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FINE TIME SYNCHRONIZATION ALGORITHM FOR MIMO-OFDM

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ABSTRACT

In this paper, we propose a fine time synchronization for a Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) system. The proposed algorithm uses one more IFFT to find the timing offset, then correct it. The simulations show that comparing to the conventional algorithm using cross-correlation method, the proposed algorithm has a higher timing detection probability.

1. INTRODUCTION

The timing synchronization for OFDM (Orthogonal Frequency Division Multiplexing) system consists of two stages: Frame timing and Symbol timing. The frame timing synchronization is carried out by using the Guard Interval (GI) in each OFDM frame or the well-structured preamble at the beginning of each frame. The GI is commonly used in conventional receivers. The GI is the copy of the OFDM symbol tail so that the frame timing is detected by the correlation between these two parts. The advantage of this method is that it is simple to implement but it shows performance lower than the second method using the preamble. This preamble can consist of two identical or symmetrical parts that are combined to form an OFDM symbol. The simulation and practical results show that the second method can detect a frame timing with high probability.

After the frame timing is detected with low error variance, the next step is to find the OFDM symbol position. This requires the timing variance as low as several symbols (the timing is required to be within the GI to prevent the timing errors caused by the loss of orthogonality between sub-carriers).

The commonly used algorithm for the symbol timing synchronization is to transmit a special OFDM symbol then calculate the correlation between received signals and the copy of this symbol at the receiver. The timing is defined at the position that corresponds to the maximum correlation. This method can be used in systems with AWGN (Additive White Gaussian Noise) only, but has low performance in systems with multipath fading because the energy is not only concentrated on the direct ray [4, 5].

Currently, to improve the performance of communication system, multiple transmit and receive antennas are used forming a structure called Multiple Input - Multiple Output (MIMO). The combination between MIMO and OFDM has been shown to be an effective solution for next

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generation wireless network. In these systems, the synchronization is still achieved by using widely known algorithms for OFDM systems with little modification at the preamble [4, 5].

The paper is organized as follow. In the next section, we present the principle of the timing synchronization algorithm used for MIMO-OFDM system. The proposed algorithm is presented in Sec. 3. Section 4 shows simulation results and the conclusions are presented in Sec. 5.

2. THE CONVENTIONAL SYMBOL TIMING ALGORITHM FOR MIMO-OFDM SYSTEM

Considering a MIMO-OFDM system using *Q* transmit antennas and *L* receive antennas. Symbol timing is detected at each receive antenna [4], then these values are averaged.

At beginning of each frame, a special symbol (called referenced symbol) is transmitted. At the receiver, the synchronizer calculates the correlation between received signals and the copy of referenced symbol. Denote *s* the transmitted signals and *r* the received signals, *N* the number of sub-carriers (and also the length of referenced symbol). The correlation is calculated as following

$$\Psi_n = \sum_{q=1}^{Q} \frac{\left|\psi_{q,n}\right|^2}{\left(P'_n\right)^2} \tag{1}$$

where, *q* is the index of transmit antenna, *n* is the index of receive antenna, the numerator and denominator are calculated as follows:

$$\psi_{q,n} = \sum_{k=0}^{N-1} s_{q,k}^{*} \cdot r_{j,n+k} \tag{2}$$

$$P'_n = \sum_{k=0}^{N-1} \left|r_{j,n+k}\right|^2 . \tag{3}$$

The simulation results in [4] show that this algorithm can be applied to the systems with AWGN only or low delay spread multipath fading channels. In case of high delay spread multipath fading channels, the algorithm has a low detection probability. The main reason is that the signal energy is distributed among coming rays going through different paths with different delays. As consequence, some delayed signals have the highest correlation with referenced symbol, and the detected timing is shifted.

3. PROPOSED TIMING ALGORITHM FOR MIMO-OFDM SYSTEM

As it shown in previous section, the method using the cross-correlation between received signals and referenced symbols often detects the delayed timing. In this section, we present an algorithm to determine the exact delay.

Considering the signal $s(t)$ transmitted on the channel with impulse response $h(t)$. Denote τ the signal delay. At the receiver, the signal is shown as

$$r(t) = s(t-\tau) \otimes h(t) \tag{4}$$

In the frequency domain (after taking the FFT processing), the signal can be shown as

$$R(f) = S(f)H(f)e^{-j2\pi f\tau} \tag{5}$$

As $s(t)$ is the referenced symbol, it is known both at the transmitter and receiver. Then, the $S(f)$ is available at the receiver. Dividing the output of FFT block by this known value, we get

$$\frac{R(f)}{S(f)} = H(f)e^{-j2\pi ft} \tag{6}$$

Applying the inverse FFT, we obtain $h(t-\tau)$, with the same delay as in transmitted signal. As a result, the delay in detected timing is determined by observing the impulse response. For example, Fig. 1 shows the case where $\tau = 4$. In this case, the 4-sample delayed ray (compared to the direct ray) has the biggest power so that it has the highest correlation with the copy of referenced symbol at the receiver. As consequence, the synchronizer calculates the timing that is delayed 4 samples compared to the exact timing, corresponding to the 4-sample right shifted impulse response. The values before the channel amplitude of direct ray (from sample 1 to 4) are nearly zeros. The determination of channel coefficient (amplitude) of the direct ray is carried out by finding the first value that is greater than some preset value, called threshold.

