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Performance Comparison of LS and LMMSE Channel Estimation Algorithm for CO-OFDM System

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Abstract. The CO-OFDM single-mode optical fiber system is constructed by the Matlab coupled with the Optisystem. And the influence of different channel algorithm on the receiver of system is researched. The simulation results show that the system performance is improved by using LS or LMMSE channel algorithm. And the LMMSE channel algorithm can provide better performance than the LS channel algorithm. Compared with LS algorithm, the required receiver OSNR is reduced by about 1 dB using improved LMMSE algorithm at bit-error-rate (BER) $=10^{-4}$ in the CO-OFDM single-mode optical fiber system.

Introduction

Coherent optical orthogonal frequency-division multiplexing (CO-OFDM) has emerged as an attractive modulation format for optical communications. Coherent optical orthogonal frequency-division multiplexing (CO-OFDM) system takes the advantage of both the OFDM technology and the coherent optical communication [1]. And it may contribute greatly to the future high speed fiber transmission system. The chromatic dispersion and polarization mode dispersion (PMD) can be estimated and mitigated effectively. However, the CO-OFDM system is sensitive to noise. Noise influences the amplitude and phase of the receiver signals.

At the receiver in CO-OFDM systems, coherent detection is better for providing the channel decoder with proper constellation knowledge. This requires channel estimation and tracking [2]. Two basic algorithms for wireless channel estimation are least-squares (LS) and linear least mean-square error (LMMSE). The algorithm for CO-OFDM single-mode optical fiber system is evolved from radio channel algorithm [3].

LS algorithm is easy to be realized, and computation is relatively small. But the influence of the noise is not considered in LS estimator, so the performance will deteriorate when large noise occurs. On the contrary, LMMSE estimator is more accurate than LS estimator, when noise is taken into consideration [4]. However, some statistic information about the channel is needed in the LMMSE estimator. The CO-OFDM single-mode optical fiber system is constructed and the influence of the channel algorithm to the receiver system is studied. The simulation results show that those two algorithms are effective, improved LMMSE algorithm is better than LS algorithm.

Principle of coherent optical OFDM

CO-OFDM combines two powerful techniques, coherent optical detection and orthogonal frequency-division multiplexing (OFDM). Fig. 1 shows the conceptual diagram of a generic coherent optical OFDM system constructed by five basic functional blocks: RF OFDM transmitter, RTO up converter, optical link, OTR down converter, and RF OFDM receiver [5]. In the RTO up converter, single Mach Zehnder modulator (MZM) is used to convert RF information to light information. The fundamental assumption for the OFDM technique is the transmission channel linearity.

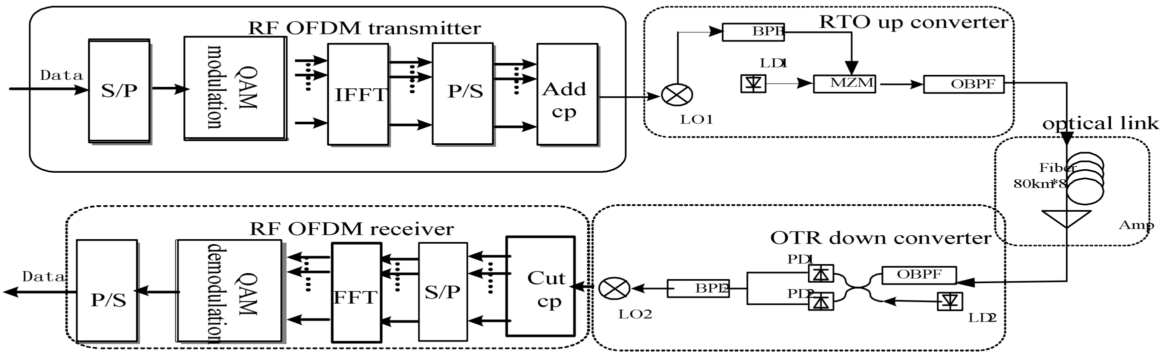


Fig. 1. Conceptual diagram for a generic CO-OFDM system

In this system, the Nsc = 128 is set for IFFT transform. The number of transmission sub-carriers is 112. However, in some practical situation, the middle 16 sub-carriers do not carry data, which are suitable for filter characteristics. The length of circulation prefix (CP) is relevant with the transmission distance. Generally, CP = 16 can perform well to the transmission within 1000km. The transmission distance is set to 640km, so CP=16 is taken.

