Influence of Digital Dispersion Equalization on Phase Noise Enhancement in Coherent Optical System

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Abstract: The phase noise enhancement due to digital dispersion equalization is investigated, which indicates that the phase noise from transmitter laser can also interact with the dispersion depending on the choice of digital dispersion compensation methods.
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1. Introduction

Coherent detection using digital signal processing (DSP) techniques can compensate the system impairments in the electrical domain, such as chromatic dispersion (CD) equalization, polarization mode dispersion (PMD) equalization and carrier phase noise (PN) mitigation [1,2]. Phase noise compensation (PNC) using DSP has been validated as an effective method for mitigating the influence of the PN from the laser sources [3]. However, the analysis of phase fluctuation is usually performed without considering the influence of large CD, which is insufficient for a coherent communication system using DSP-based CD equalization and carrier phase estimation (PE). W. Shieh et al. have proposed the theory of equalization enhanced phase noise (EEPN) in digital coherent communication system, which indicates that the local oscillator (LO) phase noise can be aggravated by digital dispersion equalization (DDE) [4,5]. Meanwhile, C. Xie has also reported the similar phenomenon that the high speed transmission system is stringently limited by LO phase noise due to the phase noise to amplitude noise conversion [6]. These analysis indicates that the EEPN scales linearly with the accumulated dispersion and the linewidth of the LO laser [4-6]. Worth noting here is that the EEPN will not exist in the system with entire optical dispersion compensation (ODC) [4].

In this paper, we further investigate the impacts of EEPN in a 112-Gbit/s non-return-to-zero polarization division multiplexed quadrature phase shift keying (NRZ-PDM-QPSK) coherent optical transmission system, in which the CD is compensated by using three digital filters respectively: a fiber dispersion finite impulse response (FD-FIR) filter, a blind look-up (BLU) filter and a least mean square (LMS) adaptive filter [1,2,7]. The results are compared with the performance of phase noise compensation in the system with only optical dispersion compensation. Our work shows that the phase noise from the transmitter (TX) laser can also interact with the dispersion compensation when the LMS CD equalizer is used.

2. High speed PDM-QPSK coherent optical transmission system

The 112-Gbit/s NRZ-PDM-QPSK coherent transmission system implemented in the VPI simulation platform is illustrated in Fig. 1.

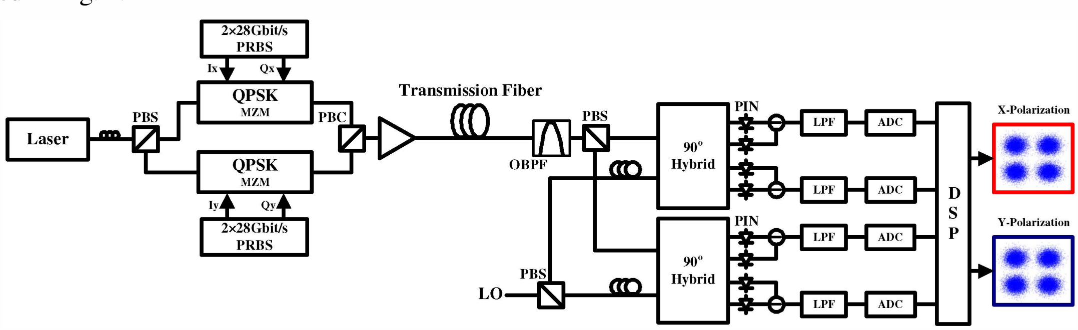


Fig. 1. Scheme of 112-Gbit/s NRZ-PDM-QPSK coherent optical transmission system

The data sequence output from the four 28-Gbit/s pseudo random bit sequence (PRBS) generators are modulated into two orthogonally polarized NRZ-QPSK optical signals by two Mach-Zehnder modulators. The orthogonally polarized signals are integrated into one fiber channel by a polarization beam combiner (PBC) to form the 112-Gbit/s NRZ-PDM-QPSK optical signal. Using a local oscillator in the coherent receiver, the received optical signals are mixed with the LO laser to be transformed into four electrical signals by the photodiodes. These signals are digitalized by the 8-bit analog-to-digital convertors (ADCs) at twice the symbol rate. The transmission fibers are with the CD coefficient equal to 16 ps/nm/km, and the central wavelength of the TX laser and the LO laser are both 1553.6 nm. The carrier phase noise compensation is performed by a one-tap normalized least mean square (NLMS) adaptive filter [8]. For simplicity, the influences of fiber attenuation, polarization mode dispersion and nonlinear effects are neglected in this study.

