Research on Cell Search SSS Timing Synchronization Based on DSP*

Dan Wang[1], Weiping Shi[1]

[1]School of Communication and Information Engineering, Chongqing University of Posts and Telecommunications, Chongqing, China

Abstract - Research on cell search PSS timing synchronization algorithm, according to the Zadoff-Chu sequence character, a low-Complexity timing synchronization algorithm and implementation approach based on SSS is proposed in this paper. Both the theory analysis and simulation results show that the algorithm proposed can reduce computational complexity and it is accurate when frequency offset is existed. The algorithm has been implemented in the TMS320C64xDSP, which satisfy the performance requirements on cell search in TD-LTE system.

Index Terms - TD-LTE, SSS, Timing Synchronization, DSP realization

1. Introduction

In the system of TD-LTE, when the user equipment (UE) power on, it needs to search the surrounding cell first, and then selects the appropriate cell to register. Only the appropriate cell is registered can the UE obtains more detailed information of the cell and the neighboring cell, which is meant to initiate the other physical layer process[1][2]. Therefore, cell search is an important part for the research on LTE (Long Term Evolution).

We need to process the cell search first before the timing synchronization, the conventional timing synchronization main use the symmetry and excellent self-correlation of the PSS. Study found that SSS has a time-domain conjugate symmetry. We can obtain timing synchronization point of the SSS by self-correlation. Meanwhile, this algorithm is able to resist the frequency offset; it can estimate timing synchronization point accurately in the circumstance of frequency offset. It is shown that this algorithm has low complexity and excellent reliability, easy to implement and meets the system performance of the TD-LTE through the theoretical analysis and simulation.

2.1 Synchronization Signal

In the TD-LTE system, the primary synchronization signal is generated by the Zadoff-Chu sequence of the frequency domain. Zadoff-Chu has good self-correlation characteristics. In the TD-LTE system, there are three groups of available primary synchronization signal, distinguished by the root sequence of indication: u.

he primary synchronization signal is generated as follows:

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

the root sequence of indication u are 25、29、34, they are correspond to $N_{ID}^{(2)}$

The secondary synchronization signal sequence $d(0),d(1),\dots,d(61)$ are concatenated by two binary sequence with the length of 31.The concatenated sequence is scrambled by scrambling sequence specified by the primary synchronization signal. For the secondary synchronization signal of the two sequence of length 31 in subframe 0 and subframe 5 are different. Also makes the downlink secondary synchronization sequence differently in these two positions. Formulas are follows:

$$d(2n)=\begin{cases} s_0^{(m_0)}(n)c_0(n) & \text{in subframe 0} \\ s_1^{(m_1)}(n)c_0(n) & \text{in subframe 5} \end{cases}$$
$$d(2n+1)=\begin{cases} s_1^{(m_1)}(n)c_1(n)z_1^{(m_0)}(n) & \text{in subframe 0} \\ s_0^{(m_0)}(n)c_1(n)z_1^{(m_1)}(n) & \text{in subframe 5} \end{cases} \tag{2}$$

Where $0 \le n \le 30$ .the parameters, m1 and m2,were calculated under the provisions of the physical layer cell ID mark. Therefore we can get $N_{\mathrm{ID}}^{(1)}$ once we get m1 and m2.[3]

The primary synchronization signal mapped the third OFDM symbol of the TD-LTE system radio frame to the subframe 1 and subframe 6.The secondary synchronization signal (SSS) is transmitted in slot 1 and slot 11 of the last OFDM symbols. For a variety of different system bandwidth （5、10、15、20MHz）, the synchronizing signal transmission bandwidths are the same, which occupy 1.08 MHz bandwidth of the center band. And the synchronization signal occupies 62 subcarriers. Both sides reserved 5 subcarriers as protective belt. Time-frequency structure shown in Figure 1, the middle DC is punch, as the DC carrier wave. On each side of the guard interval has 5 resource elements, These positions are reserved, do not send any signal.

