

Study on OFDM Symbol Timing Synchronization Algorithm

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Abstract

OFDM technology has become the core technology of the next generation mobile communication system because of the high bandwidth efficiency, the strong ability to resist inter-carrier interference and anti-channel interference. However, because OFDM system is a multicarrier modulation system, the system will be very sensitive to its synchronization errors. Synchronization estimation is an important part of the OFDM system. Based on the research of Schmidl & Cox and Minn synchronization algorithms, this paper proposed an improved timing synchronization algorithm which adopted the training sequence, and the timing synchronization estimation function has been optimized for this improved algorithm.

The peak platform issue of Schmidl & Cox algorithm, the no sharp peak issue of Minn (1) algorithm and the vice peak issue of Minn (2) algorithm were eliminated based on the improved algorithm. The simulation results showed that the timing judgment curve of the improved algorithm had a very sharp peak at the timing synchronization position. Compared with the conventional algorithm, the timing synchronization performance of the improved algorithm was better. The overall performance of OFDM system was improved.

Keywords: *Symbol Timing Synchronization Algorithm, OFDM, Training Sequence, Synchronization Estimation Function*

1. Introduction

Recently OFDM (Orthogonal Frequency Division Multiplexing) system has caused people's extensive concern because of its good capabilities of resisting noise and multi-path fading. OFDM technology is considered to be one of core technology of 4G [1, 2]. It is an improved multi-carrier modulation technology [3]. The main idea of OFDM technology is that the given channel is divided into many orthogonal sub-channels in frequency domain. Every sub-channel is modulated by one sub-carrier, and all sub-carriers are transported in parallel. In order to guarantee the orthogonality of sub-carrier the guard interval or cyclic prefix (CP: Cyclic Prefix) are inserted among the sub-carrier in frequency domain. Through inserting guard interval or CP the interference among the OFDM symbols is eliminated [4]. However, OFDM system is relatively sensitive to time and frequency offset. Frequency offset will destroy the inter-carrier orthogonality which can cause inter-carrier interference, and time offset will lead to the inter-symbol interference [5]. Therefore, precise time and frequency synchronization are very important to achieve good performance of the OFDM system [6].

OFDM system synchronization mainly includes the timing synchronization, carrier frequency synchronization and sampling clock synchronization. The timing synchronization includes frame synchronization and symbol synchronization. The frame synchronization is used to determine the starting position of the data packet and the symbol synchronization is used to determine the starting position of OFDM symbols. Operations above ensure the

correctness of FFT (Fast Fourier Transform) transformation. Firstly, carrier frequency synchronization need detect the frequency offset, and then be compensated. According to accuracy requirements, frequency offset can be divided into the fraction frequency offset and the integer frequency offset. The sampling clock synchronization is used to eliminate the impact of the frequency deviation and phase deviation on system performance. The frequency deviation is the value of difference between the A/D (analog-to-digital) clock frequency at the receiving terminal and the D/A (digital-to-analog) clock frequency at the sending terminal. The phase deviation is the value of difference between the phase at the receiving terminal and the phase at the sending terminal. This paper mainly studies the symbol timing synchronization.

2. Synchronous Model of OFDM System

The basic principle of OFDM is that the high-speed data streams are assigned to mutually orthogonal sub-channels for transmission [7]. And each sub-channel has a relatively low transmission rate. Operation above is achieved through the series-parallel conversion [8]. The specific process is as follows. At the sending terminal, firstly coding, interleaving and modulation of the bit stream, then series-parallel conversion and IFFT (Inverse Fast Fourier Transform) transformation, and then converting parallel data into serial data by parallel-series conversion, coupling with the CP, finally the OFDM symbol is generated. The OFDM signal is expressed as formula (1).

$$x(k) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X(n)e^{j2\pi kn/N} \quad (1)$$

Where, $X(n)$ is modulated data at the n -th sub-carrier, $x(k)$ is the time-domain sampling points of the OFDM signal. Where, the CP length is L and the length of IFFT is N [9].

At the receiving terminal, firstly, processes are synchronization and channel estimation for received signal respectively. Then, the modulated data are obtained. Finally the original bit stream is obtained by the corresponding demodulation. The synchronous model of the OFDM system is shown in Figure 1.

