The Real Time Implementation of a Simplified 2-Section Equalizer with Supernal SOP Tracking Capability

Tao Zeng[1,*], Zhixue He[1], Liheng Meng[1], Jie Li[1], Xiang Li[1], and Shaohua Yu[1]
[1] *State Key Laboratory of Optical Communication Technologies and Networks, China information and communication technology Group Corporation, Wuhan Hubei, China*
**e-mail address: zengtao@wri.com.cn*

Abstract: We propose a 2-section equalizer architecture, two adaptive multi-tap 1×1 equalizer updated by proposed joint-CMA, followed by a feedforward 1-tap 2×2 MIMO. We implement it in 10G coherent transceiver and achieve 20Mrad/s SOP tracking speed.

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

1. Introduction

For DSP in most commercial coherent communication system, a butterfly finite impulse response (FIR) will perform polarization demultiplexing and compensate inter symbol interference (ISI), including residue dispersion, the polarization mode dispersion (PMD) and the filter effect [1]. This architecture achieves great success in the metro and long haul market.

When the coherent optic communication system expand into the cost sensitive region, such as the optic access networks and short distance link of the data centers, a more simple and efficient architecture is required to reduce the resource and power consumption [2]. Otherwise, when the coherent polarization-multiplex system is installed in the optical ground wire (OPGW) cables of the electric power network, which is a very cost-effective alternative to buried cable, it meets ultrafast state of polarization (SOP) rotation problem [3-4]. It is found the lightning induced B-fields can cause ultrafast SOP change, which is reported up to 5.1Mrad/s in the field and 8Mrad/s in the lab [4-5]. Ultrafast SOP tracking is required in this scene, but the inherent complexity of adaptive butterfly FIR constitutes a huge obstacle to improve the SOP tracking ability.

To reduce the complexity of the adaptive equalizer (AEQ), Matsuda et al proposed a simplified AEQ with two sections (hereinafter called the KM-AEQ) [2], The first section is a 1-tap butterfly filter used for polarization de-multiplexing and the second section consists of two N-tap FIR filters used for the adaptive equalization. Two complex N-tap FIR filters can be reduced to 4 real N-tap FIR filters for intra-datacenter traffic with typical link distance < 2km accounts [6].

In our former work, we found if we can reduce the total number of coefficient to be calculated, it is much easier to increase SOP tracking speed and the converging speed, the latter function is essential for the burst mode coherent PON [7]. We also divide the equalizer into two sections, including two FIR and one 1-tap butterfly filter. But KM-AEQ has the inherent mismatch with our goal. To purse the fastest SOP tracking speed, we devise to use the training symbol to calculate the inverse Jones matrix directly without the iteration process. If using KM-AEQ, the training symbol will be corrupted by neighbor symbol, more training symbol need to be averaged to increase the accuracy, which will decrease the tracking speed inevitably. So in our former work, we place 2 static FIR in front of the butterfly filter, whose coefficient are calculated offline and stored in the system. Similar to KM-AEQ, our architecture is based on the fact that modern fibers have very small PMD parameter (< 0.1 ps/km$^{1/2}$) [8].

But using the static FIR will affect the deploy agility and degrade the system performance because of the slowly varying fiber channel parameter and frequency offset. In this paper, we use the adaptive FIR instead of the static FIR in the first section and propose a joint constant modulus algorithm (CMA) to update the FIR coefficient. This algorithm is decoupled from the subsequent multi-in-multi-output (MIMO) filter, it also ensures the 2 FIR to output 2 orthogonal intermediate signal. We implement this architecture in the FPGA based real time 10G coherent system and investigate its requested optic signal noise rate (OSNR) and SOP tracking capability.

2. Proposed Architecture and Algorithm

The simplified 2-section equalizer architecture is shown in the Fig.1, assuming two FIR converge to an ideal state, all ISI effect has been compensated, and two outputted intermediate polarizations signal are orthogonal, the two FIR's output denote by $E_{IM}^{X/Y}$ are expressed as

$$\begin{bmatrix} E_{IM}^{X} \\ E_{IM}^{Y} \end{bmatrix} = \exp(j2\pi n\Delta fT + j\Phi)\begin{bmatrix} A & B \\ -B^{*} & A^{*} \end{bmatrix}\begin{bmatrix} TX \\ TY \end{bmatrix}, \tag{1}$$

where TX/TY denote transmitted symbol, Δf is the frequency offset, Φ is the common phase offset of the two polarization, A/B constitute a unitary Jones matrix. Because of the polarization rotation, each E_{IM}^{X}/E_{IM}^{Y} signal doesn't have constant modulus and is not suitable to be utilized by the conventional CMA. If the error expression uses the MIMO output of the second section, the tap updating function will include the coefficient of the MIMO, which brings huge implementation complexity. More importantly, the right MIMO coefficient as the working precondition may not be assured when meeting ultra fast SOP change or at the initial state. To find an error expression decoupled from the second section, after investigating the Eq.(1), we find

$$\left|E_{IM}^{X}\right|^2+\left|E_{IM}^{Y}\right|^2=\left(AA^*+BB^*\right)\left(\left|TX\right|^2+\left|TY\right|^2\right)=\left(\left|TX\right|^2+\left|TY\right|^2\right). \tag{2}$$

So we propose the joint CMA, with the error expression expressed as

$$\text{Error}=2-\left|E_{IM}^{X}\right|^2-\left|E_{IM}^{Y}\right|^2, \tag{3}$$

The tap will be updated with gradient algorithm corresponding to Eq.(3). After converged, the two FIR filter not only compensate the ISI, also make two outputs to be orthogonal, which can improve the overall performance of the proposed architecture because the subsequent de-multiplexing assume the orthogonality of X/Y signal.

