Mitigation of Fiber Impairments by Electronic Maximum-Likelihood Polarization Diversity Receivers

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Abstract *A dual-input maximum-likelihood based receiver for polarization diversity is proposed. Compared to a single-input receiver this type of electronic equalizer reduces penalties, leading to a significantly improved outage probability.*

Introduction

Electronic equalization concepts like feed forward equalization (FFE), decision feedback equalization (DFE) and Viterbi equalization (VE) have the potential to mitigate cost efficiently chromatic dispersion (CD) and polarization mode dispersion (PMD) [1,2]. Among these, the conditional probabilities-based VE results in a near maximum-likelihood receiver, which is capable to cover non-gaussian and signal dependent noise from accumulated amplified spontaneous emission (ASE) as well as low resolution analog-to-digital conversion (ADC) effects. Recently, polarization diversity receivers in combination with VE have been applied to fibers with CD and PMD [3]. In [4] multiple-input VE in combination with differential modulation formats was proposed for CD.

In this contribution the dual-input conditional probabilities-based VE for polarization diversity (PD) is investigated in more detail for first and higher order PMD with instantaneous differential group delay (DGD) up to more than one bit interval. The range of attainable improvement in required OSNR is discussed.

In the consecutive, the PD-VE and the corresponding channel model will be presented. For realistic fiber transmission scenarios, the OSNR penalties for adaptive threshold (AT) receivers, FFE, DFE, single input VE (SI-VE) and PD-VE will be addressed. Finally, the influence of the state of polarization at the receiver side is considered.

Optical transmission system

At the transmit side of the optical transmission system, depicted in figure 1, forward error correction (FEC) is applied to the binary sequence, which is then modulated and transmitted. Throughout the paper we assume non return to zero (NRZ) data modulation. The transmitted signal is characterized by extinction ratio and optical power. CD and PMD as well as non-linear fiber characteristics are included in the optical channel [3]. The model of the optical receiver comprises an optical amplifier, which is used to provide an appropriate receiver input power, an optical filter, optionally a polarization splitter and the photo detector(s). Electronic processing includes low-pass filtering, clock recovery, adaptive equalization and data recovery, and in case of VE an ADC for each input. Finally, FEC decoding allows the system to operate at a higher raw bit error rate (BER), which enables the receiver to be more tolerant to channel noise.

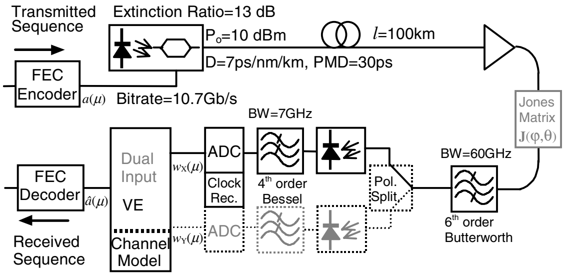

Fig. 1: Transmission model with and without PD

The PMD scenarios used in this paper result from scanning the DGD spectrum for particular DGD values at the carrier frequency, calculating the principal states of polarization and feeding equal optical power along these axes [1]. Since this tends to be close to the worst-case scenario only for non-PD receivers, we have investigated the influence of the state of polarization for the PD-VE, by an additional polarization transformation $\mathbf{E}_{\mathrm{out}} = \mathbf{J}(\theta, \varphi) \cdot \mathbf{E}_{\mathrm{in}}$ in front of the receiver. As seen in figure 1, for this purpose a Jones matrix $\mathbf{J}(\theta, \varphi) = \mathbf{A}(\theta) \cdot \mathbf{B}(\varphi)$ is included, where

$$\mathbf{E} = \begin{bmatrix} E_x \\ E_y \end{bmatrix}, \mathbf{A} = \begin{bmatrix} \cos\theta & -\mathrm{j}\sin\theta \\ -\mathrm{j}\sin\theta & \cos\theta \end{bmatrix}, \ \mathbf{B} = \begin{bmatrix} \mathrm{e}^{-\frac{\mathrm{j}\varphi}{2}} & 0 \\ 0 & \mathrm{e}^{\frac{\mathrm{j}\varphi}{2}} \end{bmatrix}.$$

Dual Input Viterbi Equalizer

In contrast to the SI-VE for real valued signals, which operates on the samples of the filtered photo current signal and is explained in more details, e.g., in [1, 5], the PD-VE jointly processes the signals from two photo-diodes, each for one polarization mode. Therefore, the optical frontend requires an additional polarization splitter, two electrical filters and two ADCs on the electrical side. The timing is provided by the same clock-recovery-unit, which has to be modified in order to reliably synchronize on the PD signals.

