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Investigation of Optimal Power Allocation for Pilot and Data in Direct-detection Optical OFDM System

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Abstract: In a baseband direct-detected optical orthogonal frequency division multiplexing (DDO-OFDM) system, when the total transmitted power is constant, increasing the power of pilots can improve channel estimation accuracy but also increases the interference from them. Therefore, in order to obtain a best performance, the optimal ratio of pilot-to-total power should be given. In this letter, we compared different systems with different pilot power to total power ratios by simulations. The results showed that the power allocation with an optimal pilot power to total power ratio was found and the optimal power allocation obtained the most accurate channel estimation and the highest receiver sensitivity.

Key words: Channel estimation, direct-detection, optical orthogonal frequency division multiplexing, power allocation for pilot and data

INTRODUCTION

Optical Orthogonal Frequency Division Multiplexing (OOFDM) has been actively investigated due to its robustness to fiber Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD) (Armstrong, 2009; Shieh, 2007; Schuster *et al*., 2008; Schmidt *et al*., 2008). Moreover, the high spectral efficiency and flexibility of bandwidth allocation make OOFDM suitable for optical access network such as OFDM-PON.

The optical OFDM system can be mainly classified to two types, coherent OOFDM (CO-OFDM) system and direct-detected OOFDM (DDO-OFDM) system. In general, CO-OFDM exhibits superior performance in receiver sensitivity, spectral efficiency and robustness against polarization dispersion. However, the complicated IQ modulator and polarization diverse optical hybrid are required in CO-OFDM. Additionally the complicated digital signal processor is of demand to track the phase, frequency and polarization variation between local oscillator light-wave and the signal light-wave. In contrast, the DDO-OFDM system consisting simple intense-modulation and direct-detection (IM-DD) structure for detection which generally, unlike the coherent detection that needs a local oscillator and an optical hybrid. The DDO-OFDM system is very easy to be implemented and the merits of lower cost and stability lead to a broader range of applications.

Channel estimation is an important procedure in optical OFDM system. The physical effects of the fiber transmission link on the optical signal transmitted over the link can be obtained with channel estimation and subsequent channel equalization can be used to improve the signal quality. Inserting some known symbols to extract channel information is the most commonly used channel estimation method. The known data can be training sequences or pilot subcarriers. In this study, we employed the both methods to complete channel estimation. The training sequence is added at the beginning of every OFDM frame to obtain frequency responses at each subcarrier frequency. Pilots are inserted to estimate the phase shift between training sequence and current data symbols (Qian *et al*., 2010). On the condition that the total transmitted power is constant, inserting pilot symbols with an increased amount of power leads to improved channel estimation but the interference from them also increases, moreover, the transmitted energy for data symbols is decreased which results in the deterioration of demodulation performance (Chen *et al*., 2003). On the other hand, decreasing the power of pilots leads to imperfect channel estimation. Therefore, the power allocation for pilots and data is critical.

Optimizing the pilot-to-data power ratio for wireless OFDM systems has received deep researches, based on maximizing a lower bound on ergodic capacity

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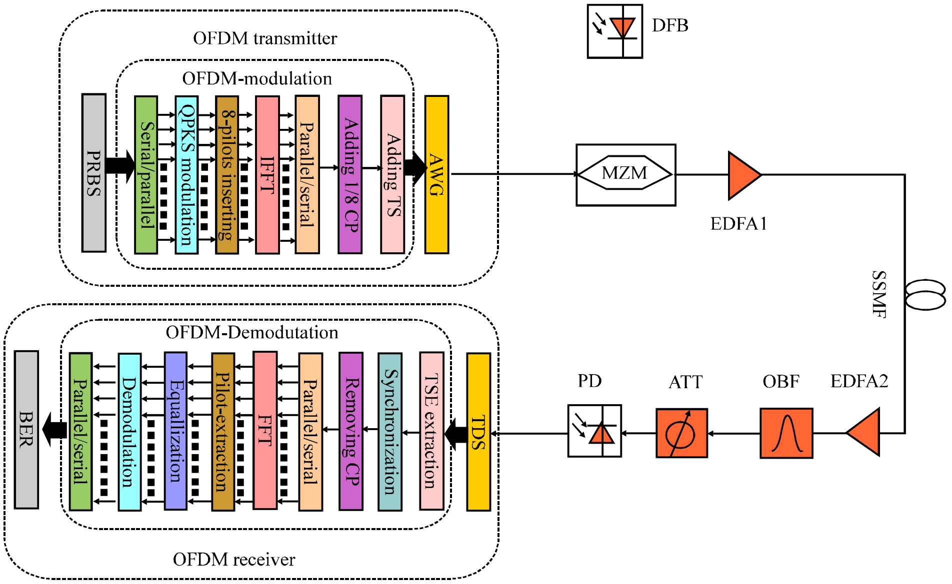

