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Optical Performance Monitoring Based on 2-D Phase Portrait Generated by Single-Channel Sampling Technique

Changyuan Yu[1*], Yi Yu[2], and Xiaodong Fu[3]

[1]*Dept. of Electronic and Information Engineering, The Hong Kong Polytechnic University, Hong Kong*

[2]*National University of Singapore (Suzhou) Research Institute, China 215123*

[3]*Zhongtian Broadband Technology Corporation, 226463, China*

**eleyc@nus.edu.sg*

ABSTRACT

Optical performance monitoring (OPM) is desired for future smart optical networks. 2-D phase portrait contains fruitful waveform information, which can be a valuable tool for OPM. In this paper, we review the generation of 2-D phase portrait by our cost-effective single-channel sampling technique, and its applications for OSNR and dispersion monitoring in different systems.

Keywords: optical performance monitoring, phase portrait, single channel sampling, optical impairment.

1. INTRODUCTION

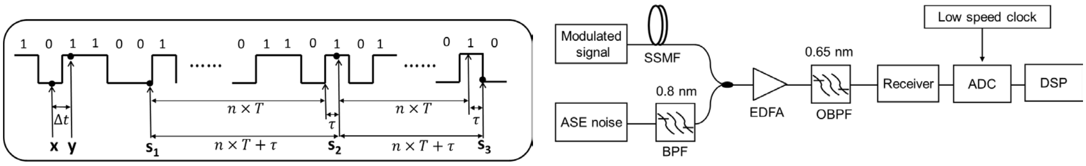
As internet service develops rapidly, optical fiber transmission becomes backbone transmission to provide ultra-broad band to meet the tremendous demand of bandwidth. Moreover, with the invention of Erbium-doped fiber amplifier (EDFA), transmission distance is extended dramatically, while wavelength division multiplexing (WDM) technique enlarges the transmission capacity of single optical fiber at the same time. However, as the capacity of optical transmission system increases, the system becomes more vulnerable to the optical impairments in the physical layer of the optical transmission system [1]. The major effects are from the optical fiber link, which are additive spontaneous emission (ASE) noise and chromatic dispersion (CD). These two effects have accumulative and variable characteristics. Thus, optical performance monitoring (OPM) is a great assistance for the system management of optical transmission systems.

So far, there are a number of monitoring methods based on different working principles [2-7]. For OSNR monitoring, the most common approach is out-band measurement [2], which is based on the assumption that the noise power spectrum is flat at the measured signal frequency range. However, as the transmission systems enter the stage of high data rate and dense WDM system, the out-band noise is difficult to be measured. Thus, in-band OSNR monitoring method is needed. At first, low-speed sub-carrier is generated to co-propagate with signal, which is used to monitor OSNR [3]. This method is able to measure in-band noise, but it is required to modify the transmitter to generate sub-carrier, which increases the complexity of transmitter. Moreover, the generated sub-carrier interferes with the transmitted data, so that it is not a practical method. The in-band noise measurement method without modification of transmitted is needed. In [4], the OSNR monitoring method based on polarization nulling technique was proposed, which is based on the different polarization features of signal and noise. However, when the system is with large amount of polarization related impairment, the measurement results become inaccurate. In [5], optical delay interferometer (ODI) is used for OSNR monitoring, which employs the filtering of the ODI, and relies on the factor that the signal and noise have different optical spectrum. Although, this scheme shows the low cost and simple benefits, it is not applicable for ultra-high-speed system, in which the signal has nearly square shape. Furthermore, the OSNR monitoring based on nonlinear effect was also proposed [6]. It is quite complicated to implement nonlinear effect in the practical system, which requires highly-nonlinear medium and high power pump. In brief, the OSNR monitoring methods based on the physical effect of the signal and noise are difficult to be applied in the field system. Besides the physical effect of the impairment, we can monitor the waveform distortion induced by the impairment. In [7], 1-dimensional (1-D) histogram of the received signal amplitude was proposed for Q-factor monitoring. This method employs single photo-detector to receiver optical signal and single analog-to-digital converter (ADC) to transfer the optical impairment induced waveform distortion into digital domain. However, 1-D histogram delivers limited information from the waveform, so that it cannot separate different optical impairments.

