Primary Synchronization Signal Low Complexity Sliding Correlation Method

Huahua Wang[1], Dongfeng Chen[1](✉), and Juan Li[2]

[1] School of Communication and Information Engineering, Chongqing University of Posts and Telecommunications, Chongqing 400065, China
chendongfengmr@foxmail.com

[2] School of Science College, Chongqing University of Posts and Telecommunications, Chongqing 400065, China

Abstract. With the development of technology, the mobile communication system has the characteristics of high rate and low delay. How to deal with the signal quickly and accurately has become a research hotspot. As the first step of the mobile communication system, the efficiency and performance of synchronization directly determine the follow-up signal Processing. In the mobile communication system, the terminal needs to synchronize the frequency and time of the received signal, that is, the synchronization signal is captured and processed. Frequency synchronization mainly carries on the digital down-conversion operation to the signal, the time synchronization is mainly through sliding the baseband signal with the locally generated synchronization sequence to determine the starting position of the synchronization signal, so as to achieve the time synchronization. Therefore, in this paper, taking LTE-A (Long Term Evolution Advanced) system as an example, a low-complexity sliding correlation method based on Fast Fourier Transform (FFT) is proposed in this paper, which can significantly reduce the computations in the synchronization process the complexity.

Keywords: LTE-A system · Primary synchronization signal · FFT · Sliding correlation

1 Introduction

LTE-A is an evolved version of LTE (Long Term Evolution). The system parameters of LTE-A are greatly improved compared with LTE, and can provide greater system capacity and lower system delay. With the improvement of LTE-A performance, it has become the new generation of mainstream mobile communication standard after 3G. After the user equipment UE (User Equipment) is powered on, a cell suitable for camping is selected to connect to the LTE-A network, and the base station eNodeB and the UE implement time-frequency synchronization, because the downlink transmission mode of the LTE-A system is OFDM, so this process is equivalent to the process of time-frequency synchronization of OFDM (Orthogonal Frequency Division Multiplexing) system [1–4].

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The primary synchronization signal PSS (Primary Synchronization Signal) implements this process in the LTE-A system. Since the primary synchronization signal is transmitted once every half frame (i.e., 5 ms), only the start position of the half frame in one radio frame can be determined, so the user terminal is not sure whether it is the first half frame or the second half frame [5]. Frame synchronization and cell ID group identification are implemented by a secondary synchronization signal SSS (Secondary Synchronization Signal). After the terminal synchronizes with the cell, the subsequent signal reception processing can be performed. The performance of the entire downlink depends on the synchronization performance. Therefore, as the first step of the cell search synchronization is crucial in the LTE-A system.

In this paper, based on FFT low complexity sliding correlation method, the synchronization signal is captured and processed, the algorithm complexity is reduced, the synchronization efficiency and performance have been improved, and the frequency and time of the received signal can be quickly synchronized.

2 Main Sync Signal

The primary synchronization signal of the LTE-A system uses a ZC (Zadoff-Chu) sequence [6] generation method with good autocorrelation in the frequency domain. This sequence is used to generate PSS [7] in the frequency domain. The three PSSs are distinguished by u, which is generated as follows:

$$d_u(n) = \begin{cases} e^{-j\frac{\pi un(n+1)}{63}} & n = 0, 1, \ldots, 30 \\ e^{-j\frac{\pi u(n+1)(n+2)}{63}} & n = 31, 32, \ldots, 61 \end{cases} \quad (1)$$

The sector number N(2) of the primary synchronization channel has an ID value of 0–2 corresponding to the ZC sequence root number u $\in \{25, 29, 34\}$ [8]. On the frequency, the main synchronization signal occupies a total of 72 subcarriers, the center of the bandwidth is used to allocate its frequency position, and the intermediate DC puncturing is used as the DC carrier. The guard interval occupies 5 resource elements on each side, and no signal is sent at this position. Reserved, its structure is shown in Fig. 1.