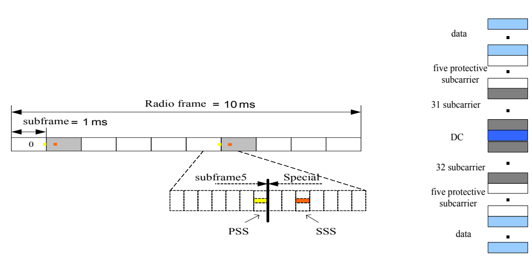

Fig 1 Time and Frequency Resource Map

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2.2 Algorithm analysis and improvement

There are three groups of the master synchronization signal of the frequency domain, the corresponding root sequence of indication u are 25、29、34.Because they are generated by the Zadoff-Chu sequence of the frequency domain, ZC sequence has a good self-correlation. Therefore, with a sequence of directions u corresponding PSS has a good self-correlation. three groups PSS of the frequency domain fill 0, and then performs IFFT change, to obtain the time domain of the three groups of local PSS, and then have the correlation calculating in the received PSS.[4]PSS timing synchronization point and $N_{ID}^{(2)}$ can be determined in accordance with the maximum value of the location and the corresponding root sequence of indication. Although this algorithm is able to calculate the PSS timing synchronization point's location and the $N_{ID}^{(2)}$, but it has large amount of calculation, high complexity, while when receiving the data it needs to open up a larger memory space, and the largest open up space is 153,600 bit. In order to reduce the computational complexity and memory space, we have to improve the performance of PSS timing synchronization.

Frequency domain PSS sequence is Zadoff-Chu sequence. Zadoff-Chu sequence is point-symmetrically according to its characteristic. Zadoff-Chu sequence still has excellent symmetry when PSS sequence was transmitted from the frequency domain into the time domain through IFFT. In actual circumstances, PSS can be made of table and be stored, we can reduce the processing time of the time domain through the way of searching the table. According to the symmetry of PSS, every group of the PSS only needs 1024bit memory space.

According to the characteristic of the PSS analyzed in (1), when we are calculating the timing synchronization position of PSS, we can use its own excellent centrosymmetric results to have a correlation calculating. When the synchronization point of the received PSS is settled, we can have a correlation calculating again between received PSS and three groups of local PSS, to determine the value of $N_{ID}^{(2)}$. It can greatly simplify the complexity of computing. When we settle the synchronization point position of PSS, having a correlation calculating with three groups of local PSS, and then determined the value of $N_{ID}^{(2)}$.we can use the low self characteristic of PSS, but we can not make sure the accuracy in the circumstances of frequency offset.[5-6]

As shown in Fig 2 the SSS signals in the time domain have conjugate symmetry through analysis. We can use the self-correlation of SSS signals to do timing synchronization. The correlation principle is the same as PSS, and it has a slight improvement on the complexity. But we can use the self-correlation of SSS to do timing synchronization, It's not only has low complexity and easier to realize but it can resist the frequency offset easily .To further reduce the complexity of computing. After downsampling the data from the receiving port, we should do self-correlation compute. There is a certain deviation of the SSS down-sampling synchronization point. The deviation is related to the number of downsampling point. While we get coarse synchronization point we can get the position of SSS through the fine synchronization. The PSS synchronization point position can be obtained according to the SSS position of the synchronization point, and then we can have a correlation calculating again between received PSS and three groups of local PSS, to determine the value of $N_{ID}^{(2)}$ according to max value that correspond to the local PSS.

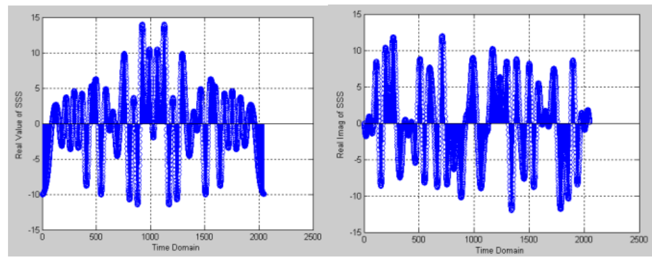

Fig 2 SSS Conjugate Symmetry

The next comparing the performance of the above algorithm, assuming the transmitted signal is $s(k)$, the received signal $r(k)=s(k)e^{\frac{j2\pi\varepsilon k}{N}}$, ε is the normalized frequency offset $k=1,2,3...N-1$. The self-correlation formula of PSS is