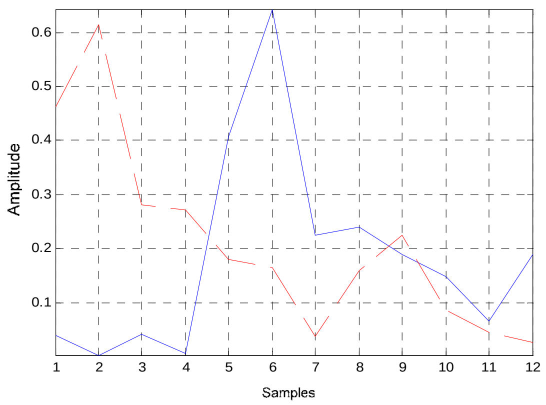

Fig. 1: *4-sample right shifted impulse response corresponding to 4-sample delayed detected timing*

With proposed algorithm, the synchronization at the receiver is carried out in the following steps. After the frame timing synchronization is performed using one of algorithms presented in Sec. 1, the receiver carries out the timing synchronization algorithm that uses the cross-correlation between received signals and the referenced symbol. The receiver left-shifts the symbol timing window with an interval of *D* samples (the value *D* preseted at the receiver is anyvalue that greater than the maximum shift interval of the symbol timing). Then, the FFT/IFFT (as in equations 4 - 6) is applied to determine the channel impulse response. After that, the receiver determines the first value in the impulse response window that is greater than the preseted threshold (this value is changed according to each system). The offset from the positions of the first and determined values equals to the offset τ of the timing. Finally, the receiver left-shifts the timing an interval equal to τ to define the exact timing.

In case of multiple transmit and receive antennas, the receiver finds the timing at each receive antenna and takes their averages.

4. SIMULATION RESULTS

In this section we present the simulation results. The MIMO-OFDM system has 2 × 2 and 2 × 3 antenna configurations with number of sub-carriers of 64 and guard interval of 16. The sampling rate is 20 MHz. The delay spread used in the channel is ranged from 50 ns to 150 ns. We use the exponential decay multipath fading channels and set the threshold equal to 0.15 to determine the channel coefficient of the direct ray (the first coming ray). The value of SNR is 6 dB. The comparison between the cross-correlation method and the proposed method is shown in Figs. 2 - 3.

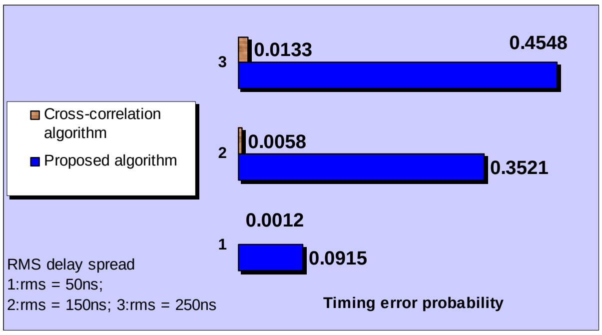

Fig. 2: *Timing detection error probability in cross-correlation and proposed algorithms with 2×2 antenna configurations*

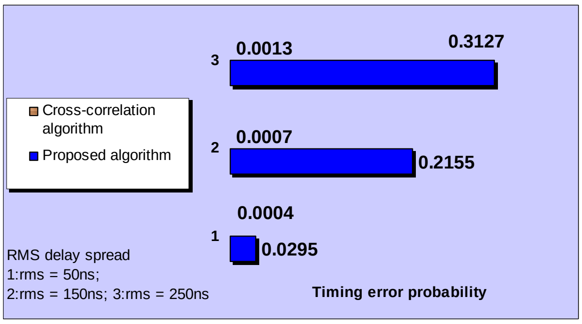

Fig. 3: *Timing detection error probability in cross-correlation and proposed algorithms with 2×3 antenna configurations*

As we can see from Fig. 2, the timing detection error in the proposed algorithm is much lower than in the conventional cross-correlation algorithm. For example, in case the rms delay spread equals to 50 ns (corresponding to the signal with maximum delay of 11 samples), the timing detection error probability in the proposed method is nearly 80 times lower than that in the cross-correlation method. When the delay spread increases, the error probability increases but the proposed algorithm still shows better performance. In case the number of receive antennas increases (3 as in Fig. 3, for example), both algorithms show better performance when using the average values.

5. CONCLUSION

The timing synchronization is the first and important block of a communication system in general and of a multi-carrier multi-antenna system in specific. In this paper, we proposed an algorithm to reduce the timing detection error probability in these systems. The simulation results show that the error probability in the proposed algorithm is much lower than in the conventional algorithm.

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