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Cell Search and Uplink Synchronization in LTE

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Abstract—In LTE User Equipment (UE) must be able to do cell search, initial synchronization and random access procedure for downlink and uplink access. To perform cell search, and initial synchronization, two synchronization signals, Primary Synchronization Signal (PSS) and Secondary Synchronization Signal (SSS), are periodically transmitted from the base station in the LTE system. Using these two signals and making use of the properties of Zadoff-Chu (ZC) and Pseudo-Noise (PN) sequence, the mobile unit will determine on which of the available cell sites it should lock into and it acquires time and frequency synchronization. After UE will do random access procedure using Physical Random Access Channel (PRACH). An appropriate design of PRACH preamble is essential to provide frequent enough random access opportunities and an accurate UE synchronization estimation to adapt to different cell ranges and network conditions without using unnecessary resources. This paper presents the complete LTE access procedure and more about PRACH implementation and detection. Then the performance of the PRACH synchronization procedure under different parameter settings is compared in a typical scenario of LTE.

Index Terms— Cell search, Initial synchronization, Pseudo-noise, PRACH, LTE, PSS, SSS, Zadoff-Chu.

1 Introduction

LTE is the brand name for emerging and developed technologies that comprise the existing 3G and 4G networks.

In cellular communication systems the UE must be able to perform initial synchronization and search for a base station to set up the downlink access. This process is called initial cell search. For the case of broadband wireless access, it is very important that the UE has to perform time and frequency synchronization procedures, containing detecting frame arrival and searching for a cell base station which is qualified to serve the UE when setting up the downlink transmission. To accomplish the operations mentioned above, PSS and SSS are periodically transmitted from base station in the 3rd Generation Partnership Project Long Term Evolution (3GPP LTE) system. There are 504 cell identities (cell IDs) defined and packed into 168 cell ID groups such that each cell ID group contains three sectors. After PSS and SSS detection UE will determine the radio cell ID and it is synchronized in time and frequency with the radio cell. Now the UE is ready to receive downlink broadcast data from the radio cell. After this step UE will detect System Information Block (SIB) which is broadcasted through Physical Broadcast Channel (PBCH). From this, the UE will detect the PRACH parameters which are needed to generate PRACH preamble for random access procedure. The complete LTE access procedure is shown in Fig. 1.

A UE can only be selected for uplink transmission if it is time-synchronized. The main role of the Random Access (RA) procedure is to request for uplink resources, and to do so it is necessary to assure such time alignment for a UE which either has not yet acquired, or has lost its uplink synchronization due to a new connection request, connection recovery, a handover, a tracking area update, etc. Therefore PRACH becomes a key factor between non-synchronized UEs and the orthogonal LTE uplink access scheme. An appropriate PRACH design means providing frequent enough RA opportunities and an accurate UE synchronization estimation. Besides, PRACH must adapt to different cell ranges and network conditions, such as traffic, propagation delay, and UE mobility, but without using unnecessary resources, which would lead to a decrease in uplink channel capacity. All these requirements make a robust PRACH design be a very complex procedure.

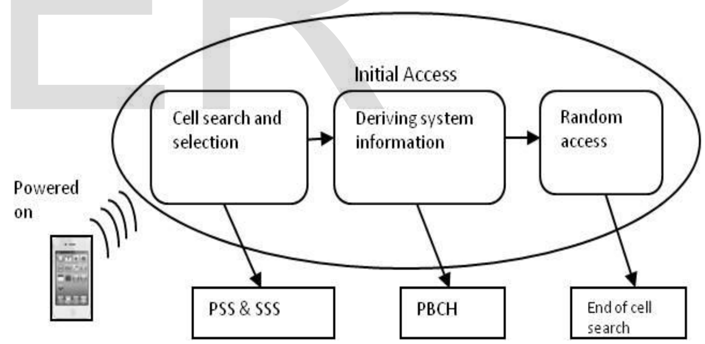

Fig. 1. The LTE Access procedure

There is a wide range of references about PRACH in LTE mainly focused on providing a detailed explanation of 3GPP specifications. There is also a contribution about cell search and RACH preamble parameters. However, literature lacks of relevant studies on complete access procedure and PRACH design oriented to facilitate network optimization. This paper explains the complete LTE access procedure and LTE PRACH design which can be used for real networks.

