Research on Timing Synchronization Algorithm of Cell Search in 5G NR System

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Abstract. For the 5G NR systems in the Third Generation Partnership Project (3GPP), the computation of synchronous signal detection algorithms is very complex. Based on the characteristics of the domain synchronous signal, this paper proposed a differential and superimposed interdependent cross correlation detection algorithm, which only performed a differential interdependent processing of the received signal with the sum of the local PSS sequence to obtain the position of the relevant peak and detects the position of the coarse synchronous point, and further performed local correlation of the coarse synchronous point, and detected the precise synchronous point according to the maximum peak, which reduced the computational complexity. A theoretical derivation and a comparative complexity analysis between the traditional cross correlation and the improved algorithms shows that the differential and superposition cross correlation joint detection algorithm has high efficiency, low complexity and strong resistance to frequency deviation, which meets the synchronization requirements of 5G NR systems.

Keywords: 5G NR system · Timing synchronization · Superposition · Differential

1 Introduction

5G New Radio (NR) is the fifth generation mobile communication technology standard developed by the Third Generation Partnership Project (3GPP) Organization. Since 2019, many countries and regions around the world have launched their own 5G services and 5G has become the mainstream mobile communication standard. The first step of cell search is to realize the detection and reception of Primary Synchronization Signal (PSS) [1]. The accuracy of detection directly affects the establishment of communication links, and 5G NR systems have more stringent requirements for frequency offset. Therefore, the study of timing synchronization algorithms with high precision and low complexity is of utmost importance.

The typical downlink timing synchronization algorithms in Long Term Evolution (LTE) systems includes autocorrelation algorithm based on PSS signal [2],

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interconnection algorithm based on PSS signal [3] and maximum release algorithm based on cyclic prefix (CP) [4–6]. 5G NR systems have more differences than LTE systems, although the algorithms in LTE systems can be used directly. The poor performance is due to the characteristics of 5G NR systems. In this paper, the existing timing synchronization algorithm was improved to meet the requirements of resisting frequency deviation and complexity of 5G NR systems in accordance with the characteristics of 5G NR systems.

In order to solve the problems in 5G NR system, this paper proposed an improved algorithm based on the traditional cross correlation algorithm, which first superimposed local signals into a set of local signals, then differential cross correlation was operated with the received signals to detect the peak, after obtaining the coarse synchronization point and sub-carrier configuration parameter μ, finally the coarse synchronization point before and after down sampling was formed into a sequence that is cross correlated with the local signals to obtain the precision synchronization point and cell group ID. This algorithm can improve the performance of timing synchronization detection against frequency deviation, and effectively reduce the complexity of implementation.

2 PSS

The number of physical cell IDs in 5G NR systems increased from 504 to 1008 and was divided into 336 groups of 3 each is different from LTE.

$$N_{ID}^{cell} = 3N_{ID}^{(1)} + N_{ID}^{(2)} \tag{1}$$

In the formula: $N_{ID}^{(1)} \in \{0, 1, 2, \ldots, 335\}$ is called the cell group ID and the formula $N_{ID}^{(2)} \in \{0, 1, 2\}$ is called the intracell group ID.

In the 5G NR system, the domain synchronous signal does not to use the Zadoff-Chu sequence in the LTE system, although the Zadoff-Chu sequence has good autocorrelation characteristics, its ability to resist frequency deviation is poor, the length of 127 Binary Phase Shift Keying (BPSK) modulation of the M sequence are adopted, which has good autocorrelation characteristics and good cross correlation characteristics.

The master synchronous signal is generated as follows.

$$\begin{gathered} PSS(n) = 1 - 2x(m) \\ m = \left(n + 43N_{\mathrm{ID}}^{(2)}\right) \bmod 127, 0 \le n < 127 \\ x(i+7) = (x(i+4) + x(i)) \bmod 2 \end{gathered} \tag{2}$$

In the formula: x(6) = 1, x(5) = 1, x(4) = 1, x(3) = 0, x(2) = 1, x(1) = 1, x(0) = 0.

3 PSS Synchronization Analysis and Improvement

3.1 Traditional Intercorrelation Algorithm

PSS has had a good cross correlation propety that can achieve timing synchronization by receiving signals directly correlated with local PSS signals [7, 8]. After detecting the relevant peaks, the metric function is.

$$C_{\mu}(n)=\left|\sum_{k=1}^{K} r(k+n)\cdot pss^{*}_{(q,\mu)}(k)\right| \quad q=0,1,2 \tag{3}$$

In the formula: $PSS_{(q,\mu)}(k)$ is the group q PSS signal when the locally generated subcarrier control parameter is μ; $r(k)$ is the received signal.