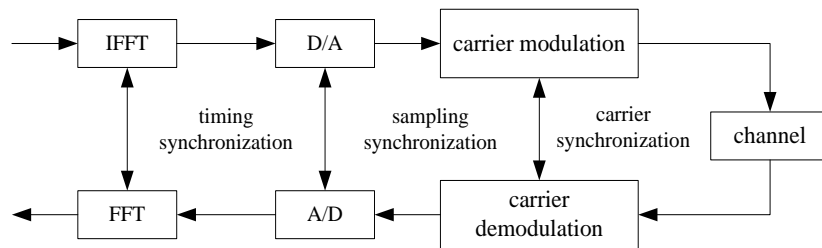


Figure 1. The Schematic Diagram of OFDM System Synchronization

3. The Conventional Timing Synchronization Algorithm Simulation

The timing synchronization algorithm can be implemented from a different perspective. From the point of using training sequence, it can be divided into data-aided timing synchronization algorithm, the non-data-aided timing synchronization algorithm and blind timing synchronization algorithm. The data-aided timing synchronization algorithm decreases the efficiency of data transmission because of using training sequences. However, this kind of algorithm has advantages of high estimation accuracy, fast synchronization speed and low computation complexity. The non-data-aided timing synchronization algorithm finishes

timing synchronization estimation by analyzing the time-domain structure characteristics and the frequency-domain structure characteristics of received signal. This kind of algorithm generally doesn't require additional data, and it has an advantage of high efficiency of data transmission. But, it has lower accuracy in the aspect of timing synchronization estimation. The blind timing synchronization algorithm finishes the timing synchronization estimation by analyzing the time-domain characteristics of received signal. However, this kind of algorithm has slow synchronization speed and high computation complexity, which hardly applied in OFDM system [10]. We will mainly studies the timing synchronization algorithm based on the training sequences in this paper.

3.1. The Study of Schmidl & Cox Algorithm

Schmidl & Cox (S&C) proposed two special training sequences for timing synchronization and carrier synchronization [11]. Training sequence 1 is used to achieve timing synchronization and the fraction frequency offset estimation. There is a difference relationship between training sequence 1 and training sequence 2. It can be used to complete the integer frequency offset estimation. We have studied timing synchronization of the training sequence 1. The time-domain structure of training sequence of S&C algorithm is shown in Figure 2.

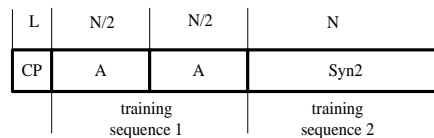


Figure 2. The Time-domain Structure of the Training Sequence of S&C Algorithm

Where N is the number of sub-carriers, L is the length of CP.

Training sequence 1 can be obtained by inserting pseudo-random sequence (PN sequence) at the even-numbered sub-carrier, and inserting zero at the odd sub-carrier, then IFFT transformation. The data of first part and latter part of the training sequence are same in time domain. The time-domain structure of training sequence 1 can be expressed as [A, A].

Timing synchronization of this algorithm is achieved by finding the ideal sampling point. The ideal sampling point was at the position of maximum of the timing judgment function M(d). The timing judgment function M(d) is expressed as formula (2).

$$M(d) = \frac{|p(d)|^2}{(q(d))^2} \quad (2)$$

Where, $p(d)$ and $q(d)$ can be expressed by formula (3) and (4), respectively.

$$p(d) = \sum_{m=0}^{N/2-1} r^*(d+m)r(d+m+N/2) \quad (3)$$

$$q(d) = \sum_{m=0}^{N/2-1} r(d+m+N/2) \quad (4)$$

Where $r(k)$ is the time-domain received signal.

The timing estimation performance of S&C algorithm is observed by using MATLAB. Simulation parameters of the algorithm are as follows. The number of sub-carriers is 256, the length of CP is 32, and the modulation index is 64. In different conditions, the timing judgment curves of this algorithm are shown in Figure 3. Where, SNR represents for signal to noise ratio.

We can obtain from Figure 3 that the timing judgment curve based on S&C algorithm exist a flat area near the ideal position, which can bring great uncertainty to the timing estimation, and with the SNR increasing, this problem was not solved. The flat area is approximately equal to the length of CP by observing the timing judgment curve. It can be explained by the time-domain structure of OFDM training sequence. Due to the presence of CP and the consistency of the structure the first and the latter parts of training sequence 1 in time domain, the timing judgment function $M(d)$ always appears maximum in the whole range of CP. Although some appropriate methods were used to further improve the timing estimation performance, there also exist timing errors.