Modulation and demodulation of OFDM signal are finished offline in Matlab. Ideal time synchronous and symbol synchronous are assumed in the system. Fig. 2 shows the CO-OFDM system diagram in Optisystem.

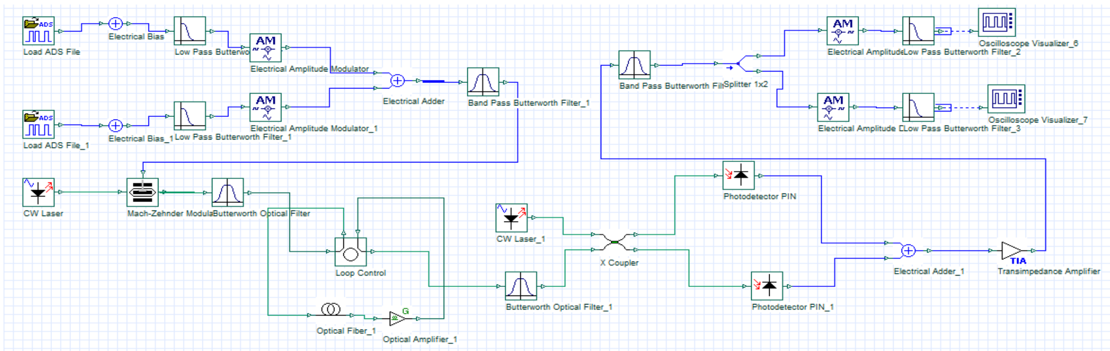


Fig. 2. CO-OFDM system diagram in Optisystem

As is shown in Fig.2, I,Q signal is imported. Then after the quadrature modulation, OFDM symbols are modulated to RF signals in intermediate-frequency architecture. RF signals are uploaded to optical links through MZM. While LS and LMMSE algorithm channel estimation are done in Matlab.

Channel estimation based on pilot

In OFDM systems, it is usually done in frequency domain by estimating the channel frequency response to deal with the signal. The block pilot assisted estimation are used in this article. Pilot signals are embedded in certain sub-carriers of each OFDM symbol. At the receiver, the channel components estimated using these pilots are interpolated for estimating the complete channel [6].

The system can be described in frequency-domain with the form of matrix notation:

$$Y = XH + W \tag{1}$$

where X is a transmitted signal matrix, Y is the received signal vector, H is the whole frequency response of the channel, and W is a vector of independent identically distributed complex zero mean Gaussian noise. $H_{LS} = X^{-1}Y$,For each carrier, H_{LS} can be expressed as:

$$\hat{H}_{k,LS} = (X_k^H X_k)^{-1} X_k^H R \tag{2}$$

LS algorithm can cause some inaccurate outcome because the pilots for LS algorithm are limited in the receiver. However, as the most direct compensation method, LS algorithm is the base of improved algorithm. Some improvement algorithms just increase some weighted coefficient based on the LS algorithm. So it can meet some special channel requirement and obtain much more accurate results.

MMSE criterion is to minimize the means square error. LMMSE is one of the special cases, L means linear. LMMSE studies the estimation error. It needs to use the sample to calculate statistic, also it must know conditional probability which means to know the distribution of transmitting signal and noise, which namely needs to know transmission function H. The LMMSE algorithm channel response function can be deduced it:

$$H_{LMMSE} = WH_{LS} = R_{HH}\left[R_{HH} + \sigma_n^2\left(XX^H\right)^{-1}\right]^{-1} H_{LS} \tag{3}$$

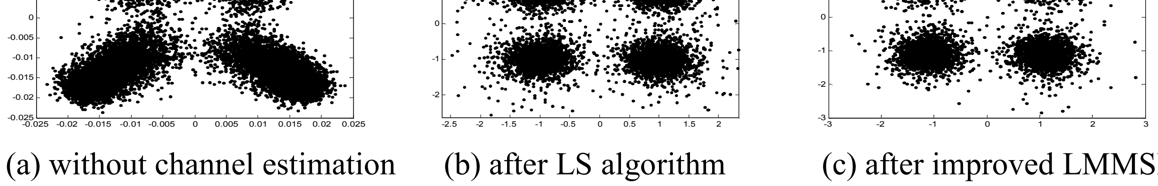
Where R_{HH} is the autocorrelation of the channel frequency response H, σ_n^2 is noise power. W is a matrix to calibrate LS, $W = R_{HH}\left[R_{HH} + \frac{\beta}{SNR} I_N\right]^{-1}$, $SNR = E\left\{\left|X_K\right|^2\right\} / \sigma_n^2$, I_N is the identity matrix. β is a constant depending on the signal Constellation. In the case of 4QAM transmission, β=1. $R_{HH} = E(H_{LS}H_{LS}^H)$. So the formula (3) can be simplified:

$$H_{LMMSE} = R_{HH}\left[R_{HH} + \frac{\beta}{SNR} I_N\right]^{-1} H_{LS} \tag{4}$$

