An Improved OFDM Synchronization Algorithm Based on Training Sequence

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Abstract—**The present study of the synchronization algorithm based on training sequence, has a small peak value easily confused with accurate timing synchronization peak value, resulting in error occurs and so on in timing synchronization. To solve this problem, this paper redesign the structure of training symbols by using a better correlation ZC sequence, to complete system synchronization task. Through effective calculation, the algorithm improves the coarse timing synchronization accuracy, increases the fractional frequency offset estimation accuracy, but also ensure the performance improvement of the fine timing synchronization and integer frequency offset estimation. Comparing simulation between the SC algorithm and the newly proposed algorithm under the Gauss channel and multipath channel, verifies the effectiveness of the newly proposed algorithm.**

Keywords-OFDM; synchronization; training sequence

I. INTRODUCTION

OFDM system is composed of a plurality of carriers transmitted information, which results in the optimum sampling time of the system difficultly to determine if synchronization is not accurately determined, on the one hand, the receiver signal will occur the severe ISI (Inter Symbol Interference) problem; on the other hand, the frequency deviation compensation correctness's premise is timing synchronization correctness, if the optimal sampling point cannot be accurately determined, the frequency offset compensating system will appear error, each sub-carrier will lose orthogonality, the receiver end signal will appear ICI(Inter-Carrier-Interference) problem. The importance of timing synchronization makes the synchronization algorithm has become the focus of various research scholars. In all the current synchronization algorithms, mainly include SC algorithm-based algorithm based on the training sequence, ML estimation algorithm-based algorithm based on cyclic prefix and the $MUSIC$ algorithm-based algorithm based on blind estimation. SC algorithm, Minn algorithm and Park algorithm, the training symbols of these classic algorithms are constituted by the PN sequence, and this paper will use a better correlation ZC sequence[1], redesign training symbols structure, to complete the system synchronization task.

II. TRAINING SEQUENCE STRUCTURE

In this paper, still insert two training sequences with length N to OFDM data symbols to achieve the system synchronization performance, the first training symbol consists of four ZC sequences with the same length in the time domain, followed by A, B, $-B'$, A'. Meanwhile, four sequences have the following relation: A and B are the two different ZC sequences, the reverse of B is the opposite of $-B'$, A' is the reverse of A, the length of each ZC sequence is $N/4$; the second training symbol consists of the composition of ZC sequence C and the conjugation of C .

L	N				L	N		
CP	A	B	$-B'$	A'	CP	$C+C^*$	CP	OFDM signal

FIGURE I. BLOCK DIAGRAM OF THE NEW TRAINING SEQUENCE

Timing synchronization can be divided into two parts, the first part capture the signal to find timing synchronization start point signal, this process we usually call coarse timing synchronization; then to keep track of signal, which is the holding signal synchronization, this process we usually call fine timing synchronization. The reason for inserting two training sequences to the new algorithm which is similar to the technical idea of SC algorithm, mainly is that we use first training symbol for coarse timing synchronization and fractional frequency offset estimation to get the correct frequency offset compensation, then use the second training symbol for fine timing synchronization and integer frequency offset estimation[2-3].

III. COARSE TIMING SYNCHRONIZATION AND FRACTIONAL FREQUENCY OFFSET ESTIMATION

When using the first training symbol for coarse timing synchronization and fractional frequency offset estimation, we choose the width of the receiver window as $N/2$, the timing metric function of the coarse timing synchronization can be defined as:

$$M_4(d)=\frac{|P_4(d)|^2}{R_4^2(d)} \tag{1}$$

If $\hat{d}$ make the timing metric function $M_4(d)$ to get a peak value, then the $\hat{d}$ corresponding to the sample point is the first sample point of training symbol, where:

$$P_4(d)=\sum_{k=0}^{N/2-1}\left[r^*(d-N/2-k)r(d+N/2+k)-r^*(d-k)r(d+k)\right]$$

$$R_4(d)=\sum_{k=0}^{N/4-1}\left[|r(d-N/2-K)|^2+|r(d-k)|^2+|r(d+k)|^2+|r(d+N/2+K)|^2\right]$$

The start position of the first sample point is $\hat{d} - N/2$.

We make the algorithm simulation, the simulation parameters are set as follows:

TABLE I. SIMULATION PARAMETERS OF NEW TRAINING SEQUENCE ALGORITHM

Item	Parameters
Channel selection	Gaussian channel
Modulation	QPSK
Sub-carriers number	N=1024
Cyclic prefix length	L=120
Sampling points delay number	100
SNR	15dB

The simulation result is shown in Figure 2. From the figure, we get to see that the peak value of the timing metric function is sharper compared to the three algorithms, and no other peaks exist, indicating the success of the new algorithm presented in precise timing synchronization can be completed, there is no other higher peak appears at the same time. For receiver signal with relatively large interference, timing synchronization performance is still able to maintain the accuracy, the timing error does not occur.