In order to derive more information from waveform, 2-dimentional (2-D) phase portrait was proposed for multiple optical impairment monitoring [8], which is also called as delay-tap sampling plot. It is an alternative expression of eye diagram. This method uses two sampling channels to sample the signal simultaneously with a short internal time delay. The sample pairs from these two channels are depicted into a 2-D coordinate system. Different optical impairment causes the pattern evolution in the phase portrait in different way. Since CD leads to the signal pulse width broadening, it changes the pattern width of the phase portrait [9]. Moreover, OSNR variation can also be observed in the pattern evolution for that the pattern line becomes noisy as the noise power increases [9]. However, this scheme employs two sampling channels, which causes high monitoring cost. Thus, we proposed to use single sampling channel to generate 2-D phase portrait. In this paper, we review our the generation of 2-D phase portrait based on single channel sampling (SCS) technique mainly for OSNR and dispersion monitoring [12-14].

2. SOFTWARE SYNCHRONIZED SINGLE CHANNEL SAMPLING TECHNIQUE

In Fig. 1(a), the X-Y pair generation processes of the SCS method and conventional two-channel delay-tap sampling method are shown. For the conventional two-channel method, two sampling channels working simultaneously with short time delay (Δt) to get two samples (x and y) as X-Y pair. The time delay (Δt) between two samples is within single symbol duration. In SCS method, single sampler works continuously with a slower frequency, so that the time interval between neighbor samples can be expressed as $n\times T+\tau$ (n is an integer number; T is one symbol duration; τ is the remaining time that is less than one symbol duration). For the X-Y pairs generation, it searches a sample (S_{k+1}) along the sample sequence, which has a time interval between S_{k+1} and S_1 is $k{\cdot}n\times T+k\times\tau$, which can also be expressed as $m\times T+\Delta t$ (m is an integer number, Δt is same as the conventional method). S_1 and S_{k+1} are formed as an X-Y pair in SCS method, and so forth.



(a) (b)

Figure 1: (a) Working principle comparison between SCS and conventional delay-tap sampling method; (b) Experimental setup.

When the SCS method is applied in the real system, the low-speed sampling frequency is un-related to signal frequency as the experimental setup being shown in Fig. 1(b). As shown in Fig. 2(a), the single sampler is working in an un-related low-speed frequency (f_s), which causes an aliasing frequency (f_a). There is a particular relationship between the aliasing frequency and sampling frequency, which is expressed as $f_a = f_b - N{\cdot}f_s$, (f_b is a bit rate and N is an integer) [10].The time interval between the neighbor samplers can be expressed by $n\times T+\tau$ (n is an integer number; T is one-symbol duration; τ is the within one-symbol time shift between neighbor samples). The relationship between the aliasing frequency and the sampling frequency can be expressed as Eq. (1) [11].

$$\frac{f_a}{f_s} = \frac{\tau}{T}. \tag{1}$$

Once the aliasing frequency is obtained, the phase difference (τ / T) between neighbor samples can be derived by Eq. (1). The accumulated phase change of the whole sample sequence can be obtained as Fig. 2(b) shows. The software synchronization of sample sequence is done. From the synchronized sample sequence, the nearest sample pairs, whose phase differences are equal to half-symbol period ($\Delta t/T = 0.5$), are selected as X-Y pairs to be depicted in a 2-D coordinate system, which is an equivalent portrait of the half-symbol delay-tap sampling (DTS) plot. The estimation of the aliasing frequency can be done by FFT based reference phase detection [11].

