JThA11.pdf

Frequency Domain Chromatic Dispersion Estimation

F.N. Hauske[1], C. Xie[1], Z. Zhang[2], C. Li[2], L. Li[3], Q. Xiong[3]

1: Huawei Technologies Duesseldorf GmbH, European Research Center, Riesstrasse 25, D-80992 Munich, Germany, e-mail: fabian.hauske@huawei.com, 2: Huawei Technologies Canada., Ltd., Ottawa R&D Centre, Ottawa, Canada, 3: Huawei Technologies Co., Ltd., Optical Network Technology Research, Shenzhen, China

Abstract: The low complexity, robust, and precise algorithm solely employs a simplified auto-correlation function of the signal spectrum for blind chromatic dispersion estimation to adapt frequency domain compensation functions in digital coherent receivers.

OCIS codes: (060.1660) Coherent communications; (060.2330) Fiber optics communications

1. Introduction

Coherent detection receivers with digital equalization allow full compensation of all linear channel impairments of a linear or weakly nonlinear optical fiber channel [1]. This allows for uncompensated transmission with digital equalization of chromatic dispersion (CD) instead of optical compensation by means of dispersion compensating fibers (DCF). It has been proposed by [2] to employ a low-complexity frequency domain (FD) filter to compensate for static CD and to use a time-domain (TD) 2x2 muli-input multi-output (MIMO) finite impulse response (FIR) filter stage with fast update for tracking time-varying effects like polarization-mode dispersion (PMD) and rotation of the state of polarization (SOP). Although the value of CD does not change largely during transmission, in switched networks, a fast and reliable initialization of the CD filter is required.

Digital CD compensation has been demonstrated, where either the filtering function has been known and pre-set [3], a training sequence has been applied for filter update [4] or the adaptation algorithm has been not disclosed [5]. Blind filter adaptation by use of a modified constant modulus algorithm (CMA) has been demonstrated in [6], [7].

We present a blind (non-data aided) FD CD estimation algorithm for adaptive equalizers solely based on the digital spectra of the signal. In contrast to [6], [7], this allows for continuous monitoring of CD and for a low speed estimation routine initializing the equalizer in a side process independent from the modulation format. Robust estimation over a wide range of CD within a fixed adaptation length is demonstrated for 112 Gbit/s polarization-division multiplex (PDM) quaternary phase-shift keying (QPSK) with combined channel impairments.

2. Frequency Domain Chromatic Dispersion Estimation

After the polarization-diverse 90°-hybrid, and analog/digital conversion (ADC), overlapping blocks of the signal sequence are transferred into the FD by a fast Fourier transform (FFT). Copies of those data blocks $S_{x,in,k}[m]$ and $S_{y,in,k}[m]$ from both polarizations x and y are used in a low speed side processor to estimate and monitor the parameter of CD (see Fig. 1). The data blocks indexed k are not necessarily adjacent. The index $m = -M/2+1, ..., M/2$ denotes discrete frequencies within a block length M (even number) with the direct current (DC) frequency centered at $m = 0$. The frequency resolution $\Delta f = R_s/M$ of each FFT block is defined by the sampling rate R_s in the ADC.

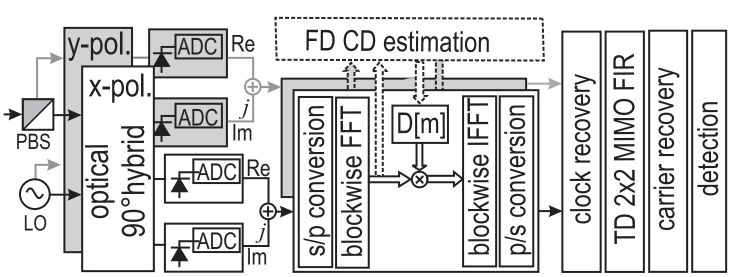

Fig. 1. Optical front-end with polarization diverse 90°-hybrid, ADC and digital equalization including FD CD compensation.

impairment	distribution	parameter
PMD	Maxwellian	mean 25 ps
PDL	linear	[0:10] dB
CD	linear	[-30:30] ns/nm
LOFO	linear	[-1.5:1.5] GHz
θ	linear	[0:2π]
ϕ	linear	[0:2π]
OSNR	constant	14 dB

Tab. 1. Table of random channel impairments including the statistical distribution.

