An improved channel estimation algorithm for CO-OFDM system and its performance analysis*

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We present an extra processing added to conventional least square (LS) channel estimation to further improve its performance in coherent optical orthogonal frequency division multiplexing (CO-OFDM) system. The influence of noise, chromatic dispersion and polarization mode dispersion on the performance of the proposed algorithm is analyzed. The simulation results show that the improved algorithm has better performance and lower complexity.

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Coherent optical orthogonal frequency division multiplexing (CO-OFDM) is considered to be a promising technology for the further optical communications[1-3]. CO-OFDM has many advantages, including scalability to the ever increasing data rate and transponder adaptability[4,5], high receiver sensitivity and spectral efficiency, and robustness against dispersion[6-10]. However, the impact of optical channel is a major limiting factor in CO-OFDM systems when the speed rate up to 100 Gbit/s or higher. Therefore, it requires to use effective channel estimation method to track the channel changes. Accurate channel estimation is the key factor to improve the receiver quality, and it is also the main requirement to improve the transmission performance of CO-OFDM systems. Nevertheless, the channel estimation has attracted limited attention in the field of CO-OFDM system in recent years. Many channel estimation methods were reported in CO-OFDM system, such as least square (LS), maximum likelihood (ML) and linear minimum mean square error (LMMSE) algorithms[11-15].

In this paper, we present an improved channel estimation based on the LS algorithm. The simulation results show that the system performance of CO-OFDM is improved by using the channel estimation presented and it has relatively low complexity.

Fig.1 shows the diagram of coherent optical OFDM system in this study. It can be divided into five blocks, including the radio frequency (RF) OFDM transmitter, the OFDM RF-to-optical up-converter, optical link, the OFDM optical-to-RF down-converter and the RF OFDM receiver. In the RF OFDM transmitter, the binary serial digital signal is first divided into *N*-way parallel signals through serial/parallel transform, each data using M-ary phase shift keying (PSK) or quadrature amplitude modulation (QAM). The obtained signals are mapped into the corresponding complex forms through constellation mapping. Then insert the pilot information required for the channel estimation. By using inverse fast Fourier transform (IFFT), these subcarrier symbols are converted to *N*-way parallel carriers, and then the *N*-way parallel carriers are converted into the serial carriers as an OFDM symbol through parallel to serial conversion. By adding the cyclic prefix (CP) at the front of each symbol, the digital-to-analog converter (DAC) converts the digital data to analog signal, called an OFDM baseband signal. The OFDM RF-to-optical up-conversion is achieved by applying the OFDM signal to an optical I/Q modulator. The two Mahnch-Zender (MZ) optical modulators biased at zero output power and a 90°phase shifter are used. Then the optical signals are launched into the optical link. The signals after optical fiber transmission are demultiplexed and detected through optical-to-RF down-converter which consists of a 90°optical hybrid, a local oscillator laser, and two balanced receivers to down-convert the optical OFDM signal to baseband. In the RF OFDM receiver, the received signal is first sampled using an analog-to-digital converter (ADC), and then the

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cyclic prefix and serial to parallel conversion are removed. The parallel signal is then through fast Fourier transform (FFT) and channel estimation. A PSK or QAM decoder is used to analyze the obtained symbol on each subcarrier to make the final decision and after parallel to serial conversion to recover the binary signal.