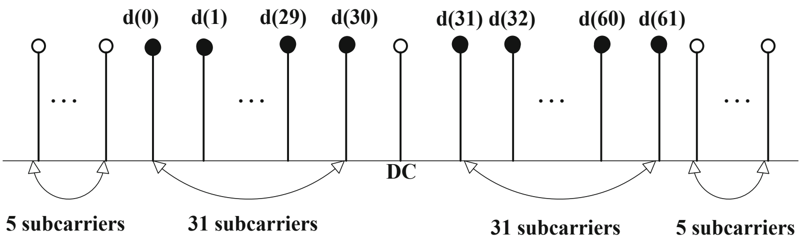

Fig. 1. Mapping of PSS sequence resources

3 Synchronization Algorithm

3.1 Traditional Synchronization Algorithm

The main synchronizing signal sequence has good cross-correlation characteristics, and the receiving sequence and the main synchronizing signal sequence time domain use sliding to complete symbol timing synchronization [9–11]. Three sets of different frequency domain PSS sequences are generated by the root sequence u ∈ {25, 29, 34}, and the relevant expressions are as follows:

$$r(n) = \sum_{m=0}^{N-1} x(n+m)y*(m) \tag{2}$$

In the expression (2), the received radio frame data is represented by x(n), M is a field length, the conjugate of y(n) is represented by y*(k), and the length of the local main synchronizing signal sequence is equal to N. The three sets of correlation results r(n) can be obtained by Eq. (2), and the value of the N(2) ID and the PSS position can be determined by the maximum value of the three sets of correlation results r(n). Because the x(n) sequence is relatively long and requires a large amount of storage space and running time to complete the time domain sliding correlation algorithm, the algorithm robustness [11–15] is lower.

3.2 Segmentation Correlation Synchronization Algorithm

The segment correlation synchronization is implemented by the local primary synchronization signal sequence y(n) and the received radio frame data x(n). The total number of segments is equal to D, and the segment-related synchronization expression is:

$$r(n) = \sum_{l=0}^{D-1} \sum_{m=0}^{N/D-1} x(n+m+Nd/D)y*(m+Nd/D) \tag{3}$$

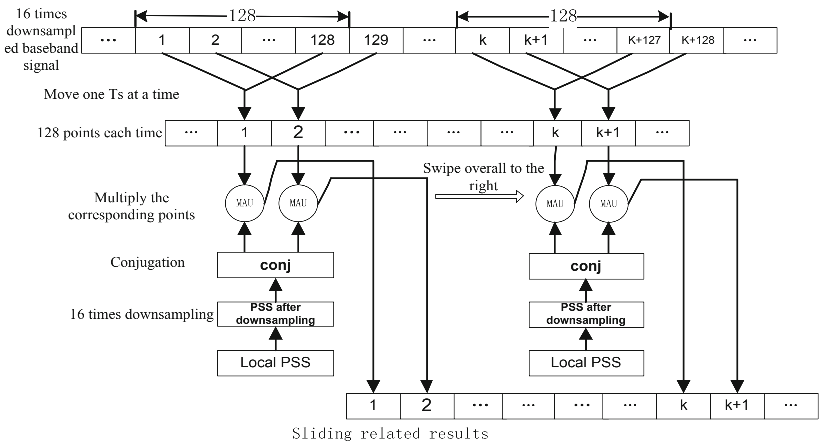

Fig. 2. Traditional sliding correlation method

The traditional sliding correlation method determines the N(2) ID and the position of the PSS by comparing the baseband signal with the local PSS and finding the maximum value of the sliding correlation result by comparison. The specific implementation scheme is shown in Fig. 2. Although the procedure is simple, the computational complexity and the number of correlations increase linearly, and the implementation complexity is still high.