The PSS coarse synchronization position and intra-cell group ID $N_{ID}^{(2)}$ are obtained by taking the maximum value of the set of three related values:

$$\left\{\widehat{\theta},N_{ID}^{(2)}\right\}=\arg\max_{\{n,\mu\}}\left\{\left|S_{\mu}(n)\right|,n=0,1,2\ldots\right\} \tag{4}$$

3.2 Piecewise Correlation Synchronization Algorithm

In practical applications, there are inevitable problems such as carrier deviation. The traditional cross correlation algorithm can not effectively solve the frequency deviation, the literature [9] proposed a synchronization algorithm related to the PSS signal segmentation, which had good frequency deviation resistance ability in the case of large frequency deviation, the metric function is.

$$C_{\mu}(n)=\sum_{m=0}^{M-1}\left|\sum_{k=0}^{L-1} pss^{*}_{(q,\mu)}(k+mL)\cdot r(k+n+mL)\right|^{2} \tag{5}$$

In the formula: q = {0, 1, 2}, μ = {0, 1, 2, 3, 4}; $r(n)$ is the N-point reception data obtained after narrowband filtering and downsampling, M is the number of segments and L is the length of each segment.

3.3 Improvement and Analysis of Timing Synchronization Algorithm

In order to reduce the complexity of the local interconnection algorithm and improve the frequency deviation resistance performance of the algorithm, this paper improved the traditional cross correlation algorithm and proposed a differential and superimposed interconnection joint synchronization algorithm, which effectively reduced the algorithm calculation volume and improved the cross correlation resistance performance. The overall design flow of the timed synchronous improvement algorithm is shown in Fig. 1.

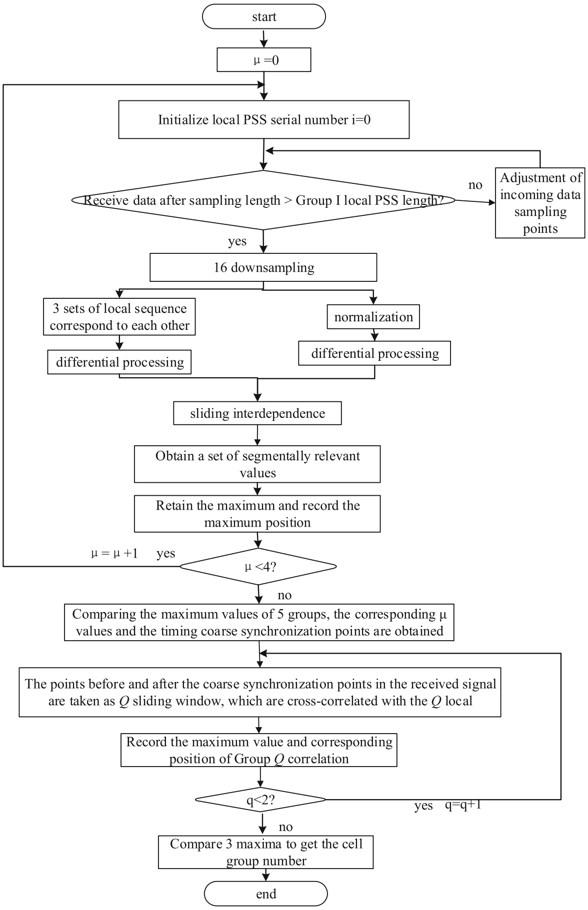

Fig. 1. Flow chart of improved timing synchronization algorithm design

First, the received signal is downsampled from the local PSS signal at 16 times the sampling rate to reduce the computation. As shown in Fig. 2, the coarse synchronization points detected are exactly the same as those obtained by the traditional cross correlation algorithm, and only one cross correlation operation is needed. The three local PSS signals after downsampling were expressed as $PSS_{(0,\mu)}(k)$, $PSS_{(1,\mu)}(k)$ and $PSS_{(2,\mu)}(k)$, respectively. Three sets of local PSS signals are processed by corresponding supersition. The following are the formula:

$$PSS_{\mu}(k) = PSS_{(0,\mu)}(k) + PSS_{(1,\mu)}(k) + PSS_{(2,\mu)}(k) \tag{6}$$

Assuming that there is just frequency deviation in channel and other conditions are perfect, the formula of received signal is.