3. Simulation results

To give a preliminary example of the phase noise tolerance of the different CD compensation methods, the bit-error-rate (BER) versus optical signal-to-noise ratio (OSNR) performance for 600 km fiber transmission system is investigated, where both the linewidths of the TX and the LO lasers are set at 500 kHz. The system behavior is evaluated by comparing the performance of the optical and the digital CD compensation without phase noise compensation, as shown in Fig. 2. In the transmission system with moderate dispersion (fiber length less than 1000 km), the LMS filter has the best performance compared to the FD-FIR filter and the BLU filter as well as the optical dispersion compensation. This is because the low order (small number of taps) LMS-based adaptive filter can realize the function of CD equalization and phase noise mitigation simultaneously [8]. It is also found that the performance of the FD-FIR equalization, the BLU equalization and the dispersion compensation fiber (DCF) compensation are very similar, when the phase noise compensation is not employed in the coherent transmission system.

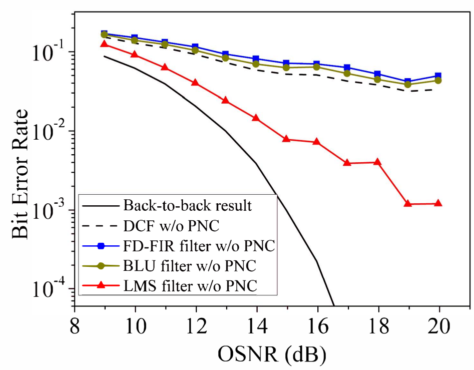
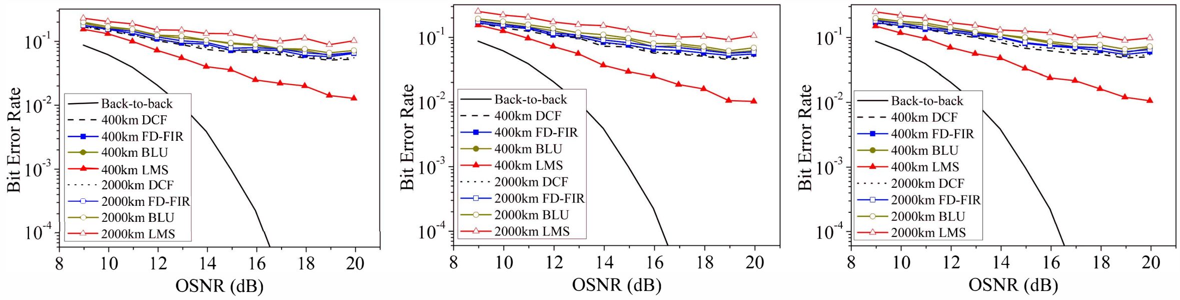


Fig. 2. The simulation result for 600 km fiber using inline DCF and DDE without PNC. Both TX and LO lasers linewidths are 500 kHz, w/o means without.

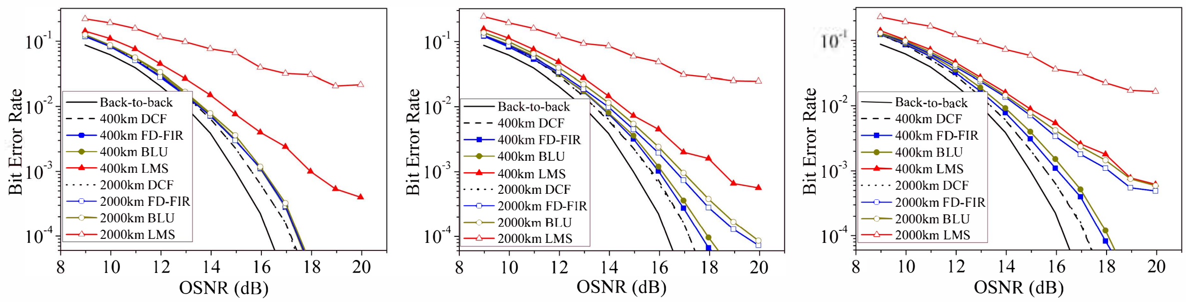
In order to investigate the enhancement effect of the phase noise from the TX and the LO lasers due to the digital CD equalization, we used different combination of the TX laser and the LO laser linewidths with the same summation. Figure 3 shows the performance of the transmission system with different fiber length using the optical and the digital dispersion compensation without phase noise compensation. It is found that the FD-FIR equalization, the BLU equalization and the DCF compensation still show little difference and insignificant fiber length dependence in all three cases. However, the LMS adaptive equalization degrades with the increment of the fiber length. It arises from the interplay between the dispersion equalization and the phase noise, which involves both the TX and the LO phase fluctuations. For relatively large accumulated dispersion (2000 km fiber), the high order (large number of taps) LMS filter behaves even worse than the other three chromatic dispersion compensation methods. This is because the phase correlation between symbols with a long delay interval fades out due to the large fluctuations occurring in the adaptive filter delay time.

