Blind Adaptive Equalization of Chromatic Dispersion for PDM-QPSK

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We propose a blind adaptive equalizer for compensation of chromatic dispersion. Simulations show no performance degradation while experiments verify adaptive compensation of 88,000ps/nm chromatic dispersion using 42.8Gbit/s PDM-QPSK.

Introduction

Coherent detection has proved to be a very attractive prospect for next generation optical networks because, when aided by high speed analog-to-digital converters (ADC), the entire optical field is translated into the digital domain. This enables digital signal processing (DSP) to be used to compensate the impairments of the optical channel and improve channel performance. Methods to compensate linear impairments such as polarization mode dispersion (PMD) and chromatic dispersion (CD) are well known [1]. In practical networks a signal between two nodes can take different routes through the system, however the receiving node does not know \textit{a priori} which path has been traversed therefore the transmission distance and the accumulated CD are unknown. Designing a system that can adaptively compensate for CD without knowing the transmission distance would ease routing constraints and allow for high reconfigurability within the network. Existing techniques that attempt to estimate the CD require look-up tables [2],[3], training symbols [4] or the use of brute force algorithms, which test an array of initial dispersion values to optimise performance [5].

Conventional equalizers can compensate for a small amount of CD, such as in short reach transmission systems or in the case of residual dispersion after a discrete (non-adaptive) CD compensator. However, they are unsuitable for compensating large amounts of dispersion as they become unstable when the number of taps is increased to accommodate the increased channel memory introduced by CD. In this work we propose a modified blind equalizer with increased stability to overcome this problem, it is then able to adaptively estimate the filter coefficients for CD compensation. The equalizer is used for pre-convergence before switching to the conventional equalizer. The performance is evaluated using simulations and is experimentally verified with 10.7Gbit/s MIMO equalizers, where a CD of 88,000ps/nm is compensated adaptively.

Proposed Chromatic Dispersion Equalization Algorithm

Conventional 2×2 multiple input multiple output (MIMO) equalizers, Fig. 1(a) are used to track time dependent polarization rotations. They can also compensate for CD if the length of the equalizer is larger than the channel memory, however this can lead to unstable behaviour. By using an equalizer dedicated to estimating the CD for pre-convergence, additional constraints can be applied to improve stability, Fig. 1(b). CD is a frequency dependent quadratic phase shift, which affects both polarizations equally. Therefore, a CD equalizer (Stage 1) should apply the same filter on both polarizations, \(h_{x,x} = h_{y,y}\), and there should be no power exchange between the polarizations, \(h_{x,y} = h_{y,x} = 0\). The error terms for the equalizer can be calculated using a constant modulus algorithm (CMA), while the update can be averaged over the two polarizations, to get a better estimate.

\[
\varepsilon_x \leftarrow 1 - |X_{out}|^2 \quad \varepsilon_y \leftarrow 1 - |Y_{out}|^2
\]

Stage 1:

\[
h_{x-x} = h_{y-y} = 0
\]

\[
h_{x-y} = h_{y-x} = h_{x-x} + \mu \frac{\varepsilon_x X_{out}X_{in}^{*} + \varepsilon_y Y_{out}Y_{in}^{*}}{2}
\]

Once pre-convergence has been achieved the equalizer is switched to (Stage 2); the conventional update scheme which fine tunes the CD compensation while also compensating for PMD.

Stage 2:

\[
h_{x-x} = h_{y-y} = \mu \varepsilon_x X_{out}X_{in}^{*}
\]

\[
h_{x-y} = h_{y-x} = \mu \varepsilon_y Y_{out}Y_{in}^{*}
\]

For any given network, the range of node separations is known in advance and determines the range over which the dispersion will vary in the network. To improve equalizer convergence, a fixed CD filter can

![Fig. 1. a) 2x2 MIMO equalizer. b) Proposed two stage equalizer for adaptive CD compensation.](image-url)
be used to compensate 50% of the maximum CD in the network, followed by an equalizer to adaptively compensate up to a further ±50%. Alternatively, the equalizer can be initialized with tap weights equal to 50% of the maximum CD; the approach taken herein. Although this technique requires more adaptive taps than conventional systems, with a frequency domain implementation [6] the complexity can be reduced significantly. Additionally, an equalizer with a larger number of taps can more effectively invert the channel response. Note that, if Nyquist filtering is used, the adaptive equalizer will also converge to the matched filter [7], eliminating the requirement for additional digital filter.

**Simulation and Experimental Configuration**

In simulations 42.8Gbit/s (10.7GBd) PDM-QPSK was generated before CD was added to the signal and detected using a coherent receiver. A linewidth of 300kHz and a frequency offset of 200MHz was used to simulate realistic conditions. The signal was quantized and a polarization rotation of π/9 was included to avoid artificial gain from ideal alignment. The signal was then resampled to 2Sa/symbol. The equalizer length was set to the required number of taps to compensate the CD [1]. The equalizer was initialized with the filter coefficients for a CD filter compensating for 50% of the dispersion. The two stage equalizer was then used to converge to the ideal CD filter and undo the polarization rotation. Afterwards a 4th power frequency offset removal and carrier phase estimator [8] was applied. Finally, hard decisions, symbol decoding and bit error rate (BER) counting were performed over 217 symbols.

**Results & Discussion**

Simulations were used to investigate the performance of the two stage equalizer. 10.7Gb/s PDM-QPSK was generated and 50,000ps/nm CD was applied before noise loading the signal. Afterwards different methods for compensating the dispersion were compared. The first method was to use a non-adaptive CD filter (187 taps) followed by an adaptive CMA to compensate for PMD (15 taps). Two different versions of the proposed two stage equalizer were tested; a serial implementation
where the filter coefficients were updated each symbol and a parallel version which was updated once every 256 symbols. Both versions used 187 taps which were initialized with coefficients sufficient for compensating 25,000ps/nm CD. Fig. 3 shows that there is no performance difference between the methods investigated, demonstrating that the proposed equalizer is able to compensate the CD successfully and that a parallel [10] or frequency domain implementation could be used to reduce the complexity.

Simulations were verified experimentally where the receiver polarization is arbitrary and continuously varying. The CD was estimated from the equalizer taps after convergence [11]. Fig. 4 shows the estimated CD versus the applied CD for a signal transmitted up to 5,240km. For each distance the equalizer was initialized with 50% of the expected CD. It is clear that there is excellent agreement between the amount of CD that is applied and the compensated CD when using the two stage equalizer up to 88,000ps/nm. Using the conventional 2×2 MIMO equalizer CD up to 30,000ps/nm could be compensated, and beyond that point the equalizer was unstable and unable to converge, resulting in loss of signal.

Conclusions
We have demonstrated experimentally a two stage blind equalizer for adaptive compensation of CD up to 88,000ps/nm using 10.7GBd PDM-QPSK. Simulations show that there is no penalty for using the equalizer with serial or parallel implementation compared to using a conventional algorithm. Using this algorithm, routing constraints can be alleviated to allow for greater flexibility within the network. This is the first demonstration of an adaptive CD compensation algorithm without using look-up tables, training symbols or brute force methods to estimate the CD.

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References