$$\begin{aligned} Q_{PSS} &= \sum_{i=1}^{\frac{N}{2}-1} r^{*}(k+i)r(k-i+N) = \sum_{i=1}^{\frac{N}{2}-1} s(k)e^{-\frac{j2\pi\varepsilon(k+i)}{N}} s(k)e^{\frac{j2\pi\varepsilon(k-i+N)}{N}} \\ &= |s(1)|^2 e^{\frac{j2\pi\varepsilon(N-2)}{N}} + |s(2)|^2 e^{\frac{j2\pi\varepsilon(N-4)}{N}} + \cdots + \\ &\left|s(\frac{N}{2}-2)\right|^2 e^{\frac{j2\pi\varepsilon(4)}{N}} + \left|s(\frac{N}{2}-1)\right|^2 e^{\frac{j2\pi\varepsilon(2)}{N}} \end{aligned} \quad (3)$$

SSS has the conjugate symmetry, The self-correlation formula is

$$\begin{aligned} Q_{SSS} &= \sum_{i=1}^{\frac{N}{2}-1} r(k+i)r(k-i+N) = \sum_{i=1}^{\frac{N}{2}-1} s(k)e^{\frac{j2\pi\varepsilon(k+i)}{N}} s(k)e^{\frac{j2\pi\varepsilon(k-i+N)}{N}} \\ &= |s(1)|^2 e^{\frac{j2\pi\varepsilon(N)}{N}} + |s(2)|^2 e^{\frac{j2\pi\varepsilon(N)}{N}} + \cdots + \left|s(\frac{N}{2}-1)\right|^2 e^{\frac{j2\pi\varepsilon(N)}{N}} \\ &= e^{\frac{j2\pi\varepsilon(N)}{N}} \left(|s(1)|^2 + |s(2)|^2 + \cdots + \left|s(\frac{N}{2}-2)\right|^2 + \left|s(\frac{N}{2}-1)\right|^2 \right) \end{aligned} \quad (4)$$

Timing synchronization point is $\hat{k} = \arg \max_{k} \left(|Q(k)|\right)$, the maximum position of $Q(k)$, and $Q(k)$ is Q_{PSS} or Q_{SSS}. [7-8]From the formula (3), when there exists frequency offset, calculating timing synchronization points using PSS self-correlation, the affection of each data after multiplying is different, this will cause erroneous judgement of the maximum and the timing synchronization point is error. However, if using self-correlation of SSS, the affection of frequency offset to each data after multiplying is coincident. There is no influence on the location of the maximum. So the algorithm of SSS is better and which could resist the frequency offset.

Assuming the normalized frequency offset $\varepsilon = 1.33$, calculate the timing synchronization points according to the above three algorithms. After calculating the Mean Square Error of timing synchronization point in different SNR, Fig 2 could be obtained. With the increase of SNR, the MSE of SSS self-correlation algorithm decrease, as can be seen from Fig 3.And the MSE is 0 when the SNR greater than 6, the synchronization points is correct. While the MSE of PSS self-correlation algorithm is also reduced with the increase of SNR, the performance is far inferior to SSS self-correlation algorithm. The cross-correlation algorithm is most affected by the frequency offset, once there is frequency offset the timing synchronization point error will occur.