3.3 Improved Low Complexity Sliding Correlation Method

In this paper, a low-complexity sliding correlation method based on fast Fourier transform is proposed. The linear correlation is replaced by the circular correlation theorem. The fast Fourier transform is segmented and transformed, and the fast linear correlation between long and short sequences is completed. The algorithm's anti-frequency offset performance improvement and time complexity are reduced. The method mainly includes six modules: data segmentation, adjacent data segment merging, FFT, corresponding point multiplication, accumulation, and IFFT. The time domain sliding correlation algorithm expression (2) of the main synchronization signal sequence is transformed:

$$r(n) = \sum_{m=0}^{N-1} \mathrm{x(m)} y*(m-n) = x(n) y*(-n) \tag{4}$$

Expression (4) establishes the equivalent relationship between cross-correlation and linear convolution. Calculating the cross-correlation of two sequences is done by calculating the linear convolution method, so that ỹ(n) represents the inversion of y*(n). The circular convolution theorem stipulates that linear convolution is equivalent to circular convolution after zero-complementing operations on x(n) and ỹ(n). Replacing a linear correlation with a circular correlation is equivalent to using a fast Fourier transform method to find a linear correlation, where $\mathrm{L} \geq \mathrm{M} + \mathrm{N} - 1$ and $\mathrm{L} = 2\gamma$ (γ is a positive integer), make:

$$x(n) = \begin{cases} \mathrm{x}(n), n = 0, 1, \ldots, \mathrm{M}-1 \\ 0, \mathrm{n} = \mathrm{M}, M+1, \ldots, \mathrm{L}-\mathrm{M} \end{cases} \tag{5}$$

$$\tilde{\mathrm{y}}(n) = \begin{cases} \tilde{\mathrm{y}}(n), n = 0, 1, \ldots, \mathrm{N}-1 \\ 0, \mathrm{n} = N, N+1, \ldots, \mathrm{L}-\mathrm{N} \end{cases} \tag{6}$$

It can be seen from the circle correlation theorem that if $\mathrm{R(m)} = \mathrm{X(m)}\tilde{Y}(\mathrm{m})$, x(n) and ỹ(n) are respectively represented by X(m), ỹ(m) after fast Fourier transform:

$$r(n) = IDFT[R(m)] = \{\sum_{m=0}^{N-1} \mathrm{x}(m)\tilde{\mathrm{y}}[(m-n)]_N\} R_N(n) \tag{7}$$

It is known from the expression (7) that the cross-correlation operation of the sequence can be performed by the fast convolution method. X(m) and ỹ(m) are obtained by zero-padding and FFT transformation of x(n) and ỹ(n), and R(m) is obtained by multiplying the frequency domain of X(m) and ỹ(m), R(m) After the IFFT transform, r(n) is the first M + N − 1 data.

Because the length M is long, the main synchronizing signal sequence needs to be complemented with zeros, so that long FFT transform is difficult and a large amount of computation is wasted. The above existing problem can be solved by the overlap addition method. First, x(n) is divided into multi-segment sequences of k length, and then the segmentation fast Fourier transform correlation calculation is performed, wherein the i-th segment of the x(n) sequence The sequence is represented by xi(n).

$$\begin{cases} x_i(n) = x(n), ik + 1 \leq n \leq (i + 1)k \\ x(n) = \sum_{i=0}^{M/k-1} x_i(n) \end{cases} \tag{8}$$

After segmentation, the expression (2) is expressed as:

$$\begin{aligned} r(n) &= \sum_{m=0}^{N-1} \left[\sum_{i=0}^{M/M_1-1} x_i(n+m) \right] y*(m) \\ &= \sum_{i=0}^{M/M_1-1} \left[\sum_{m=0}^{N-1} x_i(n+m) y*(m) \right] = \sum_{i=0}^{M/M_1-1} r_i(n) \end{aligned} \tag{9}$$

In the expression (9), the last output sequence r(n) is composed of the superposition of the N − 1 term after ri(n) and the N − 1 term of ri + 1(n).