SNR and R_{HH} are statistics, because SNR includes noise statistical characteristics and R_{HH} are channel statistical properties. The receiver performance can be improved by the LMMSE algorithm which contains both observation parameters and statistics. LS algorithm criterion is aimed to minimize the error square. And it doesn't contain statistics. However, LMMSE algorithm is based on LS algorithm, which analyzes Channel statistics (SNR, correlation matrix, etc.). So it is the estimation algorithm with statistical properties.

Simulation results

Computer simulation is used to verify the two algorithm estimation on a CO-OFDM system at 10 Gb/s. The OFDM system parameters used for the simulation are symbol period of 14.4 ns, guard time of 1.6 ns, and sub-carriers number of 112. QAM encoding is used for each sub-carrier resulting in total bit rate of 10 Gb/s. The link optical noise from the optical amplifiers is assumed to be white Gaussian noise and the phase noise of the laser is modeled as white frequency noise characterized by its line width. The performance is evaluated at 640km SSMF without optical dispersion compensation. Simulations have been carried out to show the performance of LS and improved LMMSE estimators. The comparison followed shows the differences between LS and improved LMMSE estimators. Three constellations have been laid out in figure 3 under the condition of OSNR=10^{-4}.



(a) without channel estimation (b) after LS algorithm (c) after improved LMMSE

Fig.3.The comparison of constellation

From Fig 3, we can see that: the transmitted data can't be decided correctly at all without any channel estimation in (a). (b) and (c) are the constellations after channel estimation and they have better performance than (a). In (a), signal amplitude distortion is more serious than (b) and (c).

Constellation chart spines are less in (c) than that in (b). Constellation points are more centralized in (c) than that in (b). This means: the constellation after the improved LMMSE estimator is better than the one after LS estimator. A conclusion can be drawn that channel estimation algorithm is effective.

The receiver signal is compensated by LMMSE algorithm in formula (4). So the receiver BER performance is gotten respectively. It can be known that R_{HH} is calculated by the channel function H_{LS}. When it comes to pilot data, Each H_{LS} is corresponding to different respective setting in CO-OFDM transmitter, which has different OSNR at the receiver and SNR in electric field. The statistical R_{HH} and SNR are induced by the observed quantity H. So SNR in electric field corresponds to OSNR in light receiver essentially. The relation between BER and OSNR with the employment of the LS estimator and the improved LMMSE estimator is given in Fig 4.

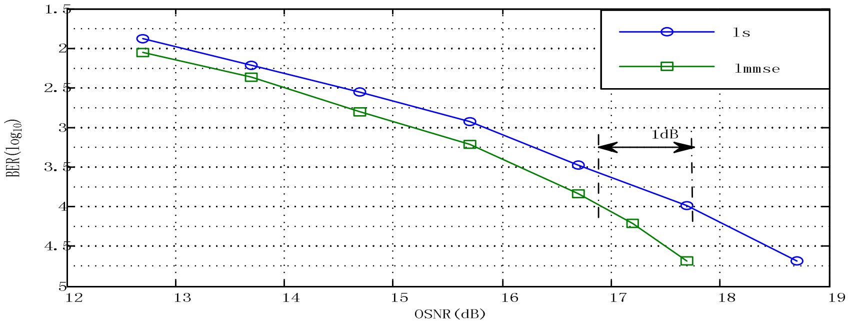


Fig. 4. The relation between BER and OSNR

In Fig.4, the BER decreases with the increase of OSNR. The improved algorithm LMMSE which increases some weighted coefficient based on LS algorithm has a better performance. Under the condition of BER=10^{-4}, the receiver OSNR used LS algorithm has about 1 dB optical power cost. The performance in the receiver applying LMMSE algorithm is improved about 1dB.

Conclusion

Significant progress has been made through theoretical analysis and experimental demonstration with the development of OFDM. In this paper, a CO-OFDM single-mode optical fiber system is constructed. The basic principle of the LS algorithm and LMMSE algorithm is elaborated. After the simulation, LMMSE superiority can be obviously seen from different algorithm constellation. The results show that: under the condition of BER=10^{-4}, the receiver OSNR applying LS algorithm has about 1 dB optical power cost.

Acknowledgments

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