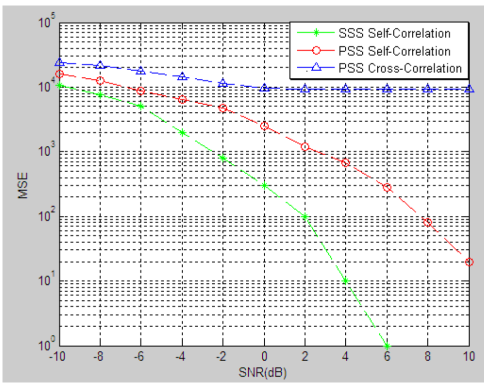

Fig 3 $\varepsilon = 1.33$ the MSE of Synchronization point

3. Implementation Procedure

By the above theoretical analysis, the Implementation flow chart of the timing synchronization of SSS is shown in Fig 4

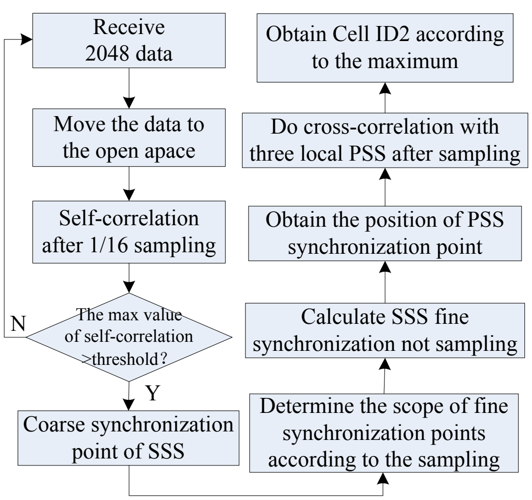

Fig 4 Implementation Flow Chart of SSS Timing Synchronization

（1） the calculation of SSS coarse synchronization point

In order to reduce memory space, we make received data real-time processing. While receiving data, the data conduct correlation calculation. This request that the receive data needs to be done before the arrival of the next data. Creating 4096 words on memory space, and each receive 2048 words of data. After moving the received data to the later 2048 words of memory space, and moving the later 2048 words of memory space to the first 2048 words of memory space, and assuming a counting device to save the PSS coarse synchronization points. The data in the first 2048 words divide into the first 1024 words and the later 1024words and proceeds center symmetry sliding correlation calculation. In the related calculation adopt 1/16 sampling, judge the sum of correlated calculation is greater than the set threshold. If it is greater than the threshold, recording the corresponding position of correlated calculation. And then add the count value of counter, the coarse timing synchronization of SSS is obtained. Continue to calculate the SSS fine synchronization point. If the sum of correlated calculation is less than the set threshold, the data slide 16 words on the basis of the original starting position, and then do sliding correlation calculation at the center of symmetry, adopting 1/16sampling, until find the sum greater than the threshold and record the position $\hat{k}$ .When all the sliding correlation calculation of the current 2048 words are less than threshold, accepting the other 2048 words once again. According to the above steps continue to find the sliding correlation calculation that greater than threshold, and at the same time, the counter adds 2048.

（2） the calculation of SSS fine synchronization point

The location of SSS coarse synchronization point can be obtained by step (1), so a range of SSS fine synchronization point can be determined. Because of the sampling is 16, the scope of SSS timing synchronization point in theory is（$\hat{k}$ -16，$\hat{k}$ +16）. In order to calculate precisely, take 64 before and after the coarse synchronization point as the sliding window of the range of fine synchronization point. The length of fine synchronization point is 2048+128, and making 128 self-correlation not sampling. The fine synchronization point is determined according to the maximum.

（3） the calculation of $N_{ID}^{(2)}$

According to the synchronization point of SSS in (2), we can obtain the synchronization point of PSS. The received PSS adopting 1/16 sampling and three groups of local PSS signals after1/16 sampling make cross-correlation calculation, $N_{ID}^{(2)}$ could be obtained in line with the largest value of the cross-correlation calculation corresponding to PSS.

Complexity Analysis

Because of the position of synchronization signals in up and down half-frame is stationary and the period of PSS is 5ms, using 153600 data calculate the synchronization point when implemented. In order to simplify the calculation, sampling 1/16 is employed in calculation. Table 1 shows the complexity of the above three algorithm. Comprehensive coarse and fine synchronization obtained that the complexity of the algorithm in this thesis is far less than PSS cross-correlation timing synchronization, and it is also improved compared with PSS self-correlation.