Fig. 1: The principle of IM-DDO-OFDM system, DFB: Distributed Feedback laser, MZM: Mach-Zehnder modulator, EDFA: Erbium Doped Fiber Amplifier, SSMF: Standard single-mode fiber, OBF: Optical Band-pass Filter, ATT: Attenuator, PD: Photodiode

(Gottumukkala and Minn, 2012; Ohno and Giannakis, 2004; Gottumukkala and Minn, 2009), minimizing the channel Mean-square Error (MSE) (Huang *et al*., 2009; Negi and Cioffi, 1998; Ohno and Giannakis, 2002) or Symbol Error Rate (SER) (Cai and Giannakis, 2004). However, the optimization of power allocation in DDO-OFDM system hasn't been dealt with. In this study, we compared systems with different pilot-to-data power ratios to find an optimal power allocation scheme applied to DDO-OFDM system by simulations. The simulation results showed the optimal power allocation can greatly improve the performance of system without any extra hardware or additional computational complexity.

System model: The IM-DDO-OFDM system employed for this work is shown in Fig. 1. At the OFDM transmitter, the Pseudorandom Binary Sequence (PRBS) data is changed to digital OFDM signal through OFDM modulation. In the OFDM modulation, 192 data OFDM subcarriers are mapped with Pseudorandom Binary Sequence (PRBS) data using QPSK format. 8 pilots $\{X_p(k)\}$ using different proposed power allocation schemes are inserted to extract the channel information for channel estimation and equalization. Another 56 subcarriers are set to zeros for oversampling. Then the frequency domain signal $\{x(k)\}$ is converted into time domain signal $\{x(n)\}$ using 256-points IFFT. A cyclic prefix with the length of 32 samples in every OFDM symbol is added to overcome inter-symbol interference. To facilitate time synchronization and rough channel estimation, a training symbol $\{X_T(k)\}$ is inserted at the beginning of each OFDM frame that contains 160 data symbols. Then the digital OFDM signal is converted to a real-time analogue OFDM signal by a digital-to-analogue converter (DAC). The electrical base-band OFDM signal is directly modulated on optical carrier with DSB transmission over Single-mode Fiber (SMF). Then optical OFDM signal is converted to base-band OFDM electrical signal after detection by a photodiode. At the OFDM receiver, the received electrical signal is then sampled by a real-time oscilloscope and is processed off-line for OFDM demodulation.

In this study, the training sequence and pilots are both used for channel estimation and their configurations are shown in Fig. 2. One training sequence OFDM symbol following by 160 OFDM symbols is transmitted. The channel estimation procedure is showed in Fig. 3.