In order to ensure the integrity of the main synchronization sequence at the time of segmentation, the expressions (7) and (9) can complete the fast correlation of the long and short sequences. Therefore, the superposition method and the fast convolution method can be used to quickly synchronize the frequency domain of the main synchronizing signal symbol.

3.4 Improved Algorithm Flow

The improved timing synchronization of the mobile communication system first segments the received sequence, and then performs adjacent splicing and merging of the adjacent data segments to perform FFT, and then segments, FFTs, and conjugates the local synchronization sequence again, and then receives the sequence. The frequency domain expression is multiplied by the corresponding point of the frequency expression of the local synchronization sequence, and finally the intermediate result is subjected to IFFT processing to obtain a sliding correlation result. Specific steps are as follows:

(1) The received signal is subjected to segmentation processing of length 1024, and the baseband signal is divided into data of a plurality of segments of 1024 lengths.
(2) The data in (1) is merged and merged adjacently, that is, the stitching of 1, 2, 2, 3, 3, 4, and so on.
(3) Perform a 2048-point FFT operation on each piece of data spliced in (2) to obtain a frequency domain expression after the baseband signal is segmented.

(4) The local synchronization sequence is divided into two segments of data of length 1024, each segment of data is subjected to 2048-point FFT processing, and then the conjugate is obtained to obtain a segmentation frequency expression of the local synchronization sequence.
(5) Multiplying the corresponding points of the results obtained by (3) and (4) to obtain the intermediate value of the correlation result.
(6) When calculating the relevant intermediate values of the two or more stitching results, add the adjacent two related intermediate values, and then proceed to (7); otherwise, proceed to (3).
(7) The addition result is 2048 points IFFT, and the first 1024 values are retained as relevant results. Repeat the above steps until the 153600 point (field) correlation values are calculated. The improved main synchronization algorithm flow is shown in Fig. 3.

