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A novel timing offset estimation method for direct-detection optical OFDM systems

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ABSTRACT

A novel timing offset estimation method for direct-detection (DD) optical orthogonal frequency division multiplexing (OOFDM) systems are proposed. The performance of the proposed method is evaluated in terms of mean and mean-square error (MSE) in one experimental system with 4 Gbits/s DD-OOFDM signal transmission over 100-km standard single mode fiber (SMF). The experimental results show that the proposed method has smaller MSE than the other methods and achieves higher timing estimation accuracy in DD-OOFDM transmission system.

1. Introduction

Optical orthogonal frequency division multiplexing (OOFDM) has been proposed as a promising technology to significantly improve the optical transmission system performance due to its good resistance to the chromatic dispersion (CD) and high spectral efficiency [1,2]. Timing synchronization is one of the major research topics in OFDM systems due to its sensitivity to symbol timing offset and carrier frequency offset [3]. Several approaches have been proposed to estimate time and frequency offset either jointly or individually in the wireless communication systems [4–6]. It is imperatively that the start of the FFT window timing synchronization is determined properly because an improper FFT window will result in inter-symbol interference (ISI) [7]. The most popular timing offset estimate algorithm is proposed by Schmidl [8]. In this method a training symbol containing the same two halves is used to estimate the symbol timing offset. But the timing metric of his method has a plateau, which causes a large variance in the timing estimate. To reduce the uncertainty caused by the timing metric plateau, Minn proposed one modification method as Schmidl's [9]. Minn's method yields a sharper timing metric and smaller variance than Schmidl's, but the timing metric is still not sharp enough. Park proposed a new training symbol to avoid the ambiguity which occurs in Schmidl and Minn's method [10]. Park's method has an impulse-shaped timing metric, which allows it to achieve a more accurate timing offset estimation. However, the performance of these synchronization approaches for OFDM base-band signal transmission over the fiber channel has not been thoroughly researched up to now. In this paper, we experimentally investigate and show the experimental results of these timing synchronization methods [8–10] used in DD-OOFDM optical fiber transmission system. Based on these methods, we present a modified method which is more suitable for optical fiber channel. The experimental results show that the proposed timing synchronization method produces an even sharper timing metric, which has only one peak in an OFDM symbol, and obtains smaller mean and MSE than the other methods.

2. System description

2.1. DD-OOFDM principle

Fig. 1 shows the principle of DD-OOFDM transmission system. The pseudorandom binary sequence (PRBS) bits are changed to OFDM baseband signal through OFDM modulation as shown in the OFDM transmitter (Tx) in Fig. 1. The OFDM modulation contains serial-to-parallel (S/P) conversion, QPSK modulation, pilot insertion, inverse fast Fourier transform (IFFT), parallel-to-serial conversion (P/S), and adding circle prefix (CP). The digital data sequence is converted to an analogue electrical signal waveform by an arbitrary waveform generator (AWG) serving as a digital to analogue converter (DAC). The electrical baseband OFDM signal is directly modulated on optical carrier. After transmission over

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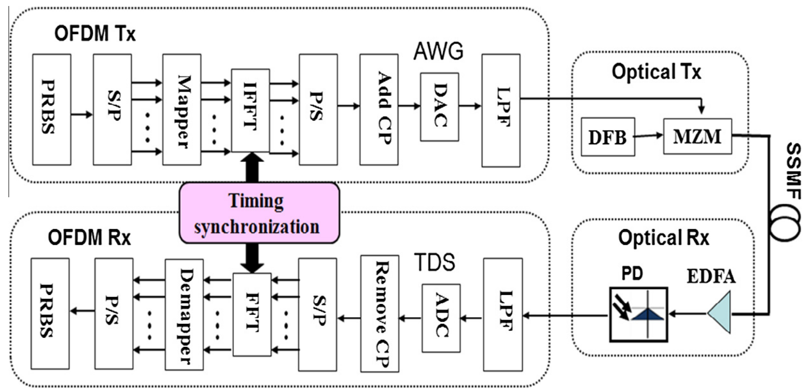

Fig. 1. Principle of DD-OOFDM transmission system. Tx: transmitter; LPF: lowpass filter; Rx: receiver.

standard single-mode fiber (SMF), the OOFDM signal is converted to a baseband OFDM electrical signal after detection by a photodiode (PD). The received electrical signal is then sampled by a real-time oscilloscope and is processed off-line for demodulation which is the inverse of the transmitter.