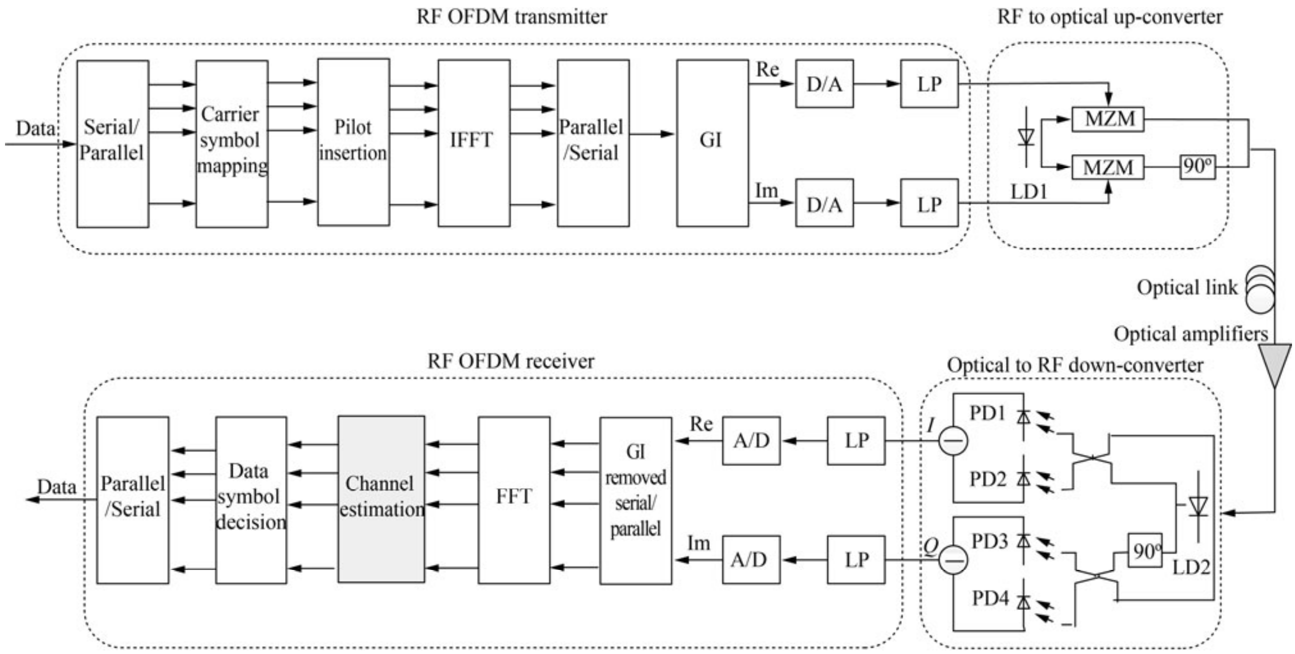


Fig.1 Schematic diagram of CO-OFDM system

The principle of LS algorithm is to minimize the value of the cost function of the estimator without considering the noise $(Y-XH)^H(Y-XH)$, where Y is the received signal in frequency domain, X is the sending signal in the frequency domain and H is the frequency response of the channel. Minimize the cost function to get the channel frequency response of LS estimation,

$$H_{\mathrm{LS}}=X^{-1}Y \quad . \tag{1}$$

The LS channel estimation algorithm is simple, with small amount of calculation and easy to implement. But its cost function can be seen when looking for the optimal solution neglecting the effect of noise, so the accuracy of the estimation algorithm is limited.

Our improved channel estimation algorithm is based on the property that the time-domain zero is equivalent to the frequency domain filtering to recover the channel frequency response.

The channel estimation can be derived in frequency domain based on LS estimation firstly, and then it can be changed to the time domain with IFT as

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

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 rest is mainly caused by the noise. In order to restrain the effect of the noise, the channel impulse response is set to zero when $n>L_g-1$. The channel impulse response in the paths within the cyclic prefix is remained.

$$\hat{h}_{\mathrm{T}}(n)=\begin{cases}\hat{h}_{\mathrm{LS}}(n), 0\le n\le L_g-1\\ 0 \quad , \quad \text{otherwise}\end{cases} . \tag{3}$$

Then the new estimation of the frequency domain can be obtained by Fourier transform:

$$\hat{H}_{\mathrm{T}}(k)=\frac{1}{N}\sum_{n=0}^{N-1}\hat{h}_{\mathrm{T}}(n)\exp\left(-\mathrm{j}2\pi\frac{nk}{N}\right), 0\le k\le N-1 . \tag{4}$$

The improved algorithm could effectively eliminate the noise neglected in the conventional LS algorithm and improve the estimation accuracy with the complexity not increased a lot. It is a good choice for coherent optical OFDM system as the improved estimator algorithm has better performance than LS estimator and lower complexity than MMSE estimator.