Table 1 the complexity

the algorithm name	coarse synchronization（cycle index）	fine synchronization（cycle index）
PSS cross-correlation	9600*128*3	128*2048
PSS self-correlation	9600*64	128*1024+8*3*128
SSS self-correlation	9600*64	128*1024+3*128

4. Analysis of Simulation Result

Through building simulation link to simulate the SSS timing synchronization, in the simulation the bandwidth of system is 5MHz, sub-carrier spacing is 15KHz, the sub-carrier number of OFDM is 2048, normal CP(cyclic prefix), carrier frequency is 2GHz, channel environment is AWGN. Cell ID in transmitting terminal is 1, that is to say $N_{ID}^{(2)}$ is 1, time offset is 0. In TDD mode, the SSS shall be mapped to the last OFDM symbol in slots 1 and 11. So in theory the timing synchronization point in the first half-frame is 30720-2048=28672. Here starting counting from 0, however, in simulation from 1, so the timing synchronization point is 28673. Simulation result as follows.

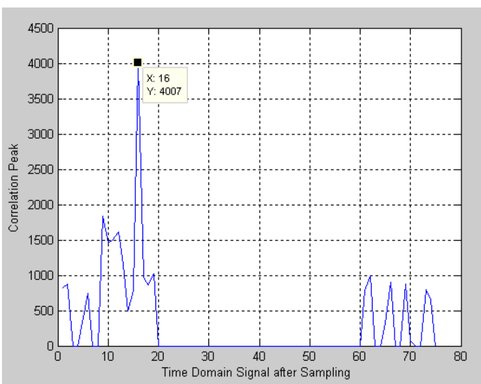

Fig 5 Correlation Peak of SSS Coarse Synchronization

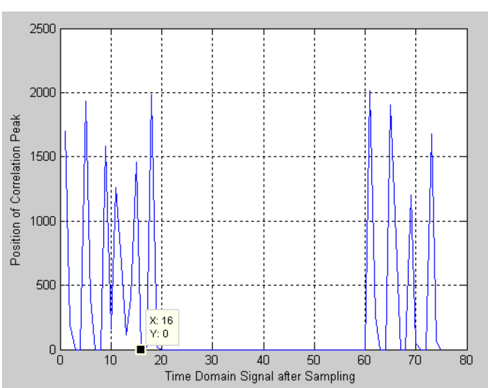

Fig 6 Correlation Peak Position of SSS Coarse Synchronization

Thanks to 2048 data are received at a time, in order to correlation calculation, patching 2048 0 before the first 2048 data. As can be seen from Fig 5 the correlated peak appeared in the 16th group and from Fig 6 the peak in the 0th in the 16th group. The coarse synchronization point is （16-2）*2048+0+1=28673

The above is coarse synchronization calculation. Owing to adopting 1/16 sampling in the coarse synchronization, coarse synchronization point could be error. In order to calculate accurately, the fine synchronization is implemented. The fine synchronization point is obtained and it is 28673-64+64=28673, and it is the same as the position of theory.

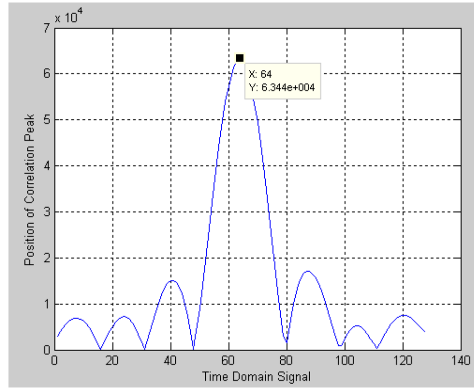

Fig 7 Correlation Peak of SSS Fine Synchronization

5. Summary

Research on Cell Search SSS Timing Synchronization algorithm, according to the SSS sequence character, a low-Complexity implementation approach is proposed in this paper. The algorithm not only can resist frequency deviation but also has lower complexity and it is easier to implement. The performance requirement of cell search algorithm in TD-LTE can be meet. The algorithm has been applied to the development of Terminal RF conformance test instrument in TD-LTE system.

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