2.2. Comparison of OFDM timing synchronization methods

OFDM systems are much more sensitive to synchronization errors than single carrier systems [11]. The goal of OFDM timing synchronization is to find the start of the symbol. Let us briefly describe the timing offset estimation methods presented in [8–10].

2.2.1. Schmidl's method

The form of the time-domain training symbol proposed by Schmidl is as follows:

$P_{Sch} = [A_{N/2}A_{N/2}]$

where $A_{N/2}$ represents samples of length $N/2$ and is generated by the method in [8].

The Schmidl's timing offset estimator finds the starting point of the symbol at the maximum point of the timing metric given by

$$M_{Sch}(d) = \frac{|P_1(d)|^2}{(R_1(d))^2} \tag{1}$$

where

$$P_1(d) = \sum_{n=0}^{N/2-1} r^*(d+n)r(d+n+N/2) \tag{2}$$

$$R_1(d) = \sum_{n=0}^{N/2-1} |r(d+n+N/2)|^2 \tag{3}$$

The timing metric of Schmidl's method has a plateau which leads to some uncertainty regarding the starting point of the OFDM symbol.

2.2.2. Minn's method

In order to alleviate the uncertainty caused by the timing metric plateau and to improve the timing offset estimation, Minn proposed a modified training symbol. Minn's training symbol has the following form:

$P_{Minn} = [B_{N/4}B_{N/4} - B_{N/4} - B_{N/4}]$

where $B_{N/4}$ represents a PN sequence of length $N/4$.

The timing metric is expressed as

$$M_{Minn}(d) = \frac{|p_2(d)|^2}{R_2^2(d)} \tag{4}$$

where

$$P_2(d) = \sum_{m=0}^{1}\sum_{n=0}^{N/4-1} r^*\left(d+\frac{N}{2}m+n\right)r\left(d+\frac{N}{2}m+n+\frac{N}{4}\right) \tag{5}$$

$$R_2(d) = \sum_{m=0}^{1}\sum_{n=0}^{N/4-1} \left|r\left(d+\frac{N}{2}m+n+\frac{N}{4}\right)\right|^2 \tag{6}$$

Minn's method uses negative valued samples at the second-half of training symbol to reduce the timing metric plateau, hence resulting in a smaller MSE.

2.2.3. Park's method

The method proposed by Park [10] is to avoid the ambiguity which occurs in Schmidl and Minn's method. Park's training symbol is designed to be of the form

$P_{Minn} = [A_{N/4}B_{N/4}A^*_{N/4}B^*_{N/4}]$

where $A_{N/4}$ represents samples of length $N/4$, generated by IFFT of a PN sequence, and $A^*_{N/4}$ represents a conjugate of $A_{N/4}$, $B_{N/4}$ is designed to be symmetric with $A_{N/4}$.

To make use of the property that $A_{N/4}$ is symmetric with $B_{N/4}$, Park defined the timing metric as follows:

$$M_{Park}(d) = \frac{|p_3(d)|^2}{R_3^2(d)} \tag{7}$$

where

$$P_3(d) = \sum_{n=0}^{N/2-1} r(d+n)r(d-n) \tag{8}$$

$$R_3(d) = \sum_{n=0}^{N/2-1} |r(d+n)|^2 \tag{9}$$

We know that in the wireless channel, the Park's method has an impulse-shaped timing metric. But in the non-coherent OOFDM system, one of the prominent differences is the existence of fiber channel nonlinearity and its intricate interaction with fiber dispersion, which is nonexistent in the wireless systems. What is more important is that only real valued signal is transmitted through SMF channel and the conjugate symmetric property of training symbol is destroyed. Therefore, we can assume that its performance will be secondary to its performance in the wireless channel.