The training sequence is a known string of symbols at the beginning of every OFDM frame to extract channel information. Then the Least Square (LS) algorithm which is the most simple channel estimation algorithm, is adopted to calculate the channel transfer function at each subcarrier:

$$\hat{H}_T(k) = Y_T(k)/X_T(k) \quad (k = 0,\cdots,N_T-1) \qquad (1)$$

where, $Y_T(k)$ is the k_{th} subcarrier of received training sequence, N_T is the number of non-null subcarriers of

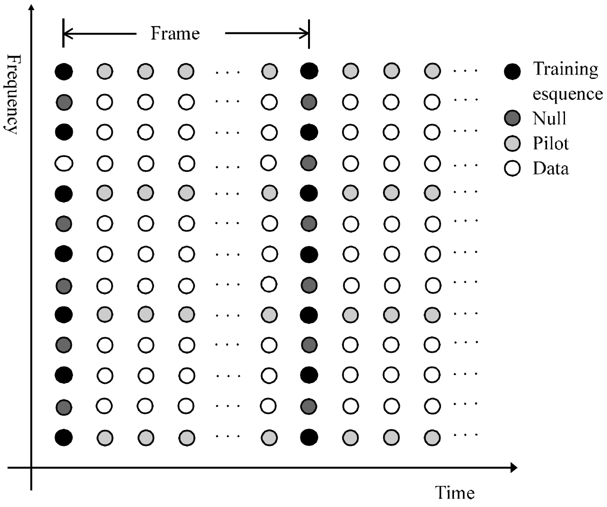

Fig. 2: The arrangements of training sequence and pilots

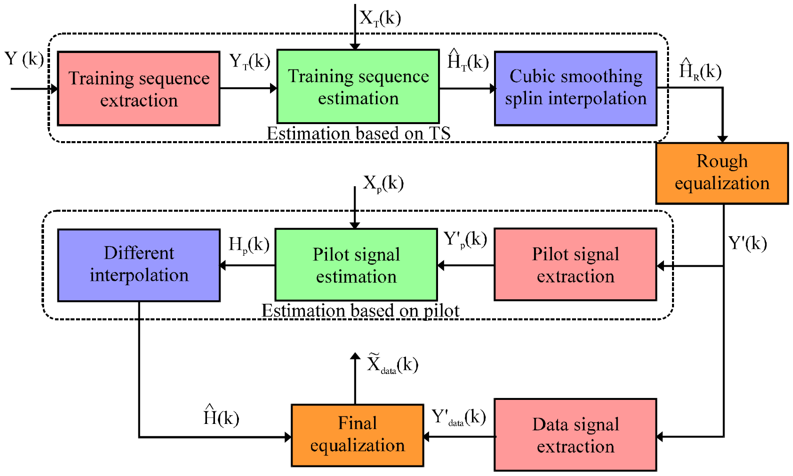

Fig. 3: The channel estimation procedure based on training sequences and pilot

received training sequence. The cubic smoothing spline interpolation method is used to obtain a rough channel estimation $\hat{H}_R(k)$. Then an initial equalization is performed:

$$Y'(k) = Y(k)/\hat{H}_R(k)\ (k = 0\cdots, N-1) \quad (2)$$

where, N is the number of subcarriers, Y(k) is the received signal. Cubic spline interpolation is employed here because it is easy to implement and produce a curve fitting the given pilot points seamlessly.

Pilots are inserted data with known values to estimate the phase shift between training sequence and current data symbols. The Least Square (LS) algorithm is adopted to calculate the channel transfer function at pilot subcarriers:

$$\hat{H}_P(k) = Y'_P(k)/X_P(k)\ (k = 0\cdots, N_P-1) \quad (3)$$

where, N_P is the number of pilot subcarriers. Cubic spline interpolation is applied to get channel estimation at the data subcarriers $\hat{H}(k)$. Finally, the data is equalized by using zero forcing equalization:

$$\tilde{X}_{data}(k) = Y'_{data}(k)/\hat{H}(k)\ (k = 0, \cdots, N_{data} - 1) \quad (4)$$

where, N_{data} is the number of data subcarriers.

