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Improved Algorithm of LTE Random Access Preamble Detection under the High Speed Condition

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Abstract

This paper improves the algorithm of preamble detection in LTE system random access under the condition of high speed. Improved algorithm mainly adopts peak filter to estimate noise and to set dynamic threshold, concerning that the constrained cyclic shift ZC array used in high speed subdistrict accumulate the useful correlated energy in incoherent way in order to avoid missing condition caused by frequency offset to increase detection rate.

Keywords: *cyclic shift array, threshold, peak detection*

1. Introduction

Random access performance in LTE system rely a great extent on detection of preamble. In random access, users send their preamble at first and only correctly detecting preamble could carry out random access process. Performance requirements of LTE system demand the support of its high-speed subdistrict, with the advent of the era of high-speed rail, and the demand of access performance under high speed environment of users is increasingly urgent. This paper improves preamble detection algorithm aimed at random access performance demand of high-speed subdistrict [1].

2. Generation of Random Access Preamble

LTE adopts different cyclic shift ZC array version to expand the original version and this cyclic shift ZC array is called CS-ZC array which is [2],

$$\begin{cases} x_u(n) = \exp\left(-j\dfrac{\pi up(p+1)}{N_{zc}}\right), 0 \le n \le N_{zc}-1 \\ p = (n + C_v) \bmod N_{zc} \end{cases} \quad (1)$$

$$\begin{cases} C_v = v \cdot N_{cs}, v = 0,1,\cdots \lfloor N_{zc}/N_{cs} \rfloor - 1, \quad \text{low - speed} \\ C_v = S \cdot \lfloor q/L \rfloor + q_{\bmod L} \cdot N_{cs}, q = 0,1,\cdots,(P \cdot G + R - 1), \quad \text{high - speed} \end{cases} \quad (2)$$

Under the environment of low-speed, N_{cs} is cyclic shift value v is a cyclic shift version generated by an original root array and its total amount is $\lfloor N_{zc}/N_{cs} \rfloor$. Aiming at frequency offset characteristic of ZC array under the high-speed moving condition, high-speed cyclic shift array set is constructed which mainly changes cyclic shift C_v. The definition of cyclic shift and expression of impact parameter d_u are as follows,

$$d_u = \begin{cases} u^{-1} \bmod N_{zc}, 0 \le u^{-1} \bmod N_{zc} < N_{zc}/2 \\ N_{zc} - u^{-1} \bmod N_{zc}, N_{zc}/2 \le u^{-1} \bmod N_{zc} \end{cases} \quad (3)$$

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Among this expression, the introduced parameter of cyclic shift is determined by d_u, which can divide into 3 conditions,

When $N_{cs} \le d_u < N_{zc}/3$, $L=\lfloor d_u/N_{cs} \rfloor, S=2d_u+L\cdot N_{cs}, G=\lfloor N_{zc}/S \rfloor$, $R=\max(\lfloor (N_{zc}-2d_u-G\cdot S)/N_{cs} \rfloor, 0)$

When $N_{zc}/3 \le d_u \le (N_{zc}-N_{cs})/2$ $L=\lfloor (N_{zc}-2d_u)/N_{cs} \rfloor, S=N_{zc}-2d_u+L\cdot N_{cs}, G=\lfloor d_u/S \rfloor$, $R=\min(\max(\lfloor (d_u-G\cdot S)/N_{cs} \rfloor, 0), L)$

When d_u is in other conditions, only root array is used and don't use deviation form which means C_v doesn't exist.

3. Traditional Preamble Detection Algorithm

The detection principle of random access preamble is to correlate the code array of cyclic shift searching window corresponding to each cyclic shift between the received code array and the local root array and to judge the correlated peak value, preamble information would be confirmed if successfully judged. Figure 1 is the detection model of random access preamble. Receive port extracts 839 point RACH signal to correlate which is to transform signal and local storied mother code array to frequency domain to make conjugate multiplication and then transform it to time domain. According to constant amplitude properties of ZC array, its modular square is 1. Take M antenna received and processed signals to obtain modular square and then make incoherent combination, at last carry out the corresponding peak detection [3].