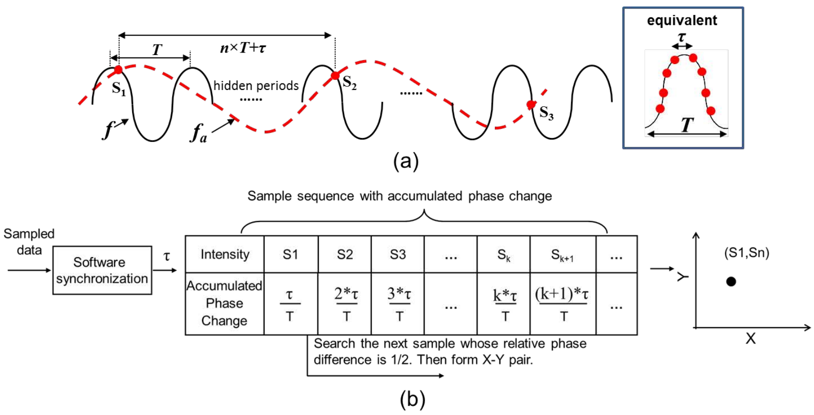


Figure 2: (a) low-speed sampling scheme; (b) Schematic diagram of X-Y pairs generation.

Conventionally, the time delay or the phase difference between X-Y pairs is a fixed value. However, for the software synchronized, the frequency estimation error would causes synchronization timing error, which can be expressed by Eq. (2):

$$\frac{f_a + f_o}{f_s} = \frac{\tau + \Delta\tau}{T}. \tag{2}$$

The frequency estimation offset (f_o) causes timing error ($\Delta\tau$), which finally leads to an incorrect phase portrait as shown in Fig. 3. When the aliasing frequency offset (FO) is within 500 Hz, the phase portrait is not affected by the timing error. However, when the phase portrait is up to 10 kHz, the pattern is changed. Thus, we proposed a variable phase difference phase portrait, in which the phase difference of X-Y pair is within a range.

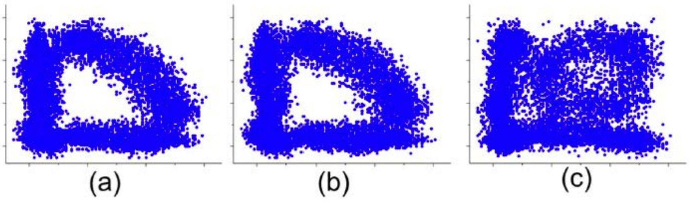


Figure 3. Half symbol delay phase portrait of NRZ-DPSK with 30-dB OSNR, which is generated under different aliasing FO: (a) 0 Hz, (b) 500 Hz, (c) 10 kHz.

The schematic diagram is shown in Fig. 4(a), the phase difference is within a tolerated range ($2t_o/T$). For instance, the phase difference between the S_1 and its partner S_p is in the range from $(\Delta t\text{-}t_o)/T$ to $(\Delta t+t_o)/T$, so that the sample pairs with the phase difference in a range would be easier to be found for the X-Y pairs generation. The time interval between the sample pairs would be reduced, which increases the tolerance to the drift phase induced by the aliasing frequency estimation offset. As shown in Fig. 4(b), the phase portrait is the variable half symbol phase difference phase portrait generated with 10-kHz aliasing frequency offset. It can be observed that the pattern is not changed for the large estimation offset. After the phase portrait is generated, the monitoring parameters can be obtained by using statistical analysis or pattern recognition.

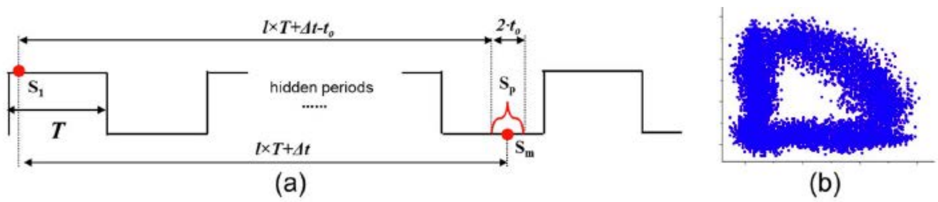


Figure 4: (a) Schematic diagram of variable phase difference phase portrait generation; (b) NRZ-DPSK signal phase portrait generated by tolerated phase difference.