In order to verify the performance of our improved channel estimation algorithm in coherent optical OFDM system, we carry out simulations. The parameter settings are as follows: the bit rate is 100 Gbit/s, OFDM parameters are 512 subcarriers, a guard interval is equal to one quarter of the observation period and 4-QAM encoding for each subcarrier, pilot insertion mode is block-type, the transmission span is 100 km and a filter is used, chromatic dispersion is 17 ps·nm^{-1}·km^{-1} and the fiber loss is 0.2 dB/km.

Fig.2 shows the system Q versus accumulated chromatic dispersion and polarization mode dispersion which are the major limits for high speed and long distance optical transmission systems. From Fig.2, the results demonstrate that the improved LS algorithm has much better tolerance to chromatic dispersion and polarization mode dispersion than the conventional LS algorithm.

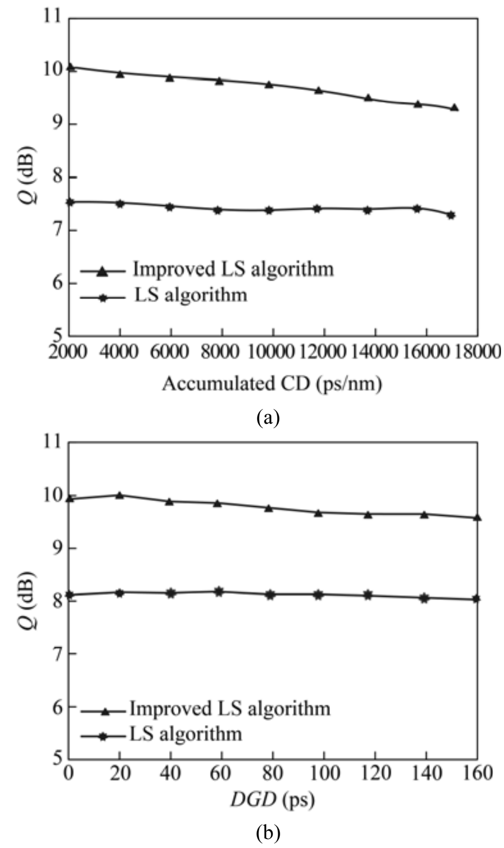


Fig.2 System *Q* versus (a) accumulated chromatic dispersion and (b) polarization mode dispersion

Fig.3 presents the results of mean square error (MSE) versus optical signal-to-noise ratio (OSNR) under the improved LS algorithm and the traditional LS algorithm. We can see that the MSE performance of the improved LS algorithm is better than that of LS algorithm under the same conditions, which is due to a reduction of noise through setting an appropriate threshold. Therefore, the improved LS algorithm has higher reliability.

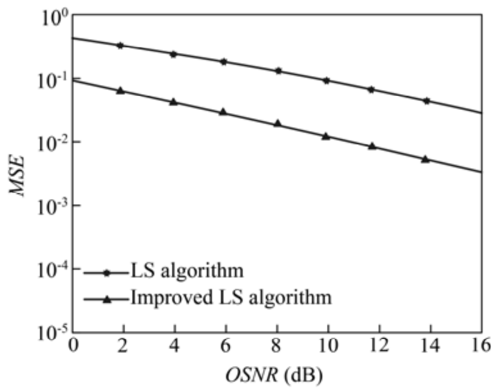


Fig.3 MSE versus OSNR

Based on Fig.4, we can see that the LS algorithm has the lowest complexity while the LMMSE algorithm has the highest complexity. Under the system subcarrier number of 512, the computation complexities of the LMMSE and our improved LS algorithms are 513 times and 10 times of that of the LS algorithm, respectively. Therefore, we can draw that the LMMSE algorithm complexity is extremely high, and it is difficult to be realized. In contract, the complexity of our improved LS algorithm is close to that of the LS algorithm, and has better performance.