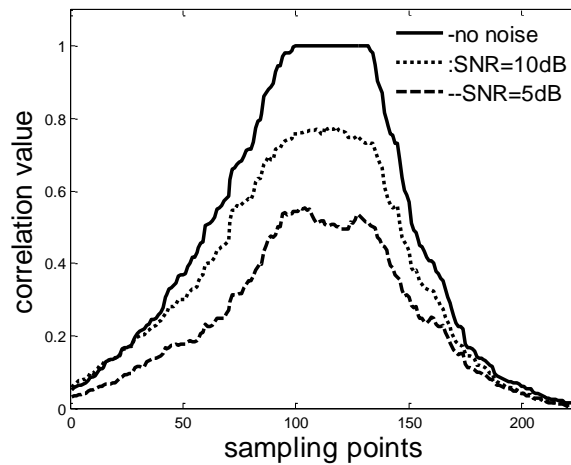


Figure 3. The Timing Judgment Curve based on S & C Algorithm

3.2. The Study of Minn Algorithm

H. Minn proposed two methods to effectively overcome the platform question. One method is sliding window, we call it by Minn (1). The other algorithm of improved training sequence structure is called Minn (2).

Minn (1) Algorithm. In the S&C algorithm, $q(d)$ is assigned fifty percent energy of one OFDM symbol. But Minn assigned all the energy of one OFDM symbol to $q(d)$, The sliding window length of time measure function is $L+1$, then the timing judgment function can be expressed as formula (5).

$$M_f(d) = \frac{1}{L+1} \sum_{k=L}^0 M(d+k) \quad (5)$$

Minn (2) Algorithm. Minn constructed a new training sequence in time domain, and the structure is shown in Figure 4. The training sequence is composed of four parts with the same length. The first part and the second part are exactly same. The third and the fourth part is the negative of the first and the second part, respectively.

L	N/4	N/4	N/4	N/4
CP	B	B	-B	-B
training sequence				

Figure 4. The Time-domain Structure of Training Sequence of Minn (2)

The timing judgment function of improved training sequence structure is expressed as formula (6).

$$M_1(d) = \frac{|p_1(d)|^2}{(q_1(d))^2} \tag{6}$$

Where

$$p_1(d) = \sum_{k=1}^2 \sum_{m=0}^{N/4-1} r^*(d + (k-1)N/2 + m)r(d + (k-1)N/2 + N/4 + m) \tag{7}$$

$$q_1(d) = \sum_{k=1}^2 \sum_{m=0}^{N/4-1} r(d + (k-1)N/2 + N/4 + m)^2 \tag{8}$$

The timing synchronization performance of three algorithms is compared by using MATLAB software. Simulation parameters of the three algorithms are the same as above except that SNR is 30 dB .The timing judgment curves are shown in Figure 5.

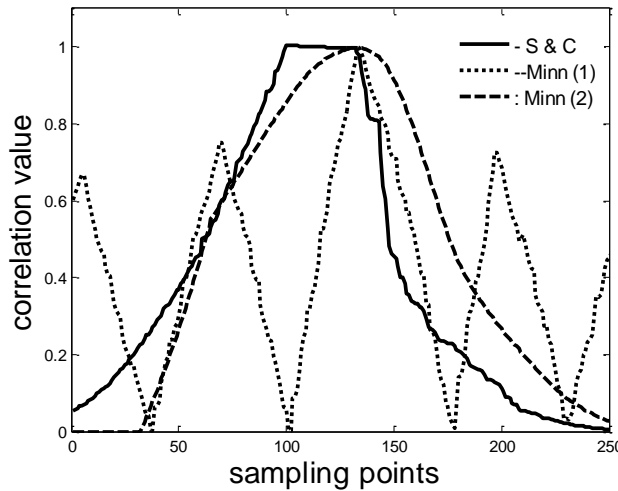


Figure 5. The Timing Judgment Curves Comparison of Three Conventional Algorithms

Minn (1), to a certain extent, overcomes peak platform problem by introducing time measure function. However, in the channels with low SNR, timing errors of the algorithm is still large. Minn (2) performance is superior to Minn (1) by introducing a negative training sequence. The timing judgment curve of Minn (2) can create a sharp peak at the ideal moment. But it is easy to appear many spikes at the incorrect moment, which makes it difficult to select decision threshold. Especially in burst system where the number of sub-carriers is small, the peak value at the incorrect moment is often bigger than the ideal moment. It also generates large timing errors.