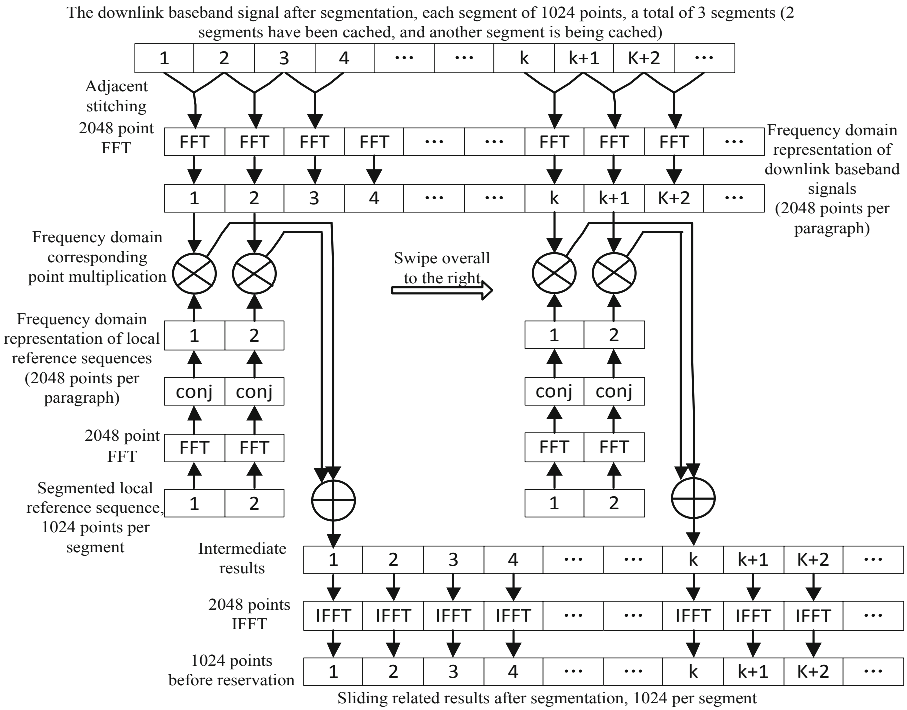

Fig. 3. Improved primary synchronization algorithm flow

4 Experimental Simulation and Analysis

4.1 Time Complexity Analysis

The computational complexity of this paper is mainly concentrated in the two processes of FFT and IFFT. The FFT calculation of N points consists of two parts: the number of complex additions is $N\log_2 N$, and the number of complex multiplications is $\frac{1}{2}N\log_2 N$. Therefore, it is derived that the computational complexity of the algorithm is $o(\mathrm{N}\log_2 \mathrm{N})$. In this paper, the complexity of the algorithm is analyzed. The computational complexity is measured by the number of complex additions and complex multiplications required to find the position of the PSS in one field (153600 points).

Table 1. Half frame data complexity comparison.

Related programs	Complex multiplication	Complex addition
Traditional convolution algorithm	143718400	143718400
Traditional sliding correlation	7697408	14460928
Existing time domain correlation	5948544	13948544

It can be found from Table 1 that the computational complexity of the frequency domain correlation scheme designed in this paper is lower than that of the existing time domain correlation scheme, and there is no backtracking process in the implementation of the project, and the original signal is not stored, and the comparison decision process does not depend on the gate. Limit. The existing time-domain sliding related scheme can further reduce the computational complexity by setting the threshold value, but the signal fluctuation in the actual environment is large, and the threshold setting size will affect the correlation peak. In this paper, the effectiveness and correctness of the algorithm are verified by using simulation and measured data. The detailed simulation system environment configuration parameters are shown in Table 2.

Table 2. Simulation system environment.

System parameters	Parameter value
Channel bandwidth/MHz	20
Sampling frequency/MHz	30.72
FFT points	2048
CP type	Conventional CP
Channel model	AWGN channel

The improved algorithm divides the received sequence into segments and then merges them in the same way, which can reduce the duration and resource consumption in the implementation process. The performance is optimal when the segment length is 1024. Figure 4 shows the performance of the improved algorithm with SNR. The performance curve of the change, the segmentation process of the algorithm when the signal-to-noise ratio is low significantly reduces the time-consuming of the algorithm. It can be seen from the figure that the algorithm is significantly more time-consuming than the traditional algorithm.