The article is organized as follows: Section II briefly explains the initial synchronization and cell search procedure. Section III provides a detailed description of random access procedure and PRACH preamble design. Section IV states the field data assumptions and gives the simulation results. Section V summarizes the main conclusions from this study and simulation results.

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2 Cell Search and Initial Synchronization

There are 504 unique physical-layer cell IDs in the LTE system. The cell IDs are grouped into 168 unique cell ID groups, each group contains three unique sector numbers. A physical layer cell identity $N_{ID}^{cell} = 3N_{ID}^{(1)} + N_{ID}^{(2)}$ is thus uniquely defined by the number $N_{ID}^{(1)}$ in the range of 0 to 167, representing the cell ID group, and the number $N_{ID}^{(2)}$ ranges from 0 to 2, representing the sector number within the cell ID group. A dedicated synchronization channel (SCH) is specified in the LTE standard for transmitting two synchronization signals, PSS and SSS. Within the SCH, both synchronization sequences are mapped onto 62 subcarriers located symmetrically around the DC subcarrier.
The PSS is based on Zadoff-Chu sequence which is a Constant Amplitude Zero Auto Correlation (CAZAC) sequence. Three root indexes are defined for PSS as 25, 29 and 34 corresponds to sector ID 0, 1 and 2. The complex value at each position (n) of each root Zadoff-Chu sequence (u) given in (1).

$$x_u(n) = e^{\left(-j*\pi*n*\frac{(n+1)}{N_{zc}}\right)} \quad (1)$$

where $0 \le n \le N_{zc}$, N_{zc}= length of sequence.

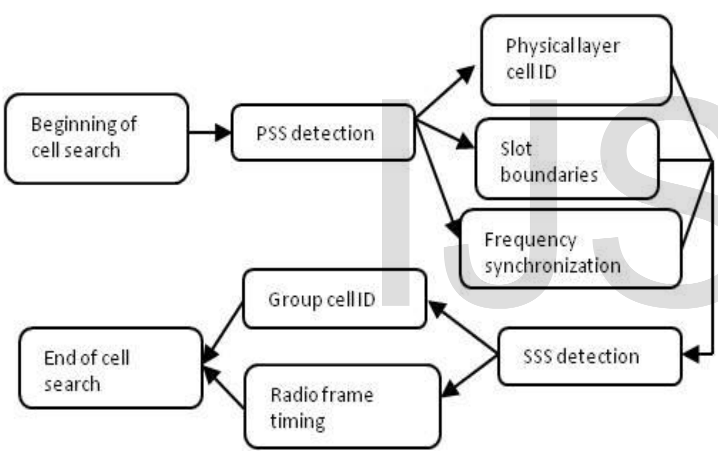

Fig. 2. Cell search and initial synchronization procedure

The synchronization signals are transmitted periodically, twice per 10 ms radio frame. In a FDD cell the PSS is always located in the first and 11th slots of the last OFDMA symbol within the radio frame, thus enabling the UE to acquire the slot boundary timing independently of the CP length. The SSS is located in the symbol immediately preceding the PSS. This design enables coherent detection of the SSS relative to the PSS, which is based on the assumption that the channel coherence duration is significantly longer than one symbol

A total of four possible SSS positions must be checked if the UE is searching for both FDD and TDD cells. Symbol boundaries are first detected by a correlator that detects the peak correlation between the CP and its delayed replica in each OFDMA symbol. In the frequency domain, the synchronization sequences occupy six blocks of resources (1 RB = 180 kHz), allowing an invariant allocation to band system (which can vary from 6 to 110 RBs). A Resource Block consists of 12 sub-carriers, which makes 72 sub-carriers for PSS. However, as the sequence length is 62 symbols both synchronization sequences are mapped into 62 subcarriers located symmetrically around the DC sub-carrier. A set of 10 sub-carriers are left unfilled, allowing a 64 fast fourier transform and a lower sampling frequency to be used for the synchronization process.