3. EXPERIMENTAL RESULTS

In Fig. 5, the experimental results show the OSNR monitoring based on the proposed SCS method with fixed phase difference in three different modulation formats, which is derived by using statistical pattern analysis. The OSNR monitoring test is from 10 dB to 30 dB. It can be observed that the OSNR monitoring performance is robust when CD is not high, which is enough for the residual CD.

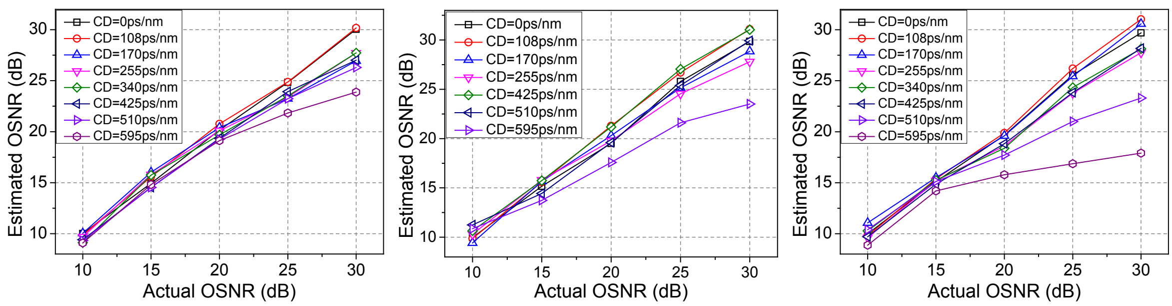


Figure 5. Experimental result for OSNR monitoring at the present of CD effect: (a) NRZ-OOK, (b) NRZ-DPSK, (c) RZ-DPSK.

In Fig. 6, the experimental results show the OSNR monitoring based on the proposed SCS method with variable phase difference in three different modulation formats. The aliasing frequency estimation offset varies from 0 Hz to 10 kHz, while the CD is changed from 0 ps/nm to 425 ps/nm. When the two factors co-exist in the monitoring system, the proposed OSNR monitoring method can keep a good monitoring accuracy from 10 dB to 25 dB. Beyond 25 dB, the OSNR monitoring accuracy is poor, since it is more sensitive to the CD induced pattern distortion, which can actually be used for CD monitoring after calibration.

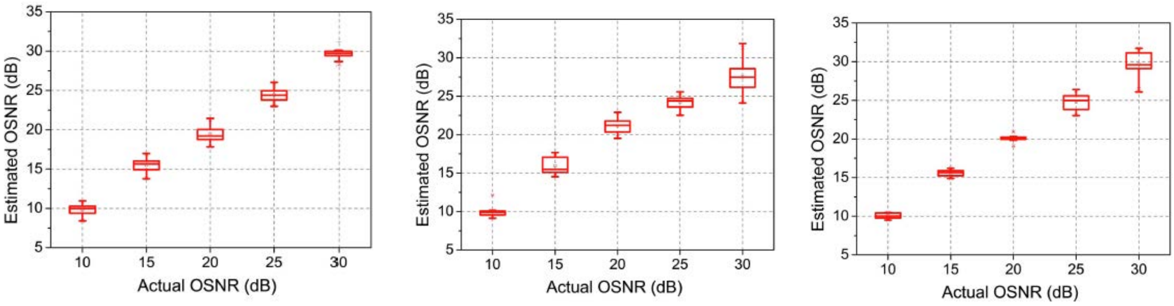


Figure 6. Experimental result for OSNR monitoring at the present of CD effect and FO:
(a) NRZ-OOK, (b) NRZ-DPSK, (c) RZ-DPSK.