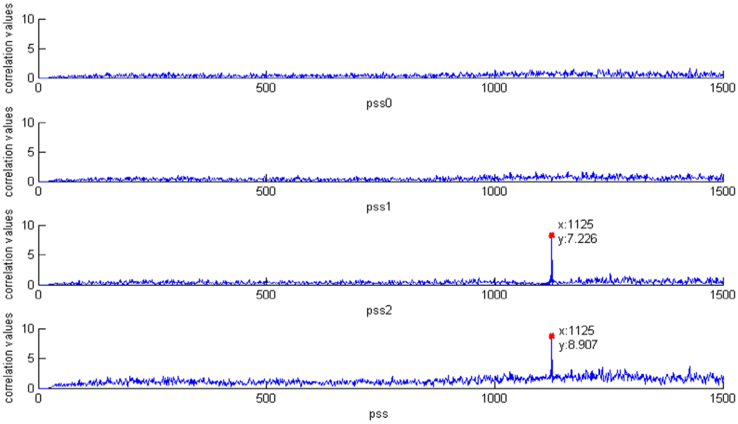

Fig. 2. Correlation between received signal and local pss signal

$$r(n) = s(n)e^{j2\pi\varepsilon n/N} \tag{7}$$

In the formula, $s(n)$ is the transmit signal, $\varepsilon = \Delta f/f_{sc}$ is the normalized frequency deviation, Δf is the value of the frequency deviation between transmit signal and received signal, and f_{sc} is the sub-carrier interval.

The differential cross correlation of the received signal and the superimposed local PSS signal is operated with the following expression.

$$\begin{aligned} C_\mu(n) &= \left|\sum_{k=0}^{K-1} r(k+n)r^*(k+n-1)(PSS_\mu(k)PSS_\mu^*(k-1))^*\right| \\ &= \left|\sum_{k=0}^{K-1} e^{j2\pi\varepsilon/N} s(k+n)s^*(k+n-1)(PSS_\mu(k)PSS_\mu^*(k-1))^*\right| \\ &= \left|\sum_{k=0}^{K-1} s(k+n)s^*(k+n-1)(PSS_\mu(k)PSS_\mu^*(k-1))^*\right| \end{aligned} \tag{8}$$

Compared with the traditional cross-correlation algorithm, the differential cross-correlation algorithm can eliminate $e^{j2\pi\varepsilon/N}$ items and reduce the influence of frequency offset as well as improve the detection performance of timing synchronization.

In the 5G NR system, $\mu = \{0, 1, 2, 3, 4\}$, therefore, five cross correlation is necessary to obtain a set of five maximum peaks and determine the corresponding μ value and coarse synchronization point of the maximum. Here is the formula.

$$\{d, \mu\} = \arg\max\{|C_\mu(n)|\} \tag{9}$$

Although the improved coarse synchronization algorithm can obtain the coarse synchronization position of the PSS in the OFDM symbol, it can not accurately determine the precision synchronization position and ID $N_{ID}^{(2)}$ within the cell group. In order to solve this problem, this paper took the coarse synchronization point before and after Q points in the received signal before sampling as a sliding window, and the three groups of local signals before sampling to do cross correlation. The formula is.

$$R_q^{'}(h) = \sum_{t=1}^{T} \tilde{r}(t+h)\tilde{S}_q^{*}(h) \quad q = 0, 1, 2 \tag{10}$$

In the formula, $\tilde{r}(h)$ is the Q-point sliding sequence before and after the coarse synchronization point; $\tilde{S}_q(h)$ is the local sequence before the three sets of downsampling.

By comparing the three maximum values in the set of related values, the sliding window maximum value position $\hat{\theta}$ can be obtained, and then combined with the coarse synchronization point, the precision synchronization position and the cell group ID $N_{ID}^{(2)}$ can be obtained, the formula is:

$$\{\hat{\theta}, N_{ID}^{(2)}\} = \arg\max\{R_q(h), h = 0, 1, 2, \ldots., 63\} \tag{11}$$

4 Simulation Results

In order to verify the performance of the algorithm, the algorithm proposed in this paper was compared with the traditional cross correlation algorithm, and the simulation is carried out using MATALB software under different conditions, the simulation parameters are shown in Table 1.