Considering the transmission of the system, PSS sequences are converted from the frequency domain to the time domain by a Discrete Fourier Transform (DFT). The transmission over a multipath propagation channel with Additive White Gaussian Noise (AWGN) introduces a Carrier Frequency Offset (CFO) due to differential velocity between platforms and frequency misalignment between transmitter and receiver oscillators. From a User Equipment point of view, the selected root combination satisfies time domain root symmetry, knowing that the sequences 29 and 34 are complex conjugates of each other and can be detected with a single correlator, thus allowing some complexity reduction. The UE must detect the PSS without any a priori knowledge of the channel, so that a non-coherent correlation is required for PSS timing detection.

$$Normalized\ detection = \frac{m_u^*}{\frac{1}{N}\sum_{i=0}^{N-1} s(i-m)y(i)} \quad (2)$$

Where the denominator of (2) is the linear cross correlation, of the replica signal s(i) with the maximum peak detected and the received signal y(i). The results obtained in the detector define the root selected each 5 ms, when the emitted sequence is the root u = 25, and the received signals are affected by AWGN, a multipath propagation channel and frequency offset. After the UE has found the 5 ms timing, the second step is to obtain the radio frame timing and the cells' group identity. This information can be found from the SSS. The process starts with the generating a basic pseudo noise sequence (m-sequence) from which the two sequences are produced. The two sequences are scrambled with $N_{ID}^{(2)}$ and $N_{ID}^{(1)}$ related parameters. After that, the sequences are interleaved into a 62-length sequence, which represents the SSS sequence (3), (4). The combination of the two length-31 sequences defining the SSS differs between slot 0 and slot 10.

$$\begin{aligned} d(2n) &= s_0^{(m0)}(n)c_0(n) \quad in\ subframe\ 0 \\ &= s_1^{(m1)}(n)c_1(n) \quad in\ subframe\ 5 \end{aligned} \quad (3)$$

$$\begin{aligned} d(2n+1) &= s_1^{(m1)}(n)c_0(n)z_1^{(m1)}(n) \quad in\ subframe\ 0 \\ &= s_0^{(m0)}(n)c_1(n)z_0^{(m1)}(n) \quad in\ subframe\ 5 \end{aligned} \quad (4)$$

The indices m0 and m1 are derived from the physical layer cell group $N_{ID}^{(1)}$ according to [2]. The two sequences $s_0^{(m0)}(n)$ and $s_1^{(m1)}(n)$ are defined as two different cyclic shifts of the m-sequence $\tilde{s}(n)$ according to (5).

$$\begin{aligned} s_0^{(m0)}(n) &= \tilde{s}\big((n+m_0)mod31\big) \\ s_1^{(m1)}(n) &= \tilde{s}\big((n+m_1)mod31\big) \end{aligned} \quad (5)$$

Where $\tilde{s}(i) = 1 - 2x(i), 0 \le i \le 30$ is defined by

$$x(\tilde{\imath}+5) = \big(x(\tilde{\imath}+2) + x(\tilde{\imath})\big)mod2, 0 \le \tilde{\imath} \le 25 \quad (6)$$

with initial conditions $x(0) = 0, x(1) = 0, x(2) = 0$, x(3)=0 and $x(4) = 1$. The two scrambling sequences $c_0(n)$ and $c_1(n)$ depend on the primary synchronization signal and are defined by two different cyclic shifts of the m-sequence c˜(n) according to (6).

$$\begin{aligned} c_0(n) &= \tilde{c}\left(\left(n + N_{ID}^{(2)}\right)mod31\right) \\ c_1(n) &= \tilde{c}\left(\left(n + N_{ID}^{(2)} + 3\right)mod31\right) \end{aligned} \quad (7)$$

where $N_{ID}^{(2)}$={0 1 2} is the physical-layer identity within the physical-layer cell identity group $N_{ID}^{(1)}$and $\tilde{c}(i) = 1 - 2x(i), 0 \le$

