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An improved least square channel estimation algorithm for coherent optical OFDM system

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ABSTRACT

This paper presents an improved processing added to conventional least square (LS) channel estimation to modify its performance for coherent optical orthogonal frequency division multiplexing (CO-OFDM) system. By testing selected limitation factors of the existing algorithms, the influence of our improved algorithm to the performance of CO-OFDM system were studied and compared with other published algorithms. The simulation results of the study demonstrated that the proposed approaches achieved better channel estimation performance and are considered as a more appropriate alternative for CO-OFDM system with the tradeoff between complexity and performance.

1. Introduction

As a promising technology for future high speed optical communications, coherent optical orthogonal frequency division multiplexing (CO-OFDM) system has been studied extensively in recent years [1–6]. Considered as prominent contender for future transmission system, CO-OFDM system can provide powerful channel estimation and compensation capabilities [7–9]. Nevertheless, when the speed rates reaching up to 100 Gb/s or higher, some optical channel impairments, such as optical noise, dispersion and nonlinearity, have become major limiting factors in CO-OFDM transmission systems. Therefore, it is important to establish an effective channel estimation method to track down channel changes. In particular, accurate channel estimation is a key factor to improve the equality of receiver. However, in published reports on channel estimation in regard to CO-OFDM system, researches have mainly concentrated on least square (LS) algorithm [10–15], although LS algorithm itself could not avoid the neglect ion of noise effect independently. To improve the algorithm, some laboratories have investigated the weakness based on LS algorithm during the processing of transfer matrix in order to reduce the effect of noise. In the studies by Shieh et al. [11] and Jansen et al. [12], they introduced a relative simple time-domain averaging (TDA) method, which averages the channel matrices estimated by multiple training symbols for each frequency subcarrier used. In another studies, Yang et al. [13] and Liu et al. [14] employed an intra symbol frequency domain averaging (ISFA) method, which averages the estimated channel matrices for multiple adjacent frequency subcarriers in the same TS. Nevertheless, while considering the merit of the two methods, TDA algorithm has to use large amount of system overhead to improve channel estimation accuracy, where such overhead incorporates considerable unnecessary signals and causes decrease of transmission efficiency. Different from TDA algorithm, ISFA method produces less accurate results under different subcarrier phases showing non-linear under the effect of dispersion in optical channels. Thus, it is valuable to find out a novel channel estimation algorithm which can smooth out the effect of noise while the algorithm suffers from minimum influence of dispersion effect.

In this paper, we propose an improved LS channel estimation algorithm for the CO-OFDM system aiming to solve the above problem. First an improved CO-OFDM system is setup for the application in our simulation. Secondly we will demonstrate our improved channel estimation algorithm under the conditions employed, including its robustness against some known transmission impairments, such as chromatic dispersion, polarization mode dispersion and optical noise. Finally the simulation results of this study will be compared with the performance of other published TDA and ISFA algorithm methods [11–14] in the same simulation conditions.

2. Coherent optical OFDM system setup

Fig. 1 shows the conceptual diagram of transmitter and receiver setup of the proposed CO-OFDM system in this study. In its

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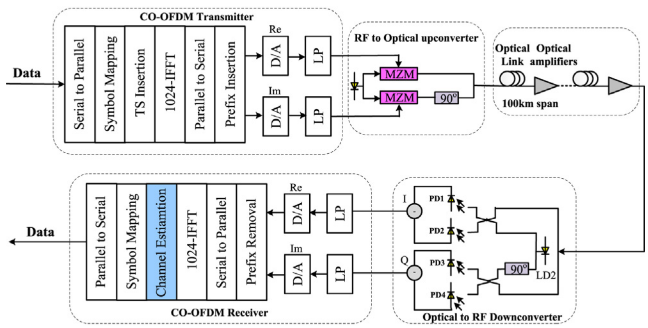

Fig. 1. Conceptual diagram of CO-OFDM system setup.

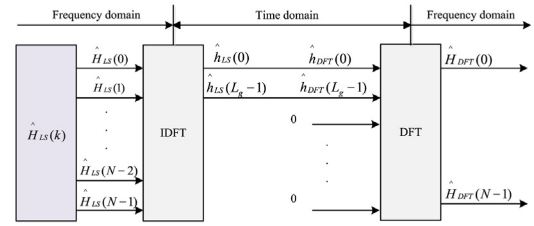

Fig. 2. The principle diagram of improved LS algorithm.

transmitter, a 100 Gb/s data stream with length of $2^{16}-1$ of pseudo random sequences (PRS) was established by a PRS generator.

In the proposed CO-OFDM system, sequences of one generator are mapped onto 512 subcarriers with a quadrature amplitude modulation (QAM) after serial/parallel transform. Sixteen training symbols required were then inserted for the channel estimation. The time domain signal was generated through using inverse fast Fourier transform (IFFT) with guard intervals applied as duration of one-quarter of the observation period. The time domain signals were then serialized and converted into analog signals by two digital to analog converters (DACs). The RF-to-optical up-convert was achieved by applying two Mahnch–Zender (MZ) optical modulators biased at zero output power, where a 90° phase shifter was used.