Principle of traditional peak detection is to detect correlated value between different cyclic shift of every root array and received preamble, and RACH signal detection is succeed if correlated value exceeds certain detecting threshold. Moreover, correlated peak value corresponding to a time sampling point is timing information and it is assumed to be noise if the value doesn't exceed detecting threshold [4].

With regards to low speed subdistrict, its cyclic shift doesn't lie in limited centralization and different cyclic shift corresponding to correlated peak is integer times of N_{cs}. So, constructing a searching window with the length of N_{cs}, when the ratio of one correlated value from the window and noise power exceeds detecting threshold, detection is to be considered successful. According to that cyclic shift and current root array calculating the preamble of sending port, eNodeB completes one random access.

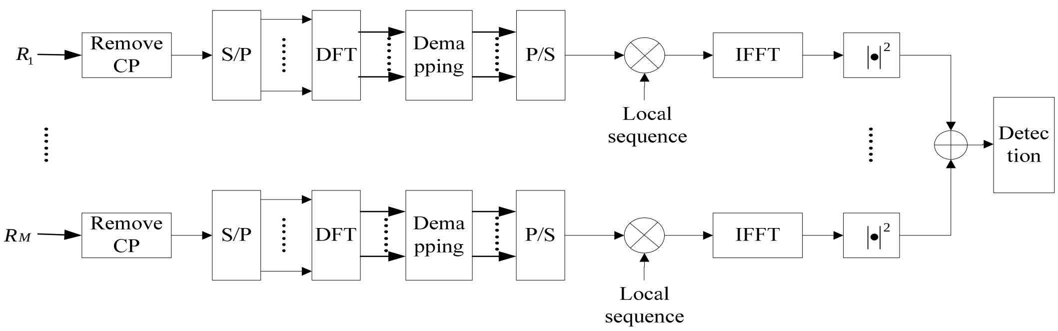

Figure 1. Random Access Preamble Received and Detection Model

Regarding high speed subdistrict, cyclic shift lies in limited centralization and each user is distributed three period cyclic shift areas which separately are $C_v \pm d_u$ and C_v, moreover, three shift areas corresponding to the places of searching window are different. Thus, under high speed environment, in order to avoid effect of Doppler frequency shift, synthetic detection of three correlated windows need to carry out which means that if any window has the correlated value satisfying detecting threshold the detection is successful. However, if all three correlated windows don't detect the correlated value, the range of searching window will enlarge to the width of 3 windows to search, on this condition, detection is successful if there exists correlated value satisfying the threshold or else the noise is assumed.

4. Preamble Detection Improved Algorithm

Improved algorithm is to make effective estimation of noise of received signal and multi-use interference, according to the power estimation of noise and interference, first filter useful correlated value and then estimate the noise and interference, and threshold is dynamically confirmed according to whether there exists useful power or not. Concerning with useful correlated power, incoherent combination of power can detect to avoid missing detection generated from peak power shift caused by frequency offset. The specific algorithm is as follows.

The base station received the preamble array version number selected by users is (u,v) signal, and the m antenna received signal at the receiving port is [5, 6]:

$$r_m(n) = \sum_{i=1}^{\theta} \left\{ s_{u_i,v_i}(n) \otimes \sum_{l=1}^{L_{i,m}} h_{i,m}^l \delta(n - \tau_{i,m}^l) \right\} + w_m(n) \tag{4}$$