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$i \leq 30$ is defined by

$$x(\bar{i}+5) = \left(x(\bar{i}+3) + x(\bar{i})\right) mod 2, 0 \leq \bar{i} \leq 25 \quad (8)$$

with initial conditions $x(0) = 0, x(1) = 0, x(2) = 0$, x(3)=0 and $x(4) = 1$. The two length-31 scrambling sequences $z_1^{(m1)}(n)$ and $z_0^{(m1)}(n)$ are defined by a cyclic shift of the pseudo noise sequence $z(i)$ like $s(n)$ or $c(n)$.

2.1 PSS detection

In LTE the rear part of symbol is appended at front side called Cyclic Prefix (CP) to avoid Inter Symbol Interference (ISI). The correlation of symbol and its delayed version will give maximum if the samples are matched. The symbol start is determined by checking the peak triangle in the ratio of the cross and auto correlation. Figure 2 shows the peak that was obtained at the symbol start.

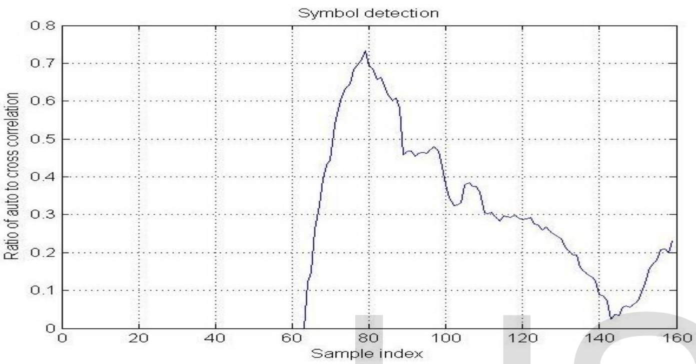

Fig. 3. Symbol detection

Then for simulation, it was assumed that the PSS with root 25 is the transmitted signal from the radio cell. It is evident from fig. 3 that the correlation amplitude maximum is obtained only when the received sequence matches with one of the sequences. The UE has determined which PSS the radio cell is transmitting (in this case, $N_{ID}^{(2)}$ is 0. Also, the UE knows the position of the amplitude maximum peak when there is no offset and depending on the position of the peak it finds when it detects the PSS it is able to calculate the offset. In this case, it was determined that for every 15 kHz frequency offset, the peak moves by one frequency bin. Now, the UE has determined the offset that it has to adjust when it receives the SSS.

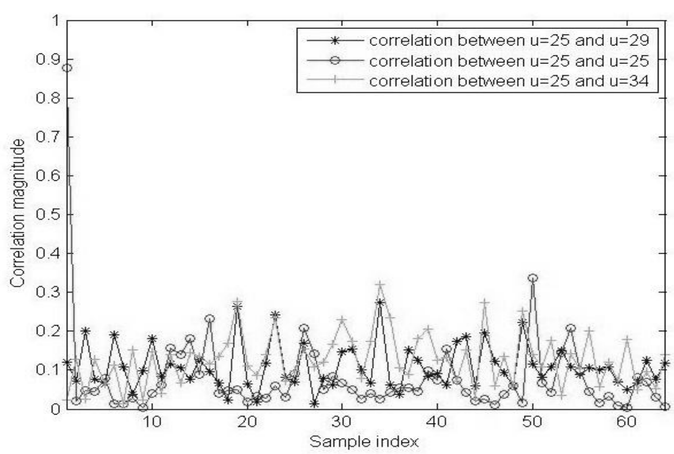

Fig. 4. PSS detection

2.2 SSS detection

By using correlation method, the UE can determine the m0 and m1 value. From fig.5 ,we can find the m0 and m1 value. The correlation value of corresponding sample index will be maximum.

