ELECTRONIC NONLINEAR COMPENSATION OVER TRANSOCEANIC TRANSMISSION DISTANCE

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Abstract: We evaluated the performance of PBP and PPD, which are nonlinear compensation techniques derived from the perturbation analysis with reduced computational complexity, over the transoceanic transmission distance (10,000km). We observed the Q-improvement ranging from 1 to 2 dB and confirmed PBP and PPD are effective for the transoceanic transmission by numerical simulations.

1. INTRODUCTION

DWDM transmission of over-100Gb/s signals over transoceanic distance is a target for next generation ultra-long haul systems. One of the commercially feasible system configurations for such systems may include RZ-DP-QPSK modulation format with coherent detection, large effective-area fiber with high local dispersion around 20 ps/nm/km without in-line dispersion compensation. The RZ format removes the undesirable transient caused by the phase change between bits. The high local dispersion fiber combined with the RZ format enables to reduce the inter-channel XPM because of increasing walk-off effect among channels. As a result, the intra-channel nonlinear effect becomes the dominant non-linear degradation. Then we can focus our effort on the mitigation of this effect.

Today, the most widely studied nonlinear mitigation algorithm is the digital backward propagation (DBP) in digital coherent receiver. It compensates the accumulated chromatic dispersion and non-linear effect alternately in cascade steps. It requires the compensation steps equal to or more than the number of repeater spans. Consequently, this heavy computational complexity becomes a significant obstacle.

To improve this, the perturbation analysis was proposed to be applied. It derives considerably more efficient compensation of the intra-channel non-linear effect which consist of self-phase modulation (SPM), Intra-channel cross phase modulation (IXPM) and Intra-channel four-wave mixing (IFWM)[1]. Two such techniques have been proposed: one for the receiver is called perturbation backward propagation [2] (PBP), and the other for the transmitter called perturbation pre-distortion [3] (PPD).

PBP: A method to compensate the accumulated chromatic dispersion and non-linear effect alternately in cascade steps using a newly added factor of IXPM derived from the perturbation analysis.

PPD: A method to subtract the distortion due to SPM, IXPM and IFWM out of the sending signals calculated from the sent sequence using the perturbation analysis. It does not require the concatenated compensation steps at all.

Previously, the effect of PBP, PPD and the combination of the two on the terrestrial network transmission distance (~2,500 km) has been reported [4]. In this paper, we report numerical simulation results applying the PBP, PPD and their combination to the transoceanic transmission distance.

2. SIMULATION SETUP

Signal channels were modulated in NRZ- or RZ- DP-QPSK format at a bit-rate of 128 Gb/s and processed with PPD. Five (5) channels were multiplexed and spaced at 50GHz.

The transmission line consisted of 150 spans of 66.7km Pure Silica Core Fiber (PSCF) without in-line dispersion compensation. The accumulated chromatic dispersion at the receiver is +205,000 ps/nm.

The receiving signals were received by coherent detection with conventional digital signal processing (DSP) algorithms with optional PBP. All the chromatic dispersion was compensated electronically in the receiver DSP.

Figure 1 shows the simulation setup.

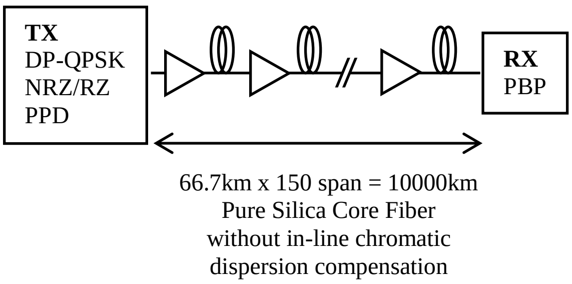


Figure 1. Simulation set up

3. RESULT

Figure 2 shows the OSNR-Q performance for single channel after 10,000km transmission.

First of all the Q improvement by replacing the NRZ pulse format with the RZ was found to be 1.1 dB. On the top of this improvement by RZ pulse carving, each of PPD or PBP showed a 1.8 dB improvement. By applying the PBP and PPD simultaneously, 2.5dB improvement was observed.

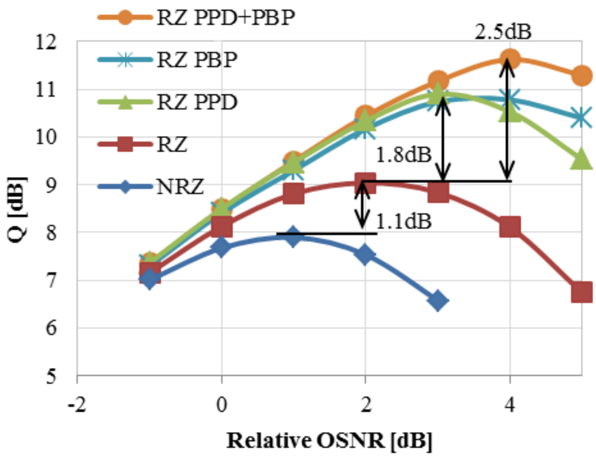


Figure 2. Improvement of OSNR-Q performance by PBP and PPD for Single channel (128 Gb/s, DP-QPSK, PSCF, 10000km w/o in-line dispersion compensation)

Figure 3 shows the OSNR-Q performance for 5 WDM channels after 10,000km transmission.