After the training symbol is located, we calculate the conjugate product of corresponding X/Y intermediate signal, the result is

$$E_{IM}^{X}\times\left(E_{IM}^{Y}\right)^*=\pm\left(A^2\text{-}B^2\right) \quad \text{when TY}=\pm\text{TX}, \tag{4}$$

$$E_{IM}^{X}\times\left(E_{IM}^{Y}\right)^*=\mp j\left(A^2+B^2\right) \text{ when TY}=\pm j\text{TX}. \tag{5}$$

So we can obtain the A^2 and B^2 value with two training symbol. Although A/B have two solutions with $\pm$ sign, the right solution can be chosen by attempting both solutions and compare the result of the training symbol.

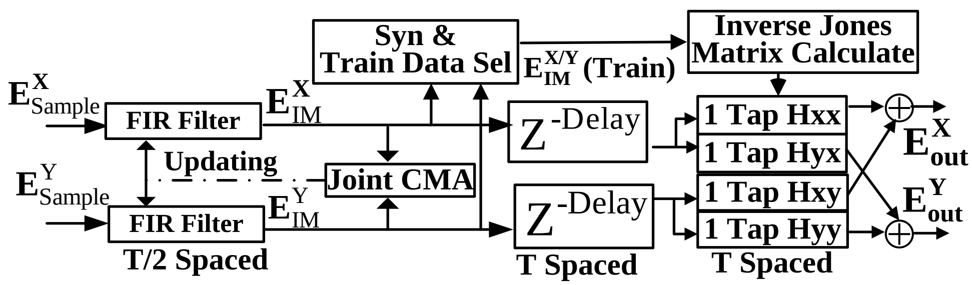

Fig.1 The simplified 2-section equalizer architecture

3. The Real Time Experimental Investigation

To investigate the performance of the 2 section equalizer proposed in this paper, as shown in Fig.2, we use a 10G coherent transceiver product as an experimental platform and test various DSP. The 10G data stream come from the commercial 10G SDH testing instrument, after forward error correction (FEC) encoding, the data rate increase to 11.46G. The FEC is implemented by the commercial CS6041 transport processor, which supports a Ultra-Strong FEC scheme as specified in Section I.7 of ITU G.975.1, the FEC limit is 3.8×10^{-3}. A training group composed of two training symbols is inserted every 16 symbols, the inserting ratio is 1/8. The actual line data rate is 13G bits/s, and the symbol rate is 3.2G baud, the train symbol rate is 400MHz. At the receiving side, we implement both the conventional butterfly FIR and proposed 2-section equalizer for comparison. When implementing the latter, a static FIR and adaptive FIR updated with joint CMA are both implemented. The static FIR coefficients are calculated offline with the CMA using the MIMO output in section 2 as the constant modulus. A^2/B^2 values obtained from N training symbol group are averaged to squeeze the noise, but increasing N will degrade the tracking speed. To find the trade point, we test varied average length. Because when N=8, the requested OSNR for error free performance in hours test vibrate greatly, we mainly demonstrate the result with N=16/32 in subsequent paragraph.

The major light induced effect is ultra SOP perturbations [9], so we use the Novoptel EPS1000 to resemble the SOP change by rotating 6 electro-optic quarter-wave plates (QWP) and 1 half-wave plate (HWP), with 40 ns updating intervals. For the QWP, the nominal scrambling speed is between 0 and 999 krad/s. For the HWP, it is between 0 and 20 Mrad/s. We rotate the HWP at the incremented nominal speed from 0 to 20Mrad/s and set QWP0~5 to nominal scrambling speeds of several dozens Krad/s. The rotation of QWP0~5 is to ensure all SOP on the Poincaré sphere to be undergone. The total fibre length is 200km, EPS1000 is inserted in the middle. The OSNR is adjusted by a variable optical attenuator (VOA) in front of EDFA and monitored by optical spectrum analyzer

(OSA). When pre-FEC BER<3.8×10^{-3}, system is error free after FEC, the requested OSNR corresponding to the nominal scrambling speed is recorded.