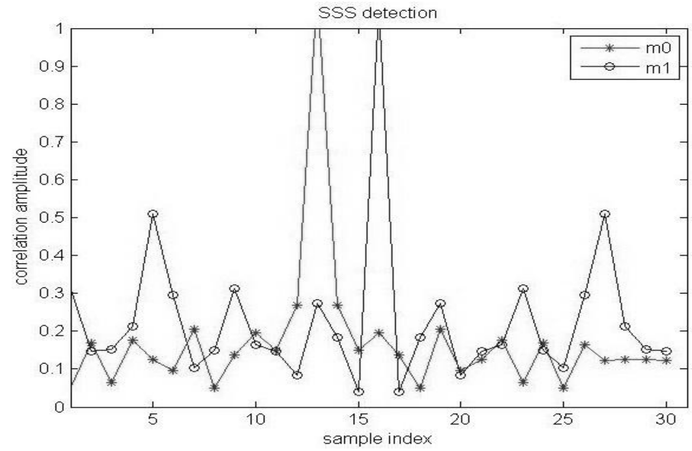

Fig.5. SSS detection

Now the UE determines the value of m_0, m_1 and $N_{ID}^{(2)}$. From look up table it can calculate $N_{ID}^{(1)}$. For our simulation it is 25. Using Cell ID equation, now it calculates the cell ID. Based on the allocation of PSS and SSS in sub frame, it can also acquire frame synchronization. After PSS and SSS detection UE has determined the radio cell ID and is synchronized in Time and Frequency with the radio cell. Now UE is ready to receive Downlink broadcast data from the radio cell.

3 DERIVING SYSTEM INFORMATION AND RANDOM ACCESS

The second part of the access procedure is where the UE needs to derive system information. This system information is periodically broadcasted in the network and this information is needed for the UE to be able to connect to the network and a specific cell within that network. When the UE has received and decoded the system information it has information about for example cell bandwidths, whether to use FDD or TDD and enough information to be able to access the cell via the random access procedure. System Information Block (SIB) periodically broadcasted through Physical Broadcast Channel (PBCH) every 160 ms. The random access procedure in LTE is shown in figure 6. The LTE RACH is used to achieve uplink time synchronization for a UE which either has not yet acquired, or has lost, its uplink synchronization. Once uplink synchronization is achieved for a UE, the (evolved Node Base station) eNodeB can schedule orthogonal uplink transmission resources for it. These roles require the LTE RACH to be designed for low latency, Good detection probability at low SNR Collision avoidance.

The parameter required to generate RACH preamble will be detected from SIB2 information which is based on cell radius and network conditions.

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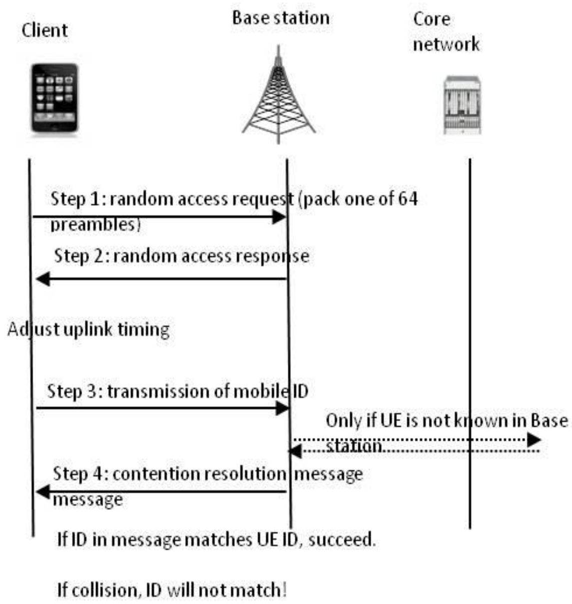

Fig. 6. Random Access procedure

3.1 PRACH preamble generation

The parameters required to generate PRACH preambles are, PRACH root index (u-0 to 838), preamble format (0 to 4), high speed flag (0 or 1), zero correlation zone index (Ncs-0 to 15), PRACH configuration index (0 to 15).