4. CONCLUSIONS

In this paper, we reviewed the 2-D phase portrait generated by using single channel sampling technique, which can be used for optical performance monitoring. This scheme simplifies the system setup and reduces the cost. Moreover, the generated phase portrait can be used for multiple optical impairment monitoring by using statistical analysis or pattern recognition.

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REFERENCES

[1] Z. Pan, C. Yu, and A. E. Willner, "Optical performance monitoring for the next generation optical communication networks," *Optical Fiber Technology*, vol. 16, no. 1, pp. 20–45, 2010.
[2] H. Suzuki and N. Takachio, "Optical signal quality monitor built into WDM linear repeaters using semiconductor arrayed waveguide grating filter monolithically integrated with eight photodiodes," *Electronics Letters*, vol. 35, no. 10, pp. 836–837, 1999.
[3] G. Rossi, T. E. Dimmick, and D. J. Blumenthal, "Optical performance monitoring in reconfigurable WDM optical networks using subcarrier multiplexing," *Journal of Lightwave Technology*, vol. 18, no. 12, pp. 1639–1648, 2000.
[4] J. Lee, O. Jung, C. Kim, and Y. Chung, "OSNR monitoring technique using polarization-nulling method," *IEEE Photonics Technology Letters*, vol. 13, no. 1, pp. 88–90, 2001.
[5] X. Liu, Y. Kao, S. Chandrasekhar, I. Kang, S. Cabot, and L. Buhl, "OSNR monitoring method for OOK and DPSK based on optical delay interferometer," *IEEE Photonics Technology Letters*, vol. 19, no. 13/16, pp. 1172–1174, 2007.
[6] R. Adams, M. Rochette, T. T. Ng, and B. J. Eggleton, "All-optical in-band OSNR monitoring at 40 Gb/s using a nonlinear optical loop mirror," *IEEE Photonics Technology Letters*, vol. 18, no. 3, pp. 469–471, 2006.
[7] Z. Li, C. Lu, Y. Wang, and G. Li, "In-service signal quality monitoring and multi-impairment discrimination based on asynchronous amplitude histogram evaluation for NRZ-DPSK systems," *IEEE Photonics Technology Letters*, vol. 17, no. 9, pp. 1998–2000, 2005.
[8] Z. Li, Z. Jian, L. Cheng, Y. Yang, C. Lu, A. P. T. Lau, C. Yu, H. Tam, and P. Wai, "Signed chromatic dispersion monitoring of 100Gbit/s CS-RZ DQPSK signal by evaluating the asymmetry ratio of delay tap sampling," *Optics Express*, vol. 18, no. 3, pp. 3149–3157, 2010.
[9] F. Khan, A. P. T. Lau, Z. Li, C. Lu, and P. Wai, "Statistical analysis of optical signal-to-noise ratio monitoring using delay-tap sampling," *IEEE Photonics Technology Letters*, vol. 22, no. 3, pp. 149–151, 2010.
[10] Wikipedia, "Aliasing," http://en.wikipedia.org/wiki/Aliasing, accessed 5/3/15.
[11] H. G. Choi, Y. Takushima, and Y. C. Chung, "Phasor monitoring of DxPSK signals using software-based synchronization technique," *Optics Express*, vol. 18, no. 21, pp. 21511–21518, 2010.
[12] Y. Yu and C. Yu, "Optical signal to noise ratio monitoring using variable phase difference phase portrait with software synchronization," *Optics Express*, vol. 23, no. 9, pp. 11284–11289, Apr. 2015.
[13] Y. Yu, B. Zhang, and C. Yu, "Optical signal to noise ratio monitoring using single channel sampling technique," *Optics Express*, vol. 22, no. 6, pp. 6874-6880, Mar. 2014.
[14] Y. Yu and C. Yu, "Dispersion insensitive optical signal to noise ratio monitoring of PDM signal by using uncorrelated signal power," *Optics Express*, vol. 22, no. 11, pp. 12823–12828, Jun. 2014.