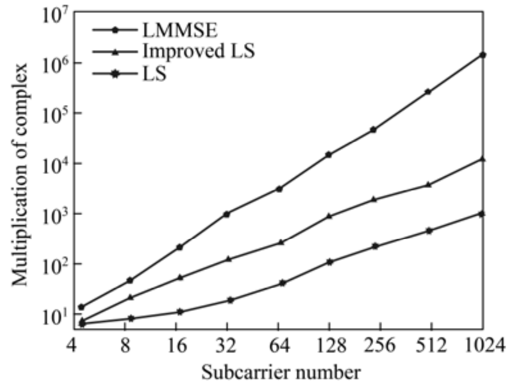


Fig.4 Computation complexity comparison of three channel estimation algorithms

From Fig.5 we can see that the BER performance of the improved LS algorithm is better than that of the traditional LS algorithm because it eliminates the effect of noise in time domain. We can also see that the BER decreases with the increase of OSNR for both two channel estimation algorithms. Under the BER of 10^{-4}, the improved LS algorithm has 2 dB OSNR gain compared with the traditional LS algorithm. Fig.6 can also clearly demonstrate the received corresponding constellation diagrams before and after LS and our improved LS estimations. Before the channel estimation, each constellation point is rotated around the origin to form a doughnut shape. The degrees of rotation are subject to fiber dispersion and noise values. From Fig.6(b) and (c), we can see that the constellation shift is determined by using channel estimation with known training symbols, and the constellation points are more centralized in (c) than (b). Under the selected conditions, the improved LS channel estimation algorithm has better performance than the LS algorithm.

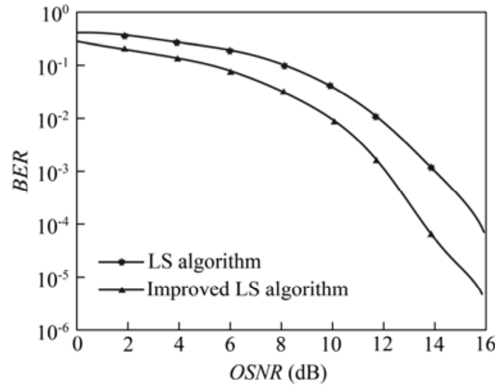
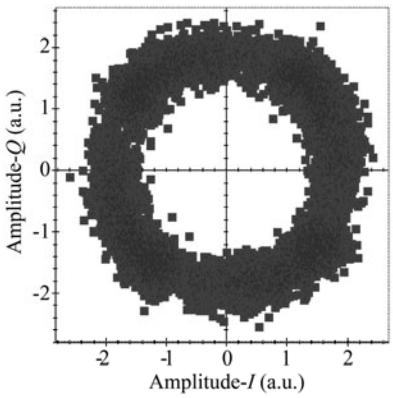
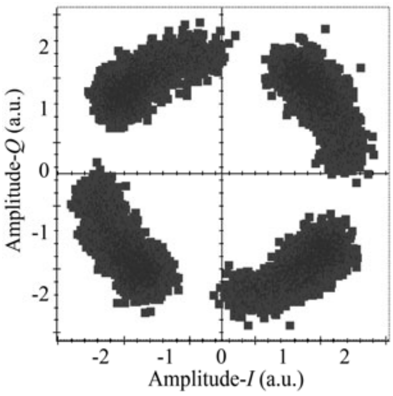


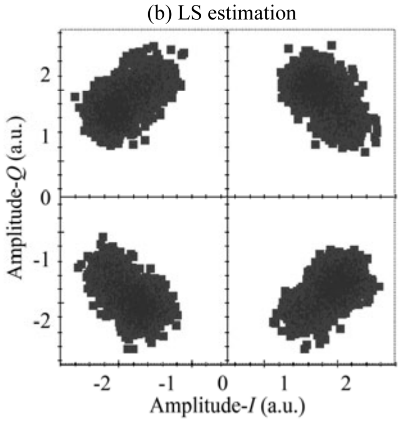
Fig.5 BER versus OSNR



(a) Without estimation



(b) LS estimation



(c) Improved LS estimation

Fig.6 Constellation diagrams under different estimation algorithms

In this paper, according to the characteristics of the channel in optical fiber, an improved LS channel estimation algorithm has been proposed to further improve the performance for CO-OFDM systems. The principle of our proposed algorithm has been presented and the simulation results show that the improved algorithm is effective to reduce the effect of noise and has 2 dB OSNR gain compared with the LS algorithm at the BER of 10^{-4}. The improved algorithm is a good choice for CO-OFDM system with the trade-off between complexity and performance.

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