4. The Study of Improved Timing Synchronization Algorithm Simulation

In order to overcome the shortcomings of above three algorithms, this paper puts forward an improved algorithm based on the new training sequence. The algorithm is described in detail below.

According to the special structure of training sequence in frequency domain, the new autocorrelation function is put forward in the algorithm. The frequency-domain structure of training sequence is shown in figure 6, where D is the reverse folded sequence of C.

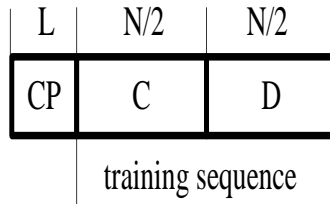


Figure 6. The Training Sequence Frequency-domain Structure of Improved Algorithm

The training sequence $Q(k)$ is gotten as follows. At first, the complex sequence $F(k)$ is generated randomly. Then, the complex sequence $G(k)$ is obtained by modulating the sequence $F(k)$ whose length is $N/2$. Finally, the complex sequence $Q(k)$ is made up of the sequence $G(k)$ and $P(k)$. $Q(k)$ can be expressed as $[G(k), P(k)]$. Where, $P(k)$ is the reverse folded sequence of $G(k)$. The length of $Q(k)$ is N . The training sequence $Q(k)$ has good autocorrelation in frequency domain because of the special structure.

The timing judgment function of the improved algorithm is expressed as formula (9).

$$M_2(d) = \frac{|p_2(d)|}{q_2(d)} \quad (9)$$

Where

$$p_2(d) = \sum_{m=0}^{N/2-1} r(d+m)r(d-m) \quad (10)$$

$$q_2(d) = \sum_{m=0}^{N/2-1} r(d+m)^2 \quad (11)$$

Where, $p_2(d)$ is the new autocorrelation function. Equation (9), (10) and (11) shows that $M_2(d)$ just can achieve maximum when the starting position of timing judgment is just at middle point of training sequence. $M_2(d)$ does not generate maximum in the range of CP.

The timing synchronization performance of this improved algorithm is analyzed by using MATLAB. Simulation parameters of the improved algorithm were the same as above. The timing judgment curve is shown in Figure 7.

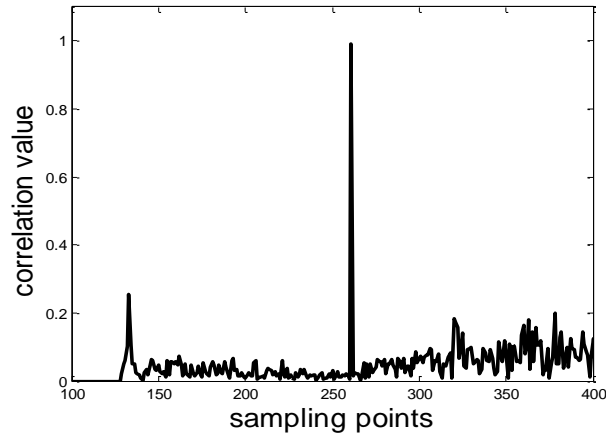


Figure 7. The Timing Judgment Curve of Improved Algorithm

It can be obtained from the simulation results of Figure 7 that the timing judgment function curve of improved algorithm only has unique peak. The peak position is ideal timing estimation point. There isn't the platform or the side lobe peak at the curve.

5. Conclusion

This paper proposed an improved timing synchronization algorithm. The improved algorithm is based on good correlation of the reverse folded sequence. The improved algorithm not only eliminates the peak platform problem, but also eliminates the multiple peaks problem. It can be concluded from the simulation results that the improved algorithm was obviously better than other three timing synchronization algorithms. The improved algorithm is able to meet timing synchronization application requirements of OFDM systems well.

Acknowledgements

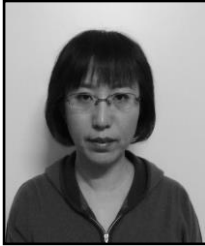
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