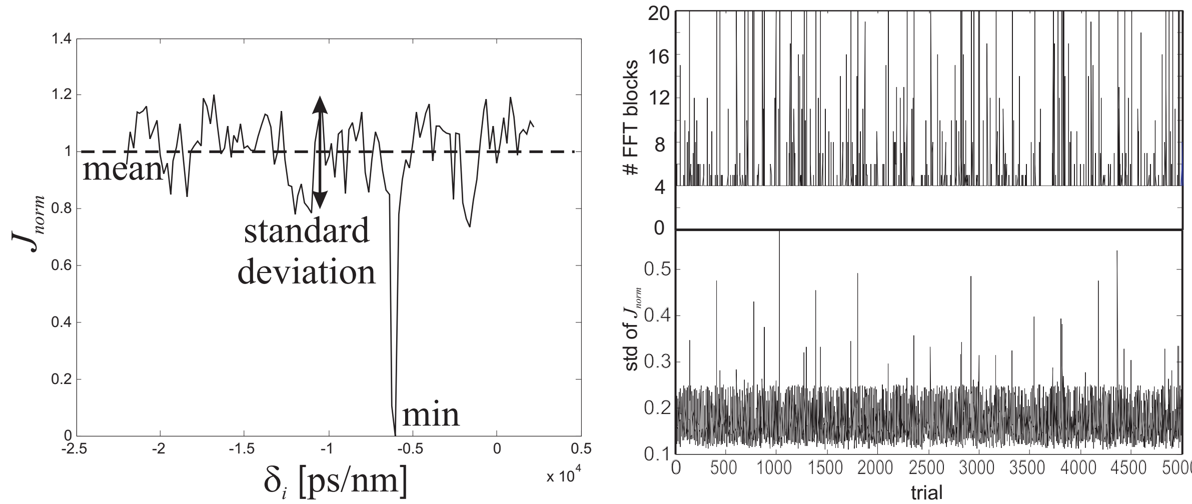

Fig. 2. Example of normalized error criterion J_{norm} (left) and standard deviation of J_{norm} for each channel realization with the required number of FFT blocks for averaging (right).

To mitigate polarization effects, we apply the signal $S_{in,k}[m] = S_{x,in,k}[m] + S_{y,in,k}[m]$ to tentative filtering functions $D_i[m] = exp(-jm^2\Delta f^2\delta_i\pi\lambda^2/c)$ with the speed of light c, the carrier wavelength λ and the CD parameter δ_i leading to filtered blocks $S_{out,k,i}[m] = S_{in,k}[m] \cdot D_i[m]$ [6]. The values of CD vary by $\delta_i = \delta_{min} + (i-1)\Delta\delta$ up to δ_{max}. A modified, discrete, circular auto-correlation

$$U_{k,i}[n] = \frac{1}{M} \sum_{m=-M/2+1}^{M/2} \textit{sign}\left(\Re\{\textit{cshift}(S_{out,k,i}[m], n)\}\right) \cdot S^*_{out,k,i}[m] + j\ \textit{sign}\left(\Im\{\textit{cshift}(S_{out,k,i}[m], n)\}\right) \cdot S^*_{out,k,i}[m] \quad (1)$$

is applied for each FFT block k and each CD filtering function D_i with a circular shift *cshift*$(S_{out,k,i}[m], n)$ of the signal $S_{out,k,i}[m]$ by $n \in m$ elements. In a hardware implementation, the sign *sign* of the according real part $\Re$ and imaginary part $\Im$ respectively just adds on the sign of the complex conjugate $S^*_{out,k,i}[m]$, reducing the processing complexity significantly to a few additions. The shift n does not necessarily cover all possible shifting values of m.

We define an error criterion

$$J[i] = \sum_k \sum_n |U_{k,i}[n]|^2 \quad (2)$$

averaging over the absolute values of the correlation functions of several FFT blocks. In principle, this FD criterion can be derived from the CMA criterion applied in the TD [6]. The argument of the minimum error criterion delivers the estimated CD parameter

$$\delta_{est} = \delta_{min} + \Delta\delta(\arg(\min_i J[i]) - 1)\ , \quad (3)$$

which is delivered to update the CD compensation function $D[m]$.

To judge on the reliability of the estimation and to evaluate the necessary number of FFT blocks for averaging, we introduce a normalized error criterion J_{norm}, which is scaled to a unity mean value and a minimum at zero as depicted in Fig. 2, left. The standard deviation of J_{norm} indicates the distance of the minimum value from the divergence of the error criterion. Low values of the standard deviation indicate a reliable estimation, large values close to one indicate weak estimations.

3. Estimation Performance

We tested the estimation performance on random data of 112 Gbit/s PDM-QPSK in a single channel, single span simulation with random channel conditions and concentrated noise loading at the receiver. The random variations and the according distributions of CD, PMD, polarization-dependent loss (PDL), local oscillator frequency offset (LOFO), optical signal-to-noise ratio (OSNR), polarization phase ϕ and polarization angle θ are listed in Tab. 1. In