$n = 0, \cdots, N-1$, $\tau_{i,m}^l$ is the delay of i user in the m antenna of the first route, $w_m(n)$ is additive white Gauss noise which its mean value is 0 and variance is σ_w^2. We adopt the frequency domain detection model in figure 7, after making conjugate multiplication to relative operations in frequency domain then transform into time domain. To simplify algorithm instruction, we adopt ideal channel without considering the decline and delay. Relative expression is [7-9]:

$$corr_m(\Delta) = \sum_{n=0}^{N-1} r_{u,v}(n) \cdot x_q^*(n+\Delta) \tag{5}$$

$$= \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} R_m(k) \cdot X_q^*(k) \cdot \exp[\ j \frac{2\pi k}{N} \cdot \Delta\ ] \tag{6}$$

Expand the relative expression into 3 parts,

$$corr_m(\Delta) = \Phi_{\mathrm{I}} + \Phi_{\mathrm{II}} + \Phi_{\mathrm{III}} \tag{7}$$

And $\Phi_{\mathrm{I}} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \left| X_{u,v}(k) \right|^2 \cdot \exp[\ j \frac{2\pi k}{N} \Delta\ ]$

$$\Phi_{\mathrm{II}} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_{u,v}(k) \cdot X_{q,p}^*(k) \cdot \exp[\ j \frac{2\pi}{N} \Delta\ ]$$

$$\Phi_{\mathrm{III}} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} W(k) \cdot X_{q,p}^*(k) \cdot \exp[\ j \frac{2\pi}{N} \Delta\ ]$$

Φ_{I} means self-correlated item with the local same array, Φ_{II} is cross correlated item of received signal and other index arrays, Φ_{III} is correlated interference item generated from array and noise.

Step 1: give correlated value modular square. Modular square of correlated value of the mantenna is expression (8),

$$\left| corr_m(\Delta) \right|^2 = \left| \Phi_{\mathrm{I}} + \Phi_{\mathrm{II}} + \Phi_{\mathrm{III}} \right|^2 \tag{8}$$

Due to the existence of $\left| \Phi_{\mathrm{I}} + \Phi_{\mathrm{II}} + \Phi_{\mathrm{III}} \right|^2 \le \left| \Phi_{\mathrm{I}} \right|^2 + \left| \Phi_{\mathrm{II}} + \Phi_{\mathrm{III}} \right|^2$, we mainly investigate the influence of the correlated peak by the interference and the noise. $\left| \Phi_{\mathrm{I}} \right|^2$ is self-correlated peak value, $\left|\Phi_{II} + \Phi_{III}\right|^2$ is cross correlated interference item and the power of the noise item, in Φ_{III} local array $x_q(n)$ and white noise signal are mutual independent and don't change by its Gauss distribution property. With the increase of users, cross correlated interference power of interference item is increasing. From the central limit theorem, we know that $\Phi_{II} + \Phi_{III}$ also approach to Gauss distribution.

With Gauss distribution A satisfying mean value is 0 and variance is σ^2, $|A|^2$ obeys the chi-square distribution with 2 freedom and the probability of exceeding η' is $f\left(|A|^2 > \eta'\right) = e^{-\eta'}$. $\Phi_{II} + \Phi_{III}$ is approximate Gauss distribution and the received mean power of every antenna is [10]:

$$\sigma_{mean}^2 = \frac{1}{MN}\sum_{\Delta=1}^{N}\sum_{m=1}^{M}\left|\Phi_{II} + \Phi_{III}\right|^2 \tag{9}$$

$$f\left(\sum_{m=1}^{M}\left|\Phi_{II} + \Phi_{III}\right|^2 > \eta\sigma_{mean}^2\right) \approx e^{-\eta}\sum_{k=0}^{M-1}\frac{\eta^k}{k!} \tag{10}$$

In receiving part, the accumulated value of power of m received antennas interference and noise is $\sum_{m=1}^{M}\left|\Phi_{II} + \Phi_{III}\right|^2$, if the value larger than the threshold limit $\eta\sigma_{mean}^2$ will cause false warning. According to 3GPP TS36.104 standard, object false warning probability normally less or equals with 10^{-3} which means $P_{fa} = f\left(\sum_{m=1}^{M}\left|\Phi_{II} + \Phi_{III}\right|^2 > \eta\sigma_{mean}^2\right) \le 0.001$. When the number of antenna is 2, the value of η is 9.2.