Sequence length should be a prime number to maximize the cross correlation properties, and it should be compatible with the sequence duration. Hence N_{ZC}=839. The sequence duration (T_{seq}) should be compatible with the maximum expected round-trip delay (RTD=2*R/C) and between PRACH and Physical Uplink Shared Channel (PUSCH) subcarrier spacings (NDFT =k.NFFT) and also it should give better coverage performance. The longest sequence simultaneously satisfying all above conditions is T_{seq}=800µs, as used for preamble formats 0 and 1. The resulting PRACH sub-carrier spacing is $\Delta f_{RA}=1/T_{seq}$=1.25 kHz.

Table 1 : Preamble configuration

Preamble format	Number of frames	CP duration in µs	GT duration in µs	Sequence time in µs	Maximum delay spread in µs	Maximum cell radius in km
0	1	103.13	96.88	800	6.25	14.53
1	2	684.38	515.63	800	16.67	77.34
2	2	203.13	196.88	1600	6.25	29.53
3	3	684.38	715.63	1600	16.67	100.16

The CP is dimensioned to maximize the coverage given a maximum delay spread. CP and GT duration is designed to overcome the effect of propagation delay and ISI. Based on traffic in the cell and preamble format number of sub frames will be allocated for PRACH transmission. Each preamble format contains 16 PRACH configuration index. Based on this parameters the preamble will be transmitted over the channel. The configuration of preamble is given in Table 1.

In LTE each cell will contain 64 preambles. All preambles will be generated by cyclically shifting the PRACH root preamble which is generated based on parameters which are given in Table 1.

$$x_{u,v}(n) = x_u((Cv + n)modNzc) \qquad (9)$$

where Cv is the cyclic shift value which depends on N_{cs} and other parameters like PRACH frequency offset. Depending on cell radius and speed, number of root sequence required to generate 64 preambles will vary and sometimes more than one sequence is required. That time the next root index will be found by adding one to the transmitted root index. Now UE will pick up one preamble and append the CP and GT. The CP and GT depend on the preamble format.

3.2 PRACH transmission and reception

At receiver side the received preamble will be correlated with all 64 preambles. If the preamble is matched, then it will give maximum correlation magnitude. Detection threshold will be set, based on noise floor and false alarm probability. The fact that different PRACH signatures are generated from cyclic shifts of a common root sequence means that the frequency-domain computation of the PDP of a root sequence provides in one shot the concatenated PDPs of all signatures derived from the same root sequence. Therefore, the signature detection process consists of searching, within each ZCZ defined by each cyclic shift, the PDP peaks above a detection threshold over a search window corresponding to the cell size.

4 Analysis Of Random Access Procedure

This parameters used for simulation is given in Table 2.

Table 2. Simulation parameters

Parameter	Value
Carrier frequency	2000 MHz
eNodeB antenna height	30 m
UE Transmitter EIRP	24 dBm
Penetration loss	0 dB
Log-normal fade margin	0 dB
Sampling frequency	30.72 MHz
Velocity of user	60 km/hr
Channel model	TU-6 model
False alarm probability	0.001

4.1 Cyclic Shift Configuration (Cv)

The cyclic shift offset Ncs is dimensioned so that the Zero Correlation Zone (ZCZ) of the sequences guarantees the orthogonality of the PRACH sequences regardless of the delay spread and time uncertainty of the UEs. The Ncs value should satisfy (9).

$$Ncs \geq floo\,r\left(\left(\frac{20}{3}r - \tau_{ds}\right)\frac{N_{zc}}{T_{seq}}\right) + n_g \qquad (10)$$

From fig. 6, it can be seen that as the cell size increases, the number of orthogonal preambles will be generated by the single root index will decrease.