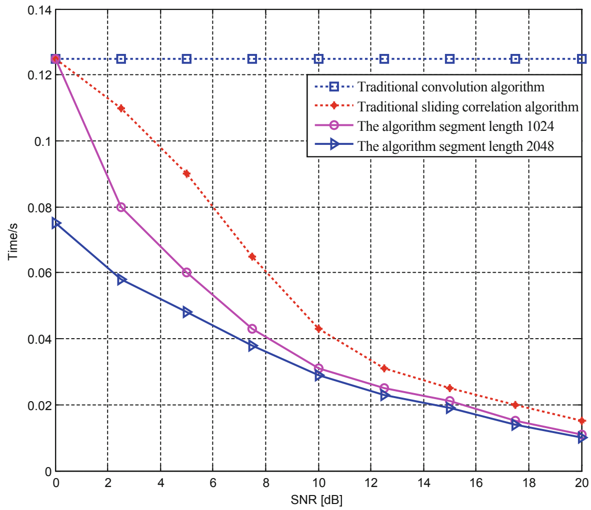

Fig. 4. Time performance comparison

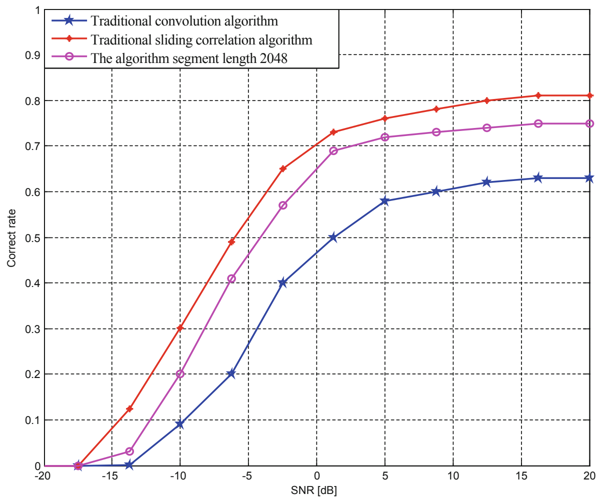

Fig. 5. Comparison of the correct rates of different algorithms

4.2 The Correctness of the Algorithm

Since the scheme designed in this paper does not depend on the threshold setting of the traditional scheme, the scheme has a higher correct signal to noise ratio than the traditional design scheme. It can be seen from Fig. 5 that the method is low in the letter. Better performance under noise ratio.

Figure 6 is a simulation result of correlation results of 4 frames of data length. In the environment where the frequency offset is 0, the signal-to-noise ratio is 0 dB and u = 29, the three sets of correlation results are obtained by the frequency domain fast synchronization algorithm. The symbol timing synchronization correlation results of $u \in \{25, 29, 34\}$ are t0, t2, and t3 in Fig. 5, respectively. It can be clearly observed that t0 and t2 do not show good correlation peaks, and the highest peak of related results does not exceed 4. The correlation result t1 has a distinct peak. In Fig. 5, the peak of t1 drops rapidly, and the correlation peak is close to 9, and the position of the peak is equivalent to the position of the main synchronization signal of the received data.

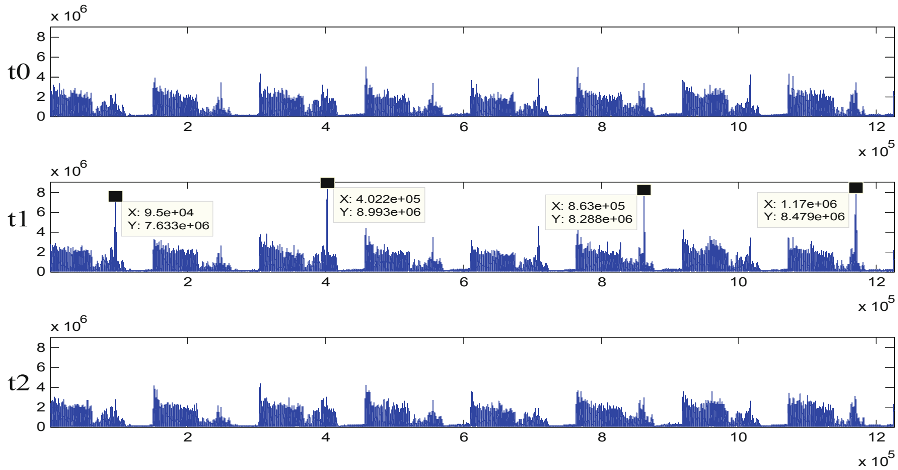

Fig. 6. Local three groups of PSS sequences

The value of the $N_{ID}^{(2)}$ ID and the position of the primary synchronization signal can be quickly and accurately located by the fast correlation method in the frequency domain, and the correctness of the synchronization algorithm is verified.

5 Conclusion

The acquisition and processing of synchronization signals is of utmost importance in LTE-A mobile communication systems, and it plays an important role in the reception and processing of subsequent signals. As the user activity range and the density of the LTE-A base station increase, the two processes of cell handover and cell reselection are performed more frequently. At present, there are some shortcomings in the synchronization algorithm. This paper presents a low-complexity sliding correlation method based on FFT for fast time-frequency synchronization, and the complexity is much lower than the traditional algorithm. This paper verifies the feasibility of the scheme by simulating the algorithm. The algorithm has the advantages of strong synchronization performance and low complexity. Since the cell search in the 5G system environment is also the synchronization process of the synchronization signal, the algorithm can meet the synchronization performance requirements of the future 5G system. The algorithm can be extended to apply. Cell search under 5G system has important reference application value for cell search in 5G environment.

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