DIFFERENT POWER ALLOCATIONS

We define the ratio of the pilot power to total power to be α with 0<α<1. Figure 4 shows the power

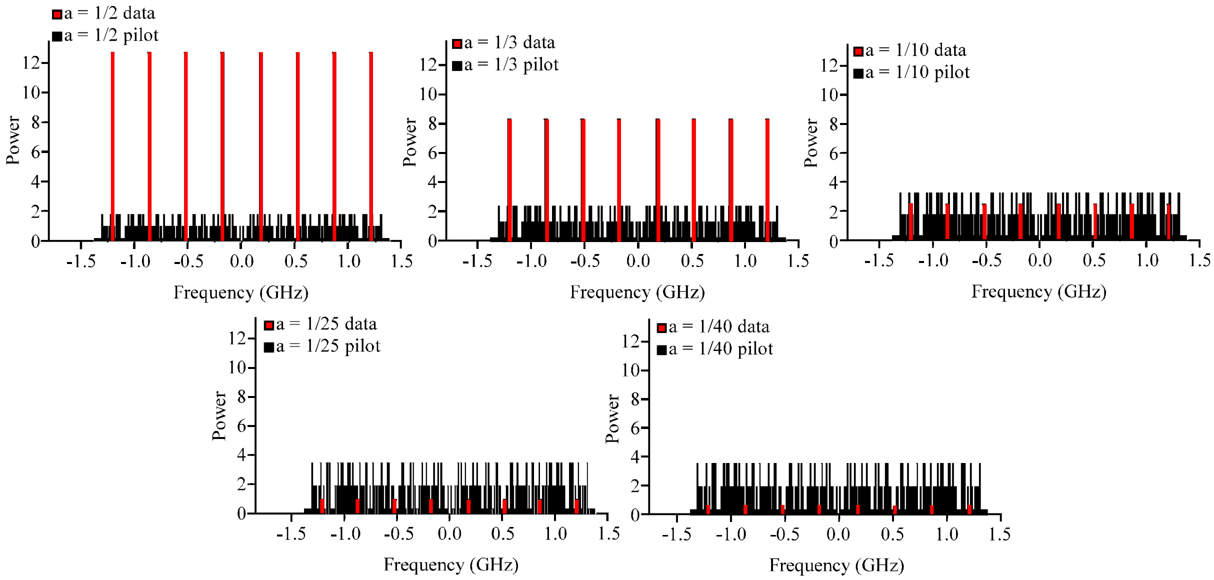

Fig. 4: Power allocations for pilots and data with different pilot-to-total power ratios

allocation with different data-to-total power ratio α. The horizontal coordinate denotes the frequency of subcarriers while the vertical one the power. The discrete lines present the power-varying pilots and data located in different frequencies, the black ones denote pilots and the red ones are the data. The ratios of average pilot power to average data power with the α equal to 1/2, 1/3, 1/10, 1/25 and 1/40 are 24, 12, 8/3, 24/19, 24/39, respectively.

SIMULATION RESULTS

The MATLAB and OptiSystem are used to implement the co-simulations. The OFDM baseband signal is generated offline with a MATLAB program. Then the generated OFDM signal is added to the optical DDO-OFDM system built by OptiSystem. Finally, the received signal is demodulated off-line with another MATLAB program functioned as an OFDM receiver.

Figure 5-7 shows the Error Vector Magnitude (EVM), Bit Error Rate (BER) and Q-factor versus the dispersion for OFDM signal with different pilot-to-total power ratios. EVM expresses the difference between the expected complex voltage of a demodulated symbol and the value of the actual received symbol. It is a performance measurement for assessing the quality of communication. BER is an important parameter in digital transmission quality assessment. It defines the probability that the bit being transmitted will be mistaken by decision. Fig. 8 shows the BER versus the length of transmission SMF. It is obviously that the system with $\alpha = 1/10$ has the lowest EVM and BER level and the highest Q-factor. That means an optimal power allocation between pilots and data is found and when the ratio of average pilot power to average data power is about 8/3, the channel estimation could play the best role.