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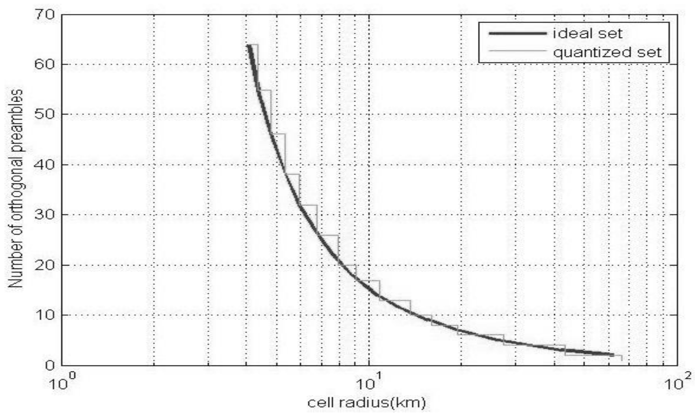

Fig. 6. Cyclic shift dimensioning

4.2 PRACH resource allocation

From fig. 7, it can be seen that PRACH allocation of 6 RBs provides a good trade-off between PRACH overhead, detection performance and timing estimation accuracy.

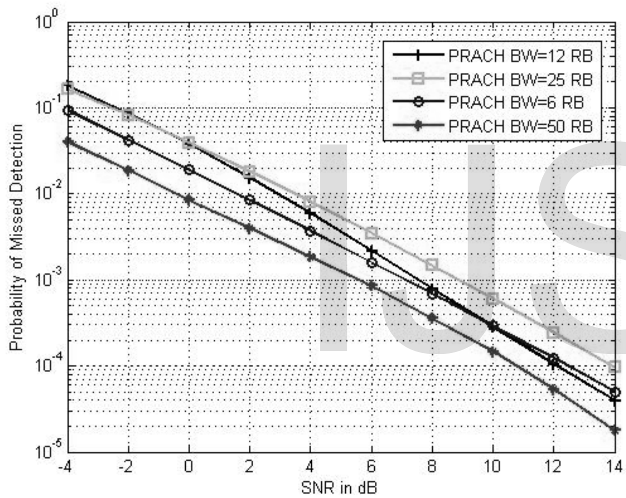

Fig. 7. Analysis of allocated PRACH bandwidth

4.3 PRACH preamble detection

The UE will transmit the preamble by using the above parameters. At the receiver it will correlate the received preamble with all 64 predefined preambles. For example the received preamble index is 42.

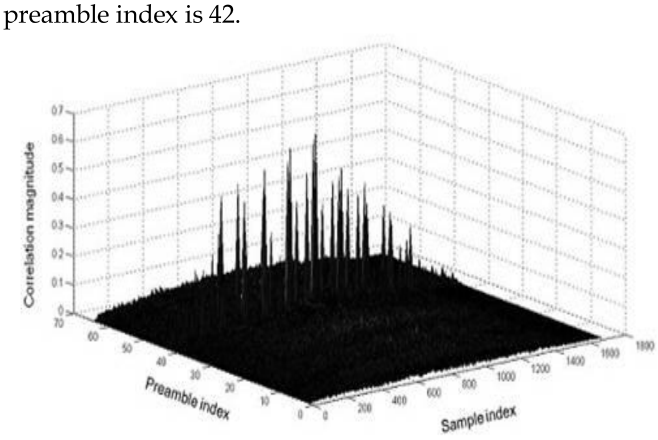

Fig. 8. PRACH preamble detection

Figure 8 shows the correlation of detected preamble with others. It will show the maximum peak only at the index 42. The detected preamble will not only give information about UE position and power, but also estimate of access delay. From access delay, UE will know when it should start the transmission.

4.4 Timing estimation

The timing estimation to detect preamble should be done exactly to support more traffic and to avoid unnecessary delay. From fig. 9, it can be seen that within 2 micro seconds, the preamble can be detected.