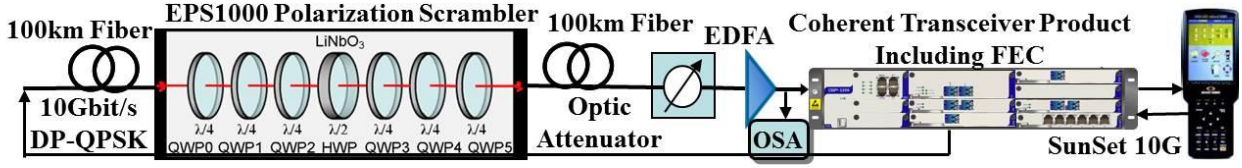

Fig.2 The experiment set up

4. Result and Discussion

As shown in Fig.3, when SOP keeps static, compare to the requested OSNR (=4.0dB) of the conventional adaptive filter, the 2-Section equalizer with the static 7-tap FIR bring 1.5/1.7 dB OSNR penalty when N=32/16. When we adopt the joint CMA to update the FIR, the OSNR penalty reduces to 0/0.2 dB when N=32/16, the improvement is due to that the joint CMA can compensate the imperfect orthogonality of X/Y signal, varied channel character. When SOP rotates rapidly, the 2-section equalizer far exceeds the conventional adaptive filter. When the nominal scramble speed exceeds 1.25Mrad/s, the OSNR penalty of the conventional adaptive filter is beyond 5dB. The 2-Section Equalizer N=16 can track up to 20 Mrad/s, with less than 0.6dB OSNR penalty. It is the highest SOP tracking speed of coherent system ever reported. These results are also a useful reference for designing burst coherent PON with proposed 2-section architecture, since N=16 bring 0.2 dB OSNR penalty, we can infer that length N=16 is enough for the training overhead of the burst PON frame.

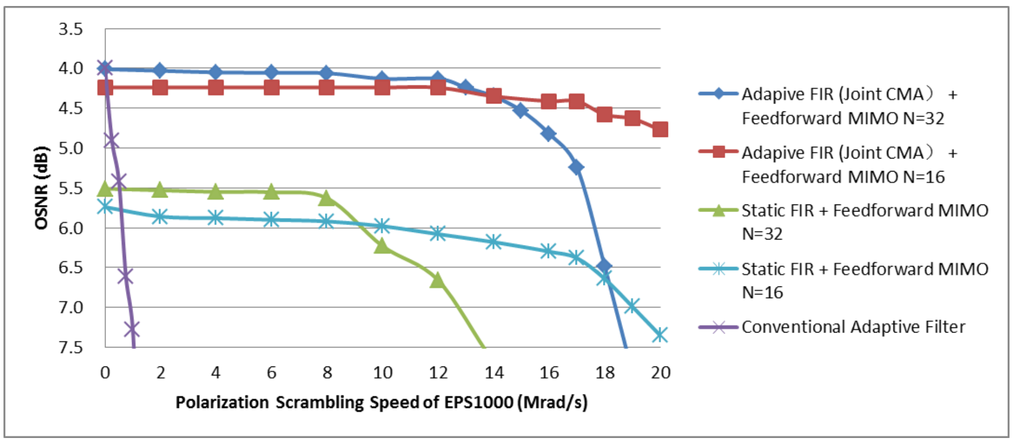

Fig.3 The OSNR penalty vs SOP rotation angular frequency with various algorithms

5. Conclusion

This paper proposes a 2-section equalizer, with FIR updated by the proposed joint CMA, followed by a feedforward MIMO. It achieves the same requested OSNR as the conventional adaptive multi-tap filter with adequate average window. It can track 20Mrad/s SOP scrambling with less than 1dB OSNR penalty, it is the highest SOP tracking speed ever reported in the real time SOP tracking experiment. This architecture can also be used in the burst PON.

References

[1] Savory S J. “Digital filters for coherent optical receivers”. Optics Express, 2008, 16(2): 804-817.
[2] K. Matsuda, et al., ‘Hardware-efficient Signal Processing Technologies for Coherent PON Systems’, ECOC 2017, paper Th.1.B.
[3] Peter M. Krummrich, et al.: 'Demanding response time requirements on coherent receivers due to fast polarization rotations caused by lightning events. ' Optics Express, 2016, 24(11), pp12442-12457.
[4] D. Charlton, et al. “Field measurements of SOP transients in OPGW, with time and location correlation to lightning strikes” Optics Express 25, 9, 9689-9696 (2017)
[5] Pittalà, Fabio, et al. "Laboratory Measurements of SOP Transients due to Lightning Strikes on OPGW Cables." Optical Fiber Communication Conference 2018: M4B.5.
[6] Jingchi Cheng, “A Low-Complexity Adaptive Equalizer for Digital Coherent Short-Reach Optical Transmission Systems”, Optical Fiber Communication Conference 2019: M3H.2.
[7] Tao Zeng, et al. “THE TRAINING BASED FEED-FORWARD 2×2 MIMO ALGORITHM AND ITS REAL TIME IMPLEMENTATION”, ECOC 2019,
[8] Mohamed Morsy-Osman. et al.”Ultrafast and low overhead training symbol based channel estimation in coherent M-QAM single-carrier transmission systems”,, Optic Express, (2012), pp. B171-B180
[9] Kurono M, et al. “Transient state of polarization in optical ground wire caused by lightning and impulse current”, International Symposium on Polarization Analysis & Applications to Device Technology. International Society for Optics and Photonics, 1996.