Regarding optical amplifiers in this system, the fiber link comprises 100 km spans of standard single-mode fiber and incorporates an amplifier of each span. The properties of the optical fiber comprise a loss of 0.2 dB/km, a dispersion of 17 ps/nm/km, differential group delay is 0.2 ps/km, a nonlinear coefficient of 2.6×10^{-20} m^2/W, and an effective area of 80 μm^2. As detected the amplifiers have a 15 dB gain and a 4 dB noise figure. The optical-to-RF down-converter through coherent detection consists of a line width of 100 kHz local laser, 90° optical hybrid, and two balanced receivers.

At the receiver, the received signals were converted into digital forms through two analog to digital converters (ADCs) and then were re-arranged in a parallel manner. Following a fast Fourier transform (FFT), the proposed channel estimation is conducted. At the last step, a QAM decoder was used to analyze the obtained symbols on each subcarrier to make the ultimate decision and to recover the original signals.

3. Improved LS algorithm

In our system, the frequency domain signal through FFT can be expressed as:

$$r_{ki}=e^{j\phi_i}e^{j\Phi_D(f_k)}T_k c_{ki}+n_{ki} \tag{1}$$

where r_{ki} is the received information of ith symbol, kth is the carrier, ϕ_i is the OFDM symbol phase noise, T_k is the Jones matrix in the optical channel, and n_{ki} is the noise. From Eq. (1), $\Phi_D(f_k)$ was caused by CD, T_k was caused by PMD and ϕ_i was caused by phase noise with c_{ki} in frequency domain being linear, $\Phi_D(f_k)$ and T_k being only connected with subcarriers k. Therefore, we can transmit the known signals into estimate, where the frequency domain channel transfer function H_{ki} composed of CD and PMD. Subsequently the study seems to show an effective recovery of received signals by H_{ki}. However ϕ_i is only connected with the amount of symbol I, namely, different symbols of different phase noise. Thus, the estimated H_{ki} will be affected by the influence of phase noise ϕ_i, and it is also affected by the influence of noise n_{ki}. Obviously how to reduce the influence of noise becomes a key for channel estimation. To avoid the limitations reflected in TDA and ISFA methods [11–14] on noise reduction, we proposed to use a DFT-based channel estimation algorithm which is expected to reduce the system overhead and has a higher tolerance to system noise, dispersion and fiber non-linearity.

The principle diagram of the improved LS channel estimation algorithm is shown in Fig. 2.

First the channel estimate can be derived in frequency domain based on LS estimation. After that, it can be changed to the time domain with anti-Fourier transformation,

$$\hat{h}_{LS}(n)=\frac{1}{N}\sum_{k=0}^{N-1}\hat{H}_{LS}(k)\exp\left(j2\pi\frac{nk}{N}\right),\quad 0\le n\le N-1 \tag{2}$$

The cyclic prefix L_g is always larger than the channel impulse L in OFDM system. The energy is concentrated in the limited paths, while the others are mainly caused by noise. In order to restrain the effect of noise, the channel impulse responses are set to zero when $n>L_g-1$. The channel impulse response in the paths within the cyclic prefix is reminded.

$$\hat{h}_T(n)=\begin{cases}\hat{h}_{LS}(n) & 0\le n\le L_g-1\\ 0 & \text{otherwise}\end{cases} \tag{3}$$

Then the new estimate of the frequency domain can be obtained by Fourier transformed:

$$\hat{H}_T(k)=\frac{1}{N}\sum_{n=0}^{N-1}\hat{h}_T(n)\exp\left(-j2\pi\frac{nk}{N}\right),\quad 0\le k\le N-1 \tag{4}$$

Based on above processes, the estimation accuracy can be improved greatly while the change of the process complexity remain insignificantly.

4. Results and discussion

In order to test the performance of the established channel estimation algorithm to CO-OFDM system, a simulation experiment was carried out in this study. We compared our improved LS algorithm with other published methods, including noise reduction TDA and ISFA algorithm [11–14], the basic LS algorithm in chromatic dispersion, polarization mode dispersion, constellations and the BER curves versus OSNR. All results are shown in Figs. 3–6.

Fig. 3 shows the system Q versus accumulated chromatic dispersion based on the improved LS, the ISFA, the TDA, and the traditional LS channel estimation algorithms. The results demonstrated that the improved LS algorithm has the best tolerance to chromatic dispersion and revealed better tolerance of CD in comparison with ISFA algorithm when the ISFA system average parameter m was set to 6. Also, the improved algorithm performed better than TDA algorithm when its parameter m set to 5. Following the growth of chromatic dispersion, the system Q of ISFA algorithm had been declining, and the values were even lower than the LS algorithm without any noise reduction treatment. It is believed that this is