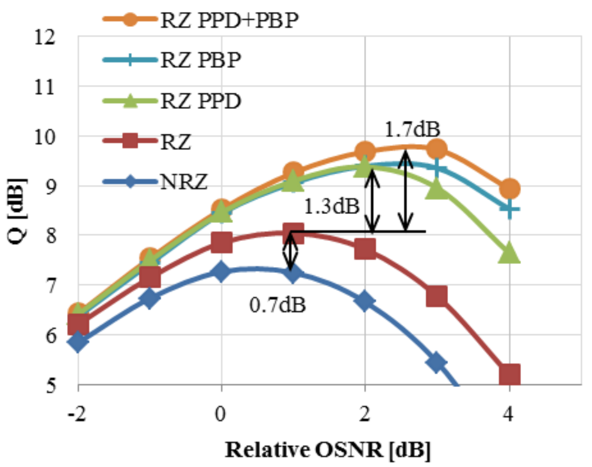


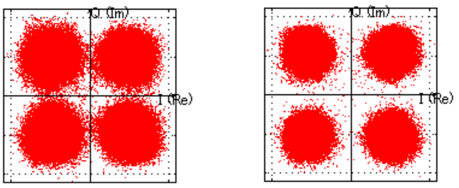
Figure 3. Improvement of OSNR-Q performance by PBP and PPD for five WDM channels

In this case, the Q improvement by adding the RZ carving was 0.7 dB. In addition, PPD and PBP showed the same 1.3 dB improvement for each, while the combination of PBP and PPD resulted in a 1.7 dB improvement.

The improvement by PBP and PPD in a terrestrial network transmission distance (SMF, 100km x 25 spans without in-line dispersion compensation) was reported to be around 1 dB [4]. In this study, we confirmed that PBP, PPD and the combination are effective for the transoceanic transmission distance as well.

For an ultra-long haul transmission without in-line dispersion compensation such as transoceanic one, the degradation caused by the intra-channel nonlinear effect (SPM, IXPM, IFWM) become more significant than for the terrestrial ones. Therefore, PPD and/or PBP to compensate the intra-channel nonlinear effect is a good fit for the next generation transoceanic transmission systems having higher symbol rates and higher local dispersion.

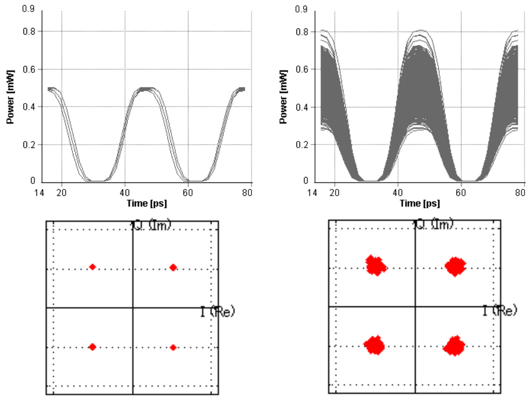
Next, we describe how the PBP and PPD work more in detail. Figure 4 (a) shows RZ received constellation after 10,000 km. Figure 4 (b) shows that processed with PBP. The constellation is more concentrated by PBP.



(a) without PBP **(b) with PBP**

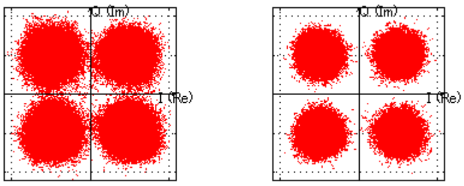
Figure 4. Improvement of received constallation by PBP

Figure 5 (a) shows optical intensity waveform after RZ-carving and its constellation. Figure 5 (b) shows those processed with PPD. Because the waveform sent with PPD includes pre-distortion to counteract the inter-symbol interference caused by the nonlinearity, the waveform looks rather noisier and the constellation are more scattered. However, this distortion works to cancel the nonlinear effect far at the receiver and create the improvement as shown in Figure 6.



(a)without PPD **(b)with PPD**

Figure 5. Sending optical intensity waveform and constellations by PPD



(a)without PPD **(b)with PPD**

Figure 6. Improved received constellation by PPD

4. CONCULUSION

We evaluated the performance of PBP and PPD, which are nonlinear compensation techniques derived from the perturbation analysis with reduced computational complexity, over the transoceanic transmission distance. We observed the Q-improvement ranging from 1 to 2 dB.

For an ultra-long haul transmission without in-line dispersion compensation, the degradation caused by the intra-channel nonlinear effect (SPM, IXPM, IFWM) become more significant than for the terrestrial transmission distance. Therefore, PPD and/or PBP to compensate the intra-channel nonlinear effect is a good fit for the next generation transoceanic transmission systems.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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