OFDM Data-Aided Channel Equalizer for Already-Deployed Optical Direct-Detection Transmission Systems

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Abstract— **We study the performance of an adaptive weighted channel equalizer for direct-detection dispersion-compensated OFDM transmission system and show that it improves the BER and reduces the overhead and sensitivity to the optical channel variations.**

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) has gained a great deal of attention in optical communications due to the ease of equalization and therefore robustness to the optical fiber transmission impairments such as chromatic dispersion (CD) and polarization mode dispersion (PMD). An important feature of OFDM transmission is its capability to send known symbols as training sequence (TS) to provide channel estimation. In optical OFDM, the zero forcing estimation (ZFE) method has been used to compute the estimated channel parameters [1]. The accuracy of this estimation is often limited by the presence of noise and pattern dependent nonlinearities. To increase the accuracy of channel estimation, usually a time domain averaging method is used in which multiple symbols in each TS are averaged to estimate the channel matrices [1,2]. Moreover, the system updates the channel information by sending new TS's at a speed that is slower than the real-time data speed, but faster than the speed of significant channel physical changes, which is usually in the order of kilohertz [2]. This basically presumes a stationary (non-varying) channel between each two consecutive TS's. Recently, we proposed an adaptive weighted channel equalizer (AWCE) for OFDM transmission systems [3]. AWCE updates the equalization parameters on a symbol-based fashion enabling the receiver to track slight drifts in the optical channel. This allows the system to increase the periodicity of TS's and consequently to reduce the overhead.

OFDM-based signals are known to be sensitive to nonlinearities due to their inherent high peak to average power ratio (PAPR). Accumulated dispersion in uncompensated links makes the OFDM system more resilient to nonlinearities. However, the majority of already-deployed long-haul transmission links are dispersion-compensated thus the effect of nonlinearities is more pronounced.

In this paper, we study the perofrmance of direct-detection OFDM (DD-OFDM) using AWCE in a dipersion-compensated long-haul transmission link via numerical simulations. A bit-error-rate (BER) improvement comparing to ZFE is observed. It is notable that since OFDM symbol rate can be much lower than the bit rate, the implementation of AWCE does not necessarily require very high speed electronics.

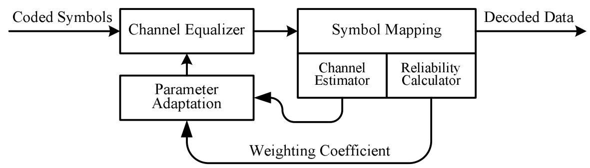

Figure 1: AWCE block diagram.

II. AWCE CONCEPT

Fig. 1 depicts the diagram of the proposed AWCE which consists of four main blocks. We define the optical channel frequency response as $H(\omega)$. The first block is the feed forward channel equalizer, $\widetilde{H}^{-1}(\omega)$, which is trying to mimic the inverse of actual channel response, $H^{-1}(\omega)$. $\widetilde{H}^{-1}(\omega)$ is initially computed by the TS and is continuously updated by each new data symbol. The next stage is responsible for symbol mapping and decision process based on least mean square (LMS) technique. Due to noise, nonlinearities and small PMD drift in the optical channel, the equalized symbols do not exactly lie on constellation points defining error vectors. By using the error vectors, the channel estimator block calculates the ideal equalization parameters ($\widetilde{H}_u^{-1}(\omega)$ in Eq. 1) and updates the feed forward equalization parameters for the next symbol by a feedback. Equalization parameters can be updated in different fashions; however, considering the presence of noise and pattern dependent channel response due to fiber nonlinearities, the new response should be averaged over all previous parameters. The channel response for kth received symbol can be updated as:

$$\widetilde{H}_k^{-1}(\omega) = \frac{\gamma_1 \times (k-1) \times \widetilde{H}_{k-1}^{-1}(\omega) + \gamma_2 \times \widetilde{H}_u^{-1}(\omega)}{\gamma_1 \times (k-1) + \gamma_2} \qquad (1)$$

where γ_1 and γ_2 are weighting parameters. We call the ratio between γ_1 and γ_2 as the weighting ratio which determines how fast the equalizer can respond to channel variations: the smaller the weighting ratio, the faster the AWCE. However, there is a trade-off since a small weighting ratio reduces the noise suppression capability of AWCE. To assign this ratio, the receiver can apply a fixed value for all symbols or adaptively compute a value based on the accuracy of previous detection as described in [4] for decision-feedback equalizers.