Step 2: set $\tilde{G} = \eta\sigma_{mean}^2$ as the interference noise threshold and filter the signal power exceeded this threshold in sampling point. The sampling point set of the rest power is ψ, then calculate the mean value of the noise and interference lower than the threshold and this value is the interference noise estimation: $\tilde{\sigma}_{mean}^2 = \underset{\Delta\in\psi}{mean}\left|\sum_{m=1}^{M} corr(\Delta)\right|$.

Step 3: make coherent accumulation of the correlated value which is higher than the interference noise threshold $P = \sum_{\Delta\notin\psi}\left|\sum_{m=1}^{M} corr(\Delta)\right|$ and judge P. The threshold value of peak detection is $G = K\tilde{\sigma}_{mean}^2$, when P is bigger than G the detection is successful and K is threshold value.

Selection of threshold value is mainly to balance false warning probability and missing detection probability, if we purse to reduce the false warning probability resulted in missing detection of useful signal, certainly the missing detection probability will increase. To keep both missing detection probability and false warning probability at about 0.1%, the range of *K* is about between 0.5 and 1.5, in this paper K is 1.2.

Table 1. Parameters of Simulation Platform

simulation parameters	value
simulation bandwidth	5MHz
carrier spacing	1.25KHz
antenna array	1*2
channel model	TU6
UE speed	120Km/h
simulation times	500

Verify the improved detection algorithm of random access preamble and the simulation uses LTE downlink simulation platform. Specific simulation parameters are shown in table 1 and the simulation result is in Figure 2.

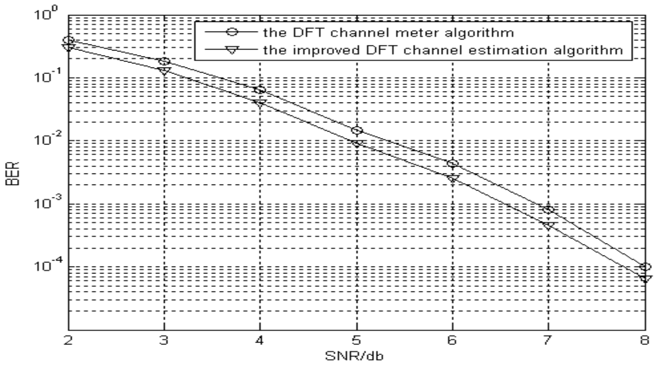

Figure 2. In High Speed Condition Comparison of Traditional and Improved Algorithm

When SNR is low, the missing detection probability of improved algorithm is apparently lower than traditional algorithm. When missing detection probability reaches 10^{-3}, improved algorithm is better than traditional algorithm about 0.3dB. Because in the moving speed of 120Km/h, the limited affect of high speed moving environment to cyclic shift array shows out. With the high-speed subdistrict, using traditional algorithm of preamble detection needs to detect 3 searching windows. If detecting fails, we need to combine and expand searching windows to detect again which makes the detection of receiving port more complicated. Moreover, caused by frequency offset, the correlated peak power transferring is possibly to make all the correlated peak values of 3 correlated windows are lower and it is more easily to cause missing detection. Detection from the improved algorithm effectively avoids this situation.

5. Conclusion

In the process of LTE random access preamble detection, aiming at high-speed subdistrict, because the influence of Doppler frequency offset, when the correlated power transfers to the false peak, if power values of 3 correlated windows compare mean value, it is possible to recognize to be noise. The improved algorithm is to make interference noise estimation after filtering the maximum peak value and to combine the useful power of the correlated windows to effectively avoid missing detection generated by power shifting caused by frequency offset.

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