Compared to the SI-VE only the lookup-table, which represents the conditional log-probabilities of the quantized input samples for a specific channel state, and the histogram-counter have to be doubled, as depicted in figure 2. This is due to the assumption that

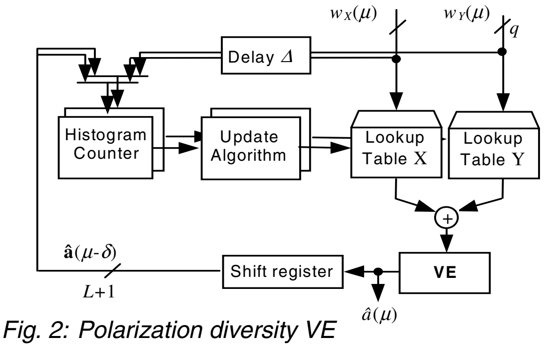

Fig. 2: Polarization diversity VE

the noise processes in the two polarization modes are statistically independent. Then, in order to calculate the appropriate branch metrics, the addressed entries in the lookup tables have to be added. Basically, the proposed PD-VE is similar to the well known VE for complex-valued signals in digital communications [6].

Simulation Results

For the realistic scenario of combined CD and PMD (including higher order PMD and non-linear fiber characteristics), figure 3 compares the performance of different receivers at 10.7 Gbit/s, i.e., AT, adaptive 2-tap DFE, adaptive 3-tap-FFE/2-tap-DFE, SI-VE (4 states, 4 bit ADC) and the corresponding PD-VE, with respect to OSNR penalty at BER=10^{-5} and the parameters given in figure 1 [3]. For fiber channel model clusters around fixed instantaneous DGDs up to 90ps, in each case 10 scenarios including those with maximum and minimum eye opening and some scenarios above 93ps have been selected.

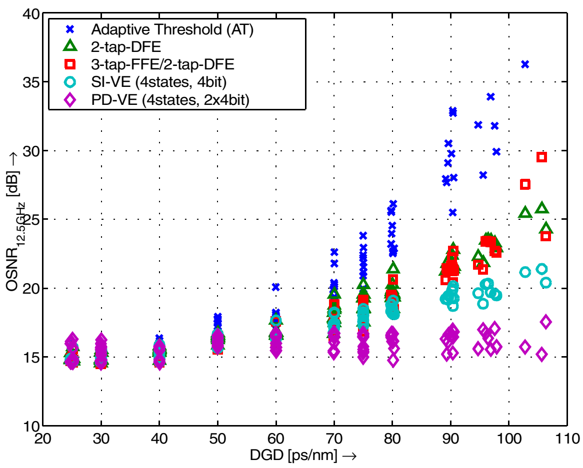

Fig. 3: OSNR penalty vs. DGD for different receivers

While the OSNR penalty of the AT increases rapidly for larger DGD, the penalty of the two DFE type receivers seems to rise only linearly in this range. The two VEs outperform the other receivers at higher dispersions, although they perform slightly worse at low distortions due to a small ADC induced loss. Equal distribution of the optical power into the two principal axes appears to be the best case for the PD-VE.

For a deeper insight into this behaviour, three high-DGD scenarios have been investigated for 100 different polarization states. The contour plot in figure 4 visualizes the PD-VE OSNR penalties of a 90ps scenario. It ranges between 14.5dB and 18.6dB, whereas the SI-VE achieves 20.1dB. Similar results have been obtained for a 80 ps scenario (14.6dB - 17.6dB and 18.0dB for SI-VE) and a 105ps scenario (14.6dB - 20.5dB and 21.2dB for SI-VE). The insets in figure 4 show the corresponding PD eye diagrams for both polarization paths and the eye of single input receivers, which is invariant to these polarizations.

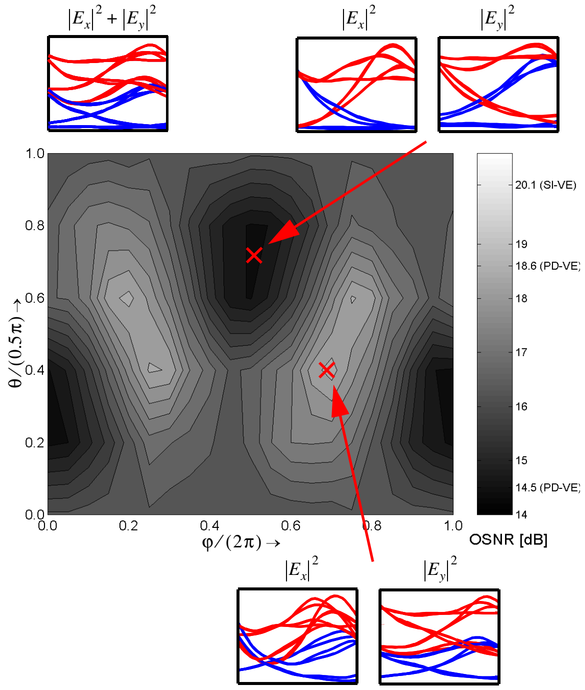

Fig. 4: Contour plot of OSNR penalty vs. φ *and* θ

Conclusions

Comparing different electronic equalizers, the results show that a PD-VE can provide significant improvements in OSNR penalty at the expense of a VE extension, a polarization splitter, and a second optical frontend, but without polarization control. For the investigated scenarios polarization variation in front of the receiver has shown that the PD-VE always performs better compared to the SI-VE. For a given system margin this will lead to a significant improvement in outage probability.

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