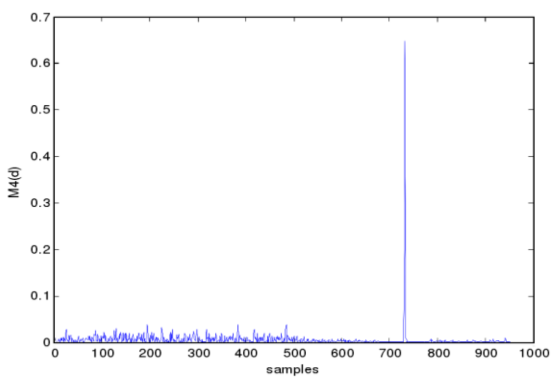


FIGURE II. THE COARSE TIMING SYNCHRONIZATION CURVE OF THE IMPROVED ALGORITHM

When you find the start point of the OFDM symbol, the first training symbol must complete fractional frequency offset estimation. We make the first two parts of first training symbol under correlation operation, then will get two fractional frequency offset estimation by using two partial correlation values of the phase offset ,at last, we take the average of the two fractional frequency offset estimation values as the best frequency offset estimation value of signal[4-5]. Two fractional frequency offset estimation values are defined as the following function, the value $\hat{\varepsilon}$ can be [1, -1].

$$\hat{\varepsilon}_1 = \frac{1}{\pi}\tan^{-1}\left[\frac{\sum_{k=1}^{N/4}\mathrm{Im}\left[r^*(\hat{d}-N/2-k)\cdot r(\hat{d}+N/2+k)\right]}{\sum_{k=1}^{N/4}\mathrm{Re}\left[r^*(\hat{d}-N/2-k)\cdot r(\hat{d}+N/2+k)\right]}\right] \quad (2)$$

$$\hat{\varepsilon}_2 = \frac{1}{\pi}\tan^{-1}\left[\frac{\sum_{k=1}^{N/4}\mathrm{Im}\left[r^*(\hat{d}-k)\cdot(-r(\hat{d}+k))\right]}{\sum_{k=1}^{N/4}\mathrm{Re}\left[r^*(\hat{d}-k)\cdot(-r(\hat{d}+k))\right]}\right] \quad (3)$$

IV. FINE TIMING SYNCHRONIZATION AND INTEGER FREQUENCY OFFSET ESTIMATION

We have found the timing synchronization start point and fractional frequency offset at the previous section, completed frequency compensation, made the correlation operation respectively [6] between the second training symbol and the ZC sequence C, C^* locally generated. Thus, the definition of timing metric function is:

$$\Lambda_i(\theta) = \sum_{m=0}^{N-1} C_i(m)\cdot r(\theta+m)e^{i2\pi\hat{\varepsilon}\frac{\theta}{N}} \quad C_1(m)=C^*(m) \quad C_2(m)=C(m) \quad (4)$$

Correlation peak position is:

$$\hat{\theta}_i = \arg\max(\Lambda_i(\theta)) \qquad i=1,2 \quad (5)$$

Timing position respectively is $\hat{\theta}_1$, $\hat{\theta}_2$.

We make improved algorithms for fine timing synchronization simulation using the same parameters with coarse timing synchronization. The simulation result is shown in Figure 3.

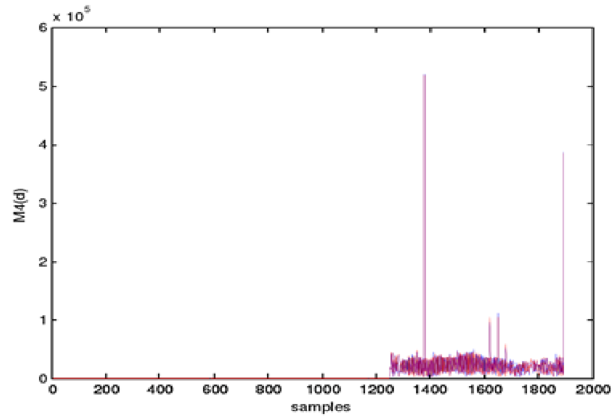


FIGURE III. THE FINE TIMING SYNCHRONIZATION CURVE OF THE IMPROVED ALGORITHM

Timing position is $\hat{\theta}_1$, put it as the back of the border, forward L (cyclic prefix length) points to define search window. Identify the leftmost sampling point $\hat{\theta}_0(\beta=0.1)$ that correlation value is greater than $\beta\Lambda_1(\theta)$ in the search window, you can find the exact position of the timing synchronization:

$$d = \hat{\theta}_0 + \frac{\hat{\theta}_2 - \hat{\theta}_1}{2} \quad (6)$$

Integer frequency offset estimation is as follows:

$$2\xi = \frac{\arg(\Lambda(\hat{\theta}_2)) + \arg(\Lambda(\hat{\theta}_1))}{2} \quad (7)$$