Figure 4 shows the BER performance of the transmission system with different fiber length employing the optical and the digital dispersion compensation by further using a one-tap NLMS filter for phase noise compensation. Again the results are obtained under different combination of the TX laser and LO laser linewidths with the same summation. We can see clearly that influenced by the EEPN, the performance of FD-FIR equalization and BLU equalization reveals obvious fiber length dependence with the increment of LO laser linewidth. The OSNR penalty in phase noise compensation scales with the LO phase fluctuation and the accumulated dispersion. This is in agreement with previous studies [4-6]. On the other hand, the dispersion equalization using the LMS filter shows almost the same behavior in the three cases. That is because the chromatic dispersion interplays with the phase noise of both TX and LO lasers simultaneously in the adaptive equalization. Moreover, Figure 4 also shows the LMS filter is less tolerant against the phase fluctuation than the other dispersion compensation methods when the one-tap NLMS carrier phase noise compensator is employed.



(a) (b) (c)

Fig. 3. The coherent detection results for different fiber length using inline DCF and digital CD compensation with different TX laser and LO laser linewidths combination without phase noise compensation. (a) TX laser linewidth is 4 MHz and LO laser linewidth is 0 Hz. (b) both TX laser and LO laser linewidth are 2 MHz. (c) TX laser linewidth is 0 Hz and LO laser linewidth is 4 MHz.



(a) (b) (c)

Fig. 4. The coherent detection results for different fiber length using inline DCF and digital CD compensation with different TX laser and LO laser linewidths combination with one-tap NLMS phase estimation. (a) TX laser linewidth is 4 MHz and LO laser linewidth is 0 Hz. (b) both TX laser and LO laser linewidths are 2 MHz. (c) TX laser linewidth is 0 Hz and LO laser linewidth is 4 MHz.

4. Conclusions

In this paper, the effect of the enhanced phase noise by different digital CD equalization methods is investigated in the 112-Gbit/s NRZ-PDM-QPSK coherent optical transmission system. Digital dispersion equalization using the FD-FIR and the BLU filters significantly impacts the performance of the carrier phase estimation by the equalization enhanced LO phase noise. However, in the LMS adaptive dispersion equalization, the behavior of carrier phase estimation is equivalently influenced by both of equalization enhanced TX phase noise and LO phase noise. Moreover, the LMS adaptive filter is less tolerant against phase fluctuation than other methods, when carrier phase noise compensation is employed.

5. References

[1] S. J. Savory, “Digital filters for coherent optical receivers,” OE **16**, 804-817 (2008).

[2] M. Kuschnerov, F. N. Hauske, K. Piyawanno, B. Spinnler, A. Napoli and B. Lankl, “Adaptive chromatic dispersion equalization for non-dispersion managed coherent systems,” in OFC 2009 (San Diego, California, 2009), paper OMT1.

[3] E. Ip, A. P. T. Lau, D. J. F. Barros and J. M. Kahn, “Coherent detection in optical fiber systems,” OE **16**, 153-791 (2008).

[4] W. Shieh and K. P. Ho, “Equalization-enhanced phase noise for coherent detection systems using electronic digital signal processing,” OE **16**, 15718-15727 (2008).

[5] A. P. T. Lau, W. Shieh and K. P. Ho, “Equalization-enhanced phase noise for 100Gb/s transmission with coherent detection,” in OECC 2009 (OptoElectronics and Communications Conference, Hong Kong, 2009), paper FQ3.

[6] C. Xie, “Local oscillator phase noise induced penalties in optical coherent detection systems using electronic chromatic dispersion compensation,” in OFC 2009 (San Diego, California, 2009), paper OMT4.

[7] S. Haykin, *Adaptive filter theory* (4th Edition, Prentice Hall, 2001).

[8] Y. Mori, C. Zhang, K. Igarashi, K. Katoh and K. Kikuchi, “Unrepeated 200-km transmission of 40-Gbit/s 16-QAM signals using digital coherent receiver,” OE **17**, 1435-1441 (2009).