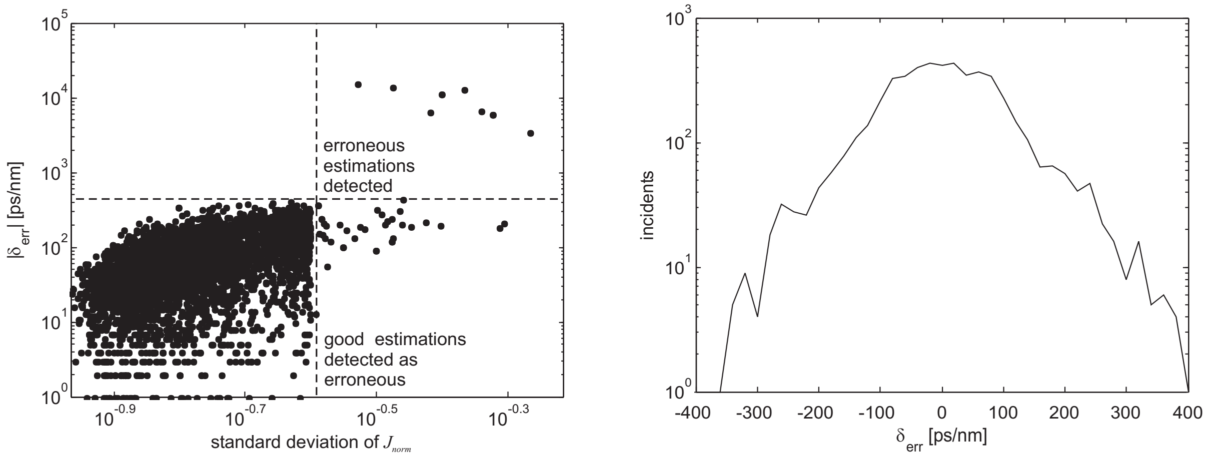

Fig. 3. Estimation error $|\delta_{err}|$ versus standard deviation of normalized error criterion J_{norm} (left) and histogram of estimation error $|\delta_{err}|$ (right).

total, 5000 independent trials have been realized. After the optical front-end (compare [1]), the signal is digitized by ADC with $R_s = 2$ samples per symbol. Overlapping FFT-blocks of $M = 1024$ samples are transferred into the FD. The tentative filtering functions have been scanned from $\delta_{min} = -32000$ ps/nm in steps of $\Delta\delta = 200$ ps/nm up to $\delta_{max} = -32000$ ps/nm. The correlation function has been applied in a range from $n = -0.7M/2$, ...,$+0.7M/2$.

Initially averaging over a minimum of 4 FFT-blocks, the number of blocks is consecutively increased until the normalized error criterion reaches a value of $J_{norm} \leq 0.25$ with a maximum number of 20 FFT blocks. The required number of FFT blocks for each channel realization is given in Fig. 2, right. About 7.5% of all trials require more than 4 blocks, less than 0.9% would require more than 20 blocks. All those trials that do not satisfy the condition $J_{norm} \leq 0.25$ are marked as potential erroneous estimations.

We evaluate the estimation performance by the estimation error $\delta_{err} = \mathrm{CD} - \delta_{estim}$. From Fig. 3, left, we can see that the indication of potential erroneous estimations correctly detected all corrupt estimations (0.2%) but also marked 0.6% of correct estimation as erroneous. In Fig. 3, right, the histogram of the estimation error proves a zero mean value with a standard deviation of the estimation error of 103 ps/nm and a maximum deviation of 400 ps/nm. This refers to a maximum deviation of two CD estimation steps $\Delta\delta$. It should be noted that about 57 ps/nm of the standard deviation result from the finite resolution of $\Delta\delta$. A step width below $\Delta\delta = 200ps/nm$ would further reduce the estimation error. As the estimation error has a zero mean value, a long-term average could reduce the estimation error close to zero. Increasing the OSNR to higher values clearly improves the estimation precision, while even lower OSNR values require more averaging. Similarly, shorter FFT-blocks require more averaging and longer blocks vice versa.

4. Conclusion

We demonstrated a low complexity, pure FD CD estimation algorithm with a high robustness against any combination of channel impairments, any polarization effect in particular. The estimation method is independent from the modulation format and from the line rate. Given a maximum estimation error of 400 ps/nm, a subsequent TD FIR filter with only 5 taps would be sufficient to compensate the remaining CD in 112 Gbit/s PDM-QPSK systems.

References

[1] C.R.S. Fludger, T. Duthel, D. van den Borne, *et al.*,"Coherent Equalization and POLMUX-RZ-DQPSK for Robust 100-GE Transmission" J. of Lightwave Technol., vol. 26, no. 1, pp. 64-72, Jan. 2008.
[2] B. Spinnler, F.N. Hauske, M. Kuschnerov, "Adaptive Equalizer Complexity in Coherent Optical Receivers", ECOC2008, We.2.E.4.
[3] S. J. Savory, "Digital filters for coherent optical receivers" Optics Express, vol. 16, no. 2, pp. 804-817, Jan. 2008.
[4] K. Ishihara, T. Kobayashi, R. Kudo, *et al.*, "Coherent Optical Transmission with Frequency-domain Equalizers", ECOC2008, We.2.E.3.
[5] H. Sun, K.-T. Wu, and K. Roberts, "Real-time measurements of a 40 Gb/s coherent system" Optics Express, vol. 16, no. 2, pp. 873-879, Jan. 2008.
[6] M. Kuschnerov, F.N. Hauske, K. Piyawanno, *et al.*., "Adaptive Chromatic Dispersion Equalization for Non-Dispersion Managed Coherent Systems", OFC2009, OMT1.
[7] M. Kuschnerov, F.N. Hauske, K. Piyawanno, *et al.*,"DSP for Coherent Single-Carrier Receivers" J. of Lightwave Technol., vol. 27, no. 16, pp. 3614-3612, Aug. 2009.