III. AWCE PERFORMANCE SIMULATIONS FOR LONG-HAUL OPTICAL OFDM SYSTEM

The simulated OFDM transmission link is depicted in Fig. 2. The principle of operation of optical OFDM is well-known and the specific usage of each block diagram can be found elsewhere [1,2]. Simulations are performed in MATLAB. The original data at 10 Gb/s were first divided and mapped onto 256 frequency subcarriers with QPSK modulation, and subsequently transferred to the time domain by an IFFT of size 512 while zeros occupy the remainder. A cyclic prefix of length 60 is used to accommodate dispersion. Following this, an up-conversion stage shifts the OFDM signal to 5-10 GHz band. As the optical transmitter a continuous-wave (CW) laser source and a chirp-less Mach-Zehnder modulator (MZM) were employed. Then the transmitted signal is optically filtered to suppress the sideband. Transmission link has 25 spans: each consists of a 60 km section of single mode fiber (SMF) with dispersion parameter of 17 ps/nm.km, nonlinear coefficient of 1.5 $W^{-1}.km^{-1}$ and loss parameter of 0.2 dB/km. Spans are separated by erbium doped fiber amplifiers (EDFA) with a noise figure of 6 dB and 12 km of dispersion-compensating fiber (DCF) with nonlinear coefficient of 5.3 $W^{-1}.km^{-1}$. Injected power to each fiber span is set to -4 dBm to limit the fiber nonlinearities. At the optical receiver, an optical filter is applied to reject out-of-band amplified spontaneous emission (ASE) noise.

Fig. 3 compares the performance of ZFE and AWCE with a weighting ratio equal to the variance of the normalized error of previous received constellation points. Both estimation algorithms are based on four-symbol TS's. We simulated a continuous random drift of 10% over the phase and amplitude response of optical channel as an extreme case which can mainly originate from PMD. For ZFE, we observe broadening and rotation of received signal constellation. This can be translated into a Q-factor penalty of 2 dB. However, AWCE due to its adaptive feedback can track these drifts as it only experiences a 0.8 dB degradation of Q-factor. In other words, the transmission system can rely on AWCE estimation for a longer time period without sending the new TS which increases the periodicity of TS and subsequently reduces the overall overhead. Furthermore, as we see in Eq. 1, AWCE gets updated by receiving more symbols via averaging. This suppresses the accumulated noise and pattern dependent nonlinearities that might affect the estimation accuracy. One can improve the performance of ZFE by averaging over more symbols in each TS however, it significantly reduces the throughput.

In Fig. 4, we compare the BER performance of ZFE and AWCE in a dispersion-compensated link. The performance of AWCE is simulated for both fixed weighting ratio of unity and an adaptive weighting ratio equal to the variance of the normalized error of previous received constellation points. As we see for the BER of 10^{-3} (FEC limit), AWCE shows a 1.2 dB OSNR improvement comparing to the ZFE. Moreover, AWCE with adaptive weighting ratio shows slightly better performance than AWCE with fixed ratio for higher OSNR's. This is coming from the fact that channel drifts become the dominant impairment for higher OSNR's and AWCE with adaptive weighting ratio, by reducing this ratio, makes the equalizer faster to track optical channel variations.

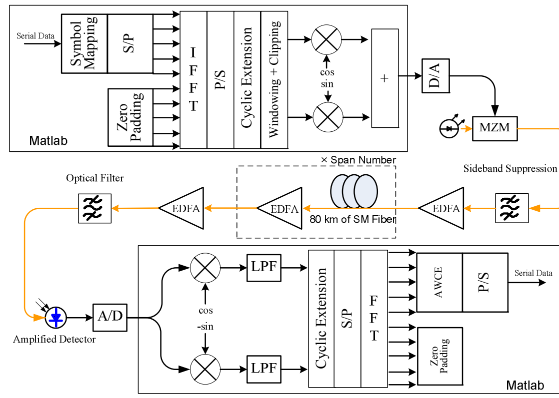

Figure 2: Simulation setup.

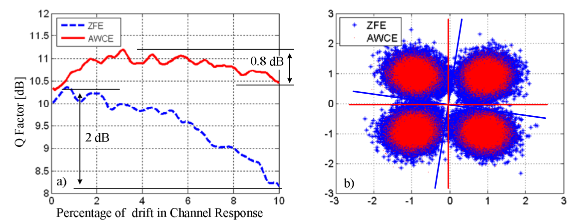

Figure 3: Q-factor versus drift in channel response (a) and signal constellation (b) after transmission.

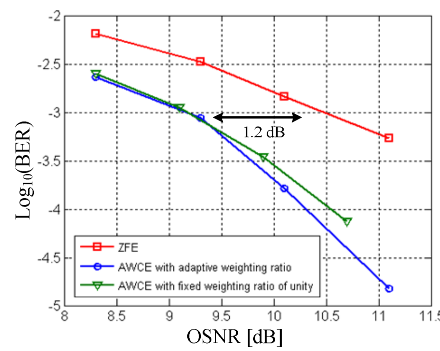

Figure 4: BER versus OSNR in dispersion-compensated channels.

IV. CONCLUSION

In this paper, we studied the performance of a data-aided channel equalizer in dispersion-compensated long-haul DD-OFDM transmission systems. AWCE is capable of overhead reduction by reducing the number of training symbols and increasing the periodicity of TS's. Moreover, AWCE shows better BER performance than ZFE in long-haul transmission.

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