, the samples of the photocurrent \( y = i(t = t_0) \) for a given sampling instant \( t = t_0 \) (where \( -T/2 \leq t_0 \leq T/2 \) will have a non-central chi-square probability distribution and their raw moments are well known. Now, the moments of the asynchronously sampled signal \( y = i(t = \tau) \) (where \( \tau \) is uniformly distributed in \([-T/2, T/2]) \) will be the raw moments averaged over the sampling instants. With some algebra, the first three raw moments of the asynchronously sampled signal are shown to be

\[ \mu_1 = P_{\text{noise}} + P_0 \]  

\[ \mu_2 = 1.5P_{\text{noise}}^2 + 3P_0 P_{\text{noise}} + P_0^2 S_4 \]  

\[ \mu_3 = 3P_{\text{noise}}^3 + 9P_0 P_{\text{noise}}^2 + 6P_0^2 P_{\text{noise}} S_4 + P_0^3 S_6 \]
where $P_0$ and $P_{\text{noise}}$ are the signal and noise powers respectively and the parameters $S_4$ and $S_6$ are given by

$$S_4 = \frac{1}{T} \int_{-T/2}^{T/2} E \left( \sum_{k=n} x_k b(\tau-kT) \right) d\tau \quad (4)$$

$$S_6 = \frac{1}{T} \int_{-T/2}^{T/2} E \left( \sum_{k=n} x_k b(\tau-kT) \right)^3 d\tau \quad (5)$$

where $E\{\cdot\}$ denotes expectation and $b(t) = (\sigma(t)*h(t)*h(t))/\sqrt{P_0}$. Using (1) to (5) we obtain

$$P_0 = \sqrt{\left( \mu_2 - 1.5\mu_1^2 \right) \left( S_4 - 1.5 \right)} \quad P_{\text{noise}} = \mu_1 - P_0$$

$$\left( \mu_1 - 3\mu_2 \right) - \left( \frac{\mu_1 - 1.5\mu_2^2}{S_4 - 1.5} \right)^{1/2} \left( 6 - 6S_4 + S_6 \right)$$

$$+ \left( \frac{\mu_2 - 1.5\mu_1^2}{S_4 - 1.5} \right) (6\mu_1 S_4 - 9\mu_1) = 0 \quad (7)$$

Equation (7) is a function of raw moments $\mu_1$, $\mu_2$, $\mu_3$ and parameters $S_4$ and $S_6$ which are functions of CD. Therefore, we can compute the moments $\mu_1$, $\mu_2$, $\mu_3$ of the asynchronously sampled signal and then sweep $S_4$ and $S_6$ jointly for various CD values until (7) is satisfied. That CD value then indicates the accumulated CD in the link. Once the CD is estimated, we can plug-in the corresponding $S_4$ value in (6) to evaluate $P_0$ and $P_{\text{noise}}$. Finally, we can calculate OSNR by using the relation

$$\text{OSNR} = 10 \log \left( \frac{P_0}{P_{\text{noise}}} \right).$$

3. Simulation results

Numerical simulations are conducted for 10/40 Gbps RZ-DPSK/RZ-DQPSK systems to study the validity of proposed technique. The CD monitoring results are shown in Fig. 2. It is obvious that quite accurate CD estimates are obtained. The CD estimation error remains less than 55 ps/nm for CD values up to 3000 ps/nm for 10 Gbps RZ-DPSK system while it remains less than 27 ps/nm for CD values up to 800 ps/nm for 40 Gbps RZ-DQPSK system. It is also clear from Fig. 2 that the CD monitoring results are not perturbed by the OSNR variations thus enabling OSNR independent CD monitoring. The OSNR monitoring results for 10 Gbps RZ-DPSK and 40 Gbps RZ-DQPSK systems are shown in Fig. 3 and it is evident that OSNR estimates are quite accurate especially for low OSNR values. The estimation error remains less than 1 dB for OSNR values up to 20 dB. However, for 40 Gbps RZ-DQPSK system, the error is slightly larger for 25 dB OSNR especially at large CD values. It is also clear from Fig. 3 that OSNR monitoring results are not significantly affected by the CD up to 4000 ps/nm and 1000 ps/nm for 10 Gbps RZ-DPSK and 40 Gbps RZ-DQPSK systems respectively, thus allowing CD independent OSNR monitoring.

4. Conclusions

We proposed a novel technique for joint CD and OSNR monitoring by employing the empirical moments of asynchronously sampled signal amplitude. This technique is low-cost and valid for multiple modulation formats and data rates. Numerical simulations are performed for 10/40 Gbps RZ-DPSK/RZ-DQPSK systems which demonstrate simultaneous and independent monitoring of CD and OSNR with good accuracies and large dynamic ranges.

5. References