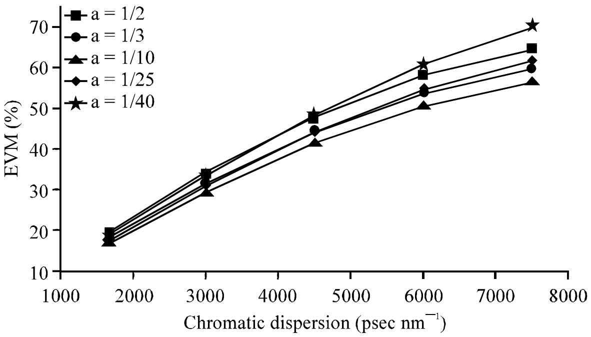

Fig. 5: Measured EVM versus chromatic dispersion

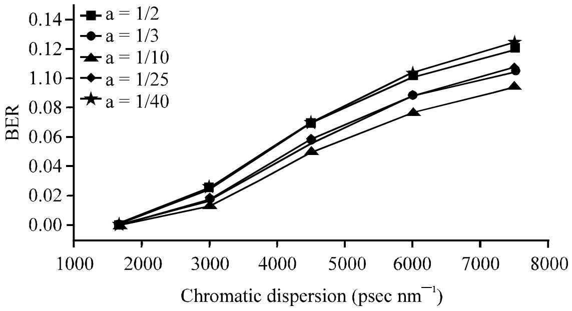

Fig. 6: Measured BER versus chromatic dispersion

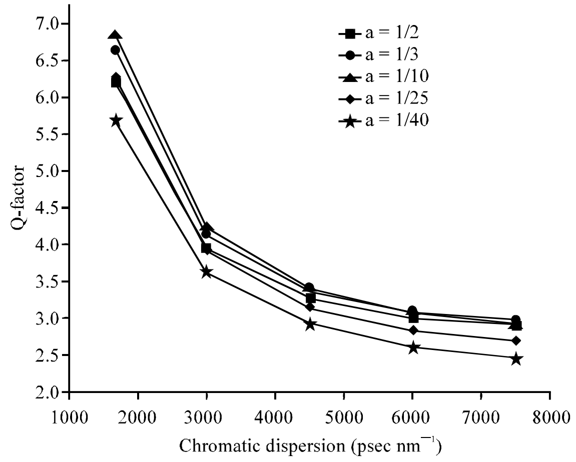

Fig. 7: Measured Q-factor versus chromatic dispersion

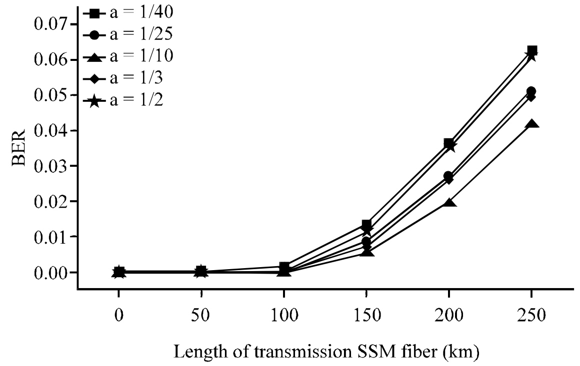

Fig. 8: Measured BER versus length of transmission SSMF

As mentioned in Introduction, increasing the power of pilots can not only lead to an improved channel estimation but also increase the interference introduced by pilots. Meanwhile, the transmitted energy for data symbols is decreased which results in the deterioration of demodulation performance. On the other hand, decreasing the power of pilots leads to imperfect channel estimation. Therefore, pilots with too high or too low power may degrade the system performance or decrease the accuracy of channel estimation.

CONCLUSION

Present study has investigated different power allocations between pilots and data in the DDO-OFDM baseband system. The simulation results show that when the pilot-to-total power ratio is 1/10, in other words, when the ratio of average pilot power to average data power is 8/3, the system can achieve the best channel estimation accuracy and highest receiver sensitivity. These results indicate that the power allocation optimization for pilots and data in DDO-OFDM system can be implemented to improve system performance without any extra hardware or additional computational complexity.

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