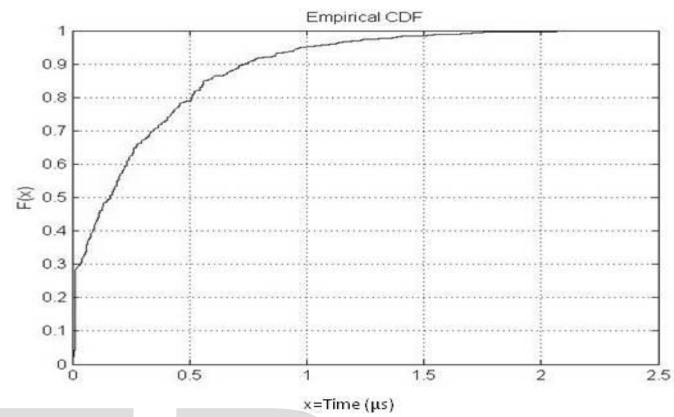

Fig. 9. Timing Estimation for PRACH detection

4.5 Detection Performance

The detection performance is analyzed in terms of probability of missed detection with respect to signal to noise ratio. Figure 10 shows the detection performance of three different LTE scenarios.

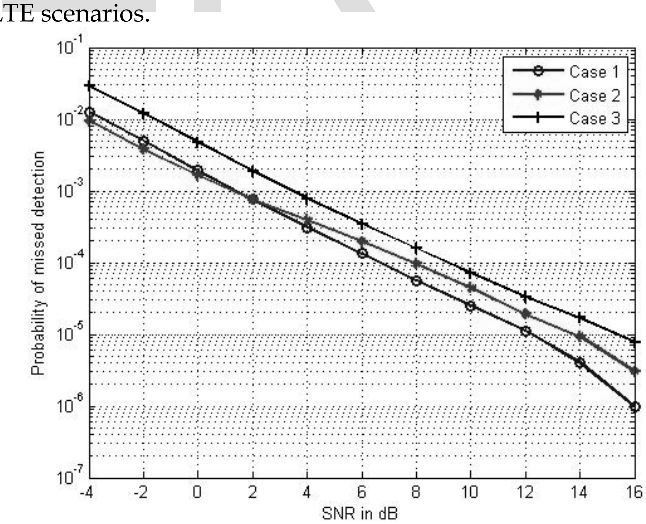

Fig. 10. Detection performance

The three scenarios are, 1.only one UE transmits the preamble 2.two UE transmits, preamble generated from same root sequence 3.two UE transmits, preamble generated from different root sequence. Scenario 3 gives high detection performance compared to other two scenarios.

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5 Conclusion

This paper gives the detailed explanation and simulation results of complete LTE access procedure which involves cell search, time and frequency synchronization, deriving system information and random access procedure. The two synchronization signals used in the cell search have been presented i.e. the PSS and SSS. Where the PSS is needed to find the group ID and frame synchronization and SSS is needed to provide the terminal with information about the cell ID, frame timing properties and the cyclic prefix (CP) length. Then it explains about random access procedure and parameters to be designed. The PRACH preamble is designed and results are obtained in typical LTE scenario.

References

[1] Zhongshan Zhang, Jian Liu, Keping Long, "Low-Complexity Cell Search With Fast PSS Identification in LTE" ,IEEE Trans., on Vehicular Technology, May 2012.

[2] Eric M. Silva C, Gordana J. Dolecek,Fredric J. harris , " Cell Search in Long Term Evolution Systems: Primary and Secondary Synchronization" IEEE, March 2012

[3] Fa-tang Chen, Zheng Zhang,'' Design and Simulation of Random Access Procedure in TD-LTE", ICCIS,IEEE, April,2012

[4] Carlos Ubeda, Salvador Pedraza, Miguel Regueira and Javier Romero,"LTE FDD Physical Random Access Channel Dimensioning and Planning", IEEE ,May 2012.

[5] Xiaobin Yang, Abraham O. Fapojuwo, Emeka E. Egbogah," Performance Analysis and Parameter Optimization of Random Access Backoff Algorithm in LTE", IEEE ,June 2012.

[6] Stefania Sesia,Issam Toufik,Matthew Baker,"LTE: From theory to practice", A John Wiley & Sons, Ltd., 2011.

[7] www.3gpp.org/Specifications