V. SIMULATION

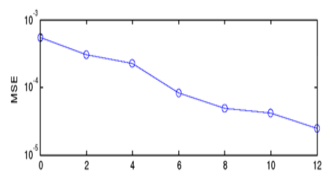
Use simulation algorithm to compare the mean square error between the improved algorithm and SC algorithm[7-8] under Gaussian channel and multipath channel . The simulation parameters are as follows:

TABLE II. THE SYNCHRONIZATION PERFORMANCE SIMULATION PARAMETERS OF THE ABOVE TWO ALGORITHMS

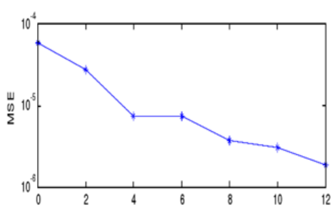
Item	**Gaussian channel**	**Multipath channel**
Modulation	QPSK	/
Sub-carriers number	N=1024	/
Cyclic prefix length	L=120	/
Sampling points delay number	100	/
Channel model	/	5
Each path delay	/	0, 20, 40, 60, 80
Each path Doppler shift	/	50Hz
Each path power delay	/	Negative exponential distribution

Figure 4 is the simulation results of the above two algorithms under Gaussian channel, we find that the improved algorithm's frequency offset estimation algorithm MSE is smaller than the SC algorithm at least an order of magnitude, it also shows that the improved algorithm synchronization performance is better than SC algorithms. Through the above analysis, we know the start point of OFDM symbols of the improved algorithm can find more precise, the timing synchronization is more accurate. After compensation on the basis of fractional frequency offset estimation, it also make the integer frequency offset estimation more precise, and the improvement of the synchronization performance of system is inevitable.

Figure 5 is the simulation results of the two algorithms under multipath channel. You can see the improved algorithm is better than the SC algorithm at least an order of magnitude. Not only that, we also find that with the increase of SNR, SC frequency offset estimation algorithm MSE decay by a big margin, and the improved algorithm MSE remain almost unchanged. This also shows that SC algorithm is better than SC algorithms under the impact of multipath interference.

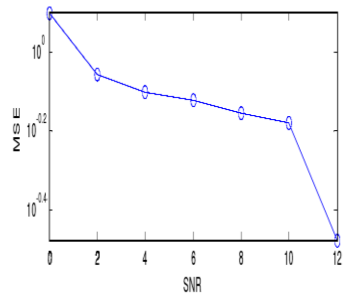


(A) FREQUENCY OFFSET ESTIMATION MSE BASED ON SC ALGORITHM

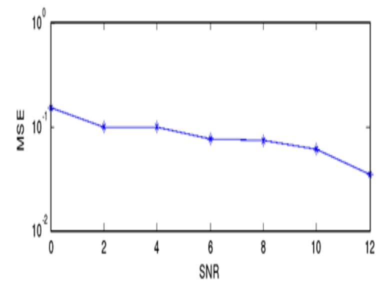


(B) FREQUENCY OFFSET ESTIMATION MSE BASED ON NEW ALGORITHM

FIGURE IV. FREQUENCY OFFSET PERFORMANCE OF THE TWO ALGORITHMS UNDER GAUSSIAN CHANNEL



(A) FREQUENCY OFFSET ESTIMATION MSE BASED ON SC ALGORITHM



(b) FREQUENCY OFFSET ESTIMATION MSE BASED ON NEW ALGORITHM

FIGURE V. FREQUENCY OFFSET PERFORMANCE OF THE TWO ALGORITHMS UNDER MULTIPATH CHANNEL

VI. CONCLUSION

In this paper, we study a improved OFDM synchronization algorithm based on training sequence, propose changing the structure of the training sequence by using ZC sequences and other methods based on the SC algorithm, to improve the coarse timing synchronization accuracy and increase the fractional frequency offset estimation accuracy, but also ensure performance improvements for the fine timing synchronization and integer frequency offset estimation. Under the Gaussian channel and multipath channel, through simulation compared the SC algorithm and the newly proposed algorithm , we find that the synchronization performance of the newly proposed algorithm is better than SC algorithm.

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