Table 1. Simulation parameter table

Parameter	Values
μ	1
Channel bandwidth/MHz	100
Frequency of sampling/MHz	122.88
FFT points	4096
ε	0.2/1.2
Channel model	AWGN channel

Figure 3 and 4 show the correlation peak plots of the conventional cross correlation algorithm at $\varepsilon = 0.2$ and $\varepsilon = 1.2$ respectively, and Fig. 5 shows the correlation peak plots of the improved algorithm of this paper at $\varepsilon = 1.2$. It can be seen in Fig. 3 and 4 that the traditional algorithm has better detection performance at small frequency range, with obvious peak, but at large frequency range, the peak is not obvious and performance is poor, but a comparison between Fig. 4 and 5 show that the improved algorithm still has obvious peak at large frequency range.

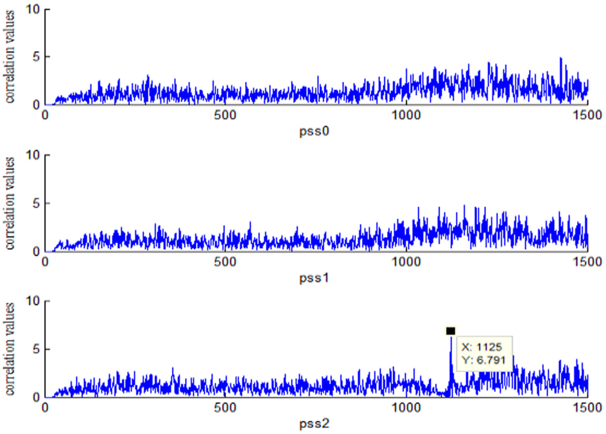

Fig. 3. Peak value of traditional algorithm when ε = 0.2

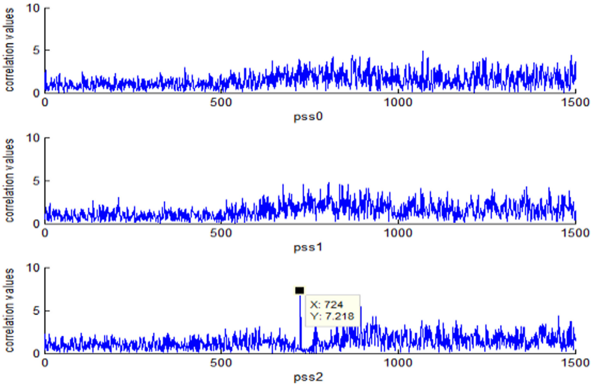

Fig. 4. Peak value of traditional algorithm when ε = 1.2

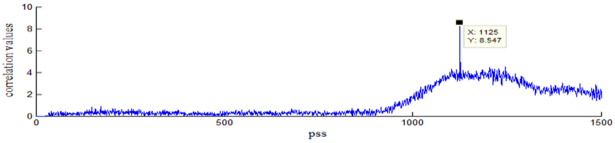

Fig. 5. Peak value of the improved algorithm when ε = 1.2

The calculation above obtained the coarse synchronization point position is 1125 and the corresponding position before the downsampling is 17985. The length of Q point before and after the interception can be shown in Fig. 6, but when $Q = 64$, the detection accuracy rate can reach 1. Figure 7 shows the cross correlation between Q point length of the received signal and three groups of local signals to detect the maximum value of the three groups of related sets and the position is 36. The cell group ID $N_{ID}^{(2)} = 2$ and precision synchronization point position is $17985 - (64/2 - 36) = 17989$.

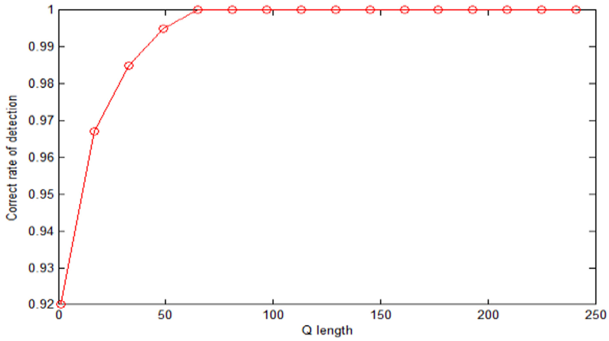

Fig. 6. The accuracy of precision synchronization point detection of main synchronization signals with different Q values

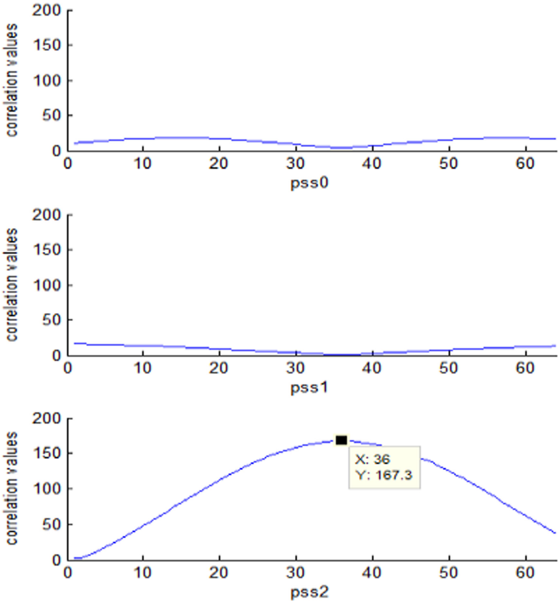

Fig. 7. Precision synchronization point timing position

Figure 8 represents the probability of detection between the improved and inter-related algorithms when $\varepsilon = 0$ and $\varepsilon = 1.2$. It can be seen from the figure that the performance of the improved algorithm in this paper is better than that of the cross correlation algorithm regardless of $\varepsilon = 0$ or $\varepsilon = 1.2$. When the signal-to-noise ratio is constant, the detection probability decreases with the increase of frequency deviation, and when the frequency deviation is constant, the detection probability increases with the increase of signal-to-noise ratio.

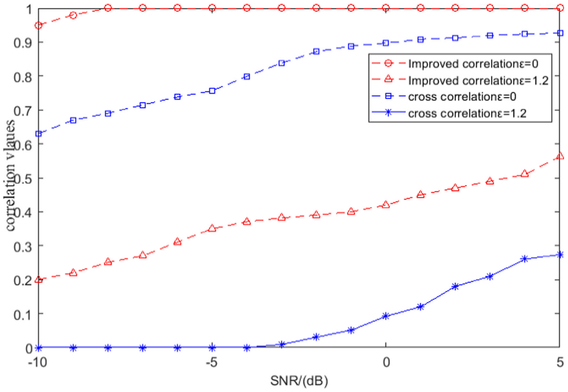

Fig. 8. Detection probability of different ε values for different algorithms

In 5G systems, there are five different cases of μ values, and in this paper, μ values, intra-cell group IDs, and timing synchronization points are determined by comparing with the peak sizes of 15 sets of related sequences. In the synchronization process, the computational complexity of the different algorithms is analyzed when $\mu = 1$, sub-carrier interval 30 kHz, sampling frequency 122.88 MHz. Data of 38400 point lengths in the post-downsampling half frame were selected for comparative analysis. The complex multiplication and complex addition calculations of the traditional cross correlation algorithm are 29753344 and 29634048 respectively. In this paper, the computational quantities of complex multiplication and complex addition of the improved algorithm are 10092544 and 10050048 respectively. The detailed computational complexity data are shown in Table 2. As can be seen from the table, the number of operations of the improved algorithm complex multiplication and complex addition is reduced by 66.47% and 66.09% compared to the traditional cross correlation algorithm. From the overall amount of computation, it can be concluded that the algorithm in this paper has a 66.28% reduction in computation compared to the traditional correlation algorithm.

Table 2. Calculation complexity analysis and comparison

Method	Multiplication	Addition	Sum
Traditional correlation algorithm	29753344	29634048	59387392
Improved algorithm	10092544	10050048	20142592

5 Conclusion

In this paper, we improved the PSS timed synchronization algorithm through the analysis of the characteristics of PSS sequences and the shortcomings of the traditional synchronization algorithm. We propose the differential and superposition correlation joint detection algorithm, and design a detailed timed synchronization detection algorithm based on this algorithm. Among them, the computational complexity of the algorithm is reduced about 66% compared with the traditional cross correlation algorithm and fast correlation detection can be achieved in case of large frequency deviation conditions. The simulation results show that in the AWGN channel, the probability of detection of the improved algorithm is significantly improved compared to the traditional cross correlation algorithm with a large frequency shift, and it needs less computation, besides, it is much easier to implement. The simulation is performed only under the AWGN channel. Readers can evaluate it under different channel environments and simulation parameters.

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