Cell Search and Synchronization in Long Term Evolution Systems

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***Abstract*- The Long Term Evolution (LTE) is a new mobile communication standard specified by the 3rd Generation Partnership Project (3GPP) within Release 8. At the beginning of communication, i.e., physical channel setup, the User Equipment (UE) must perform a cell search. In the cell search, the UE acquires the Cell Identity (Cell ID) in addition to the received sub frame and radio frame timings in the downlink. The cell search process must also be performed periodically in order to update the cell to be connected and to find a candidate cell for handover. The Cell ID corresponds to a cell-specific scrambling code, which is necessary to randomize other-cell interference in cellular system with multi-cell configuration.**

This paper proposes synchronization schemes using the digital comparator with a circular delay and makes use of the properties of Zadoff-Chu (ZC) and pseudo-noise (PN) sequences. The performances of the proposed scheme is evaluated by simulations

I. INTRODUCTION

LTE offers transmission rates up to 50 Mbps on the Uplink (UL) and 100 Mbps on the Downlink (DL) [1].

In order that an User Equipment (UE) can access a cell in a Long Term Evolution (LTE) systems, it must be able to perform an initial synchronization and search for a base station (eNodeB) to establish the downlink (DL) access. This process is called the initial cell search. Two synchronization signals are available to accomplish this process which are primary synchronization signal (PSS) and the secondary synchronization signal (SSS).

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LTE uses two Orthogonal Frequency Division multiplexing (OFDM) based systems for its modulation channel access techniques. Orthogonal Frequency Division Multiple Access (OFDMA) is used for the downlink transmission and Single Carrier. Frequency Division Multiple Access (SCFDMA) is used for the uplink.

OFDMA provides several advantages, such as high spectral efficiency, simple receiver implementation, robustness in a multipath environment, ability to handle different data rates, and it can be combined with Multiple Input Multiple Output (MIMO) antenna techniques. The use of SCFDMA presents a solution for the mobile systems because of the high Peak to Average Power Ratio issue (PAPR) [2-4].

Cell Search is a basic function of any cellular system, during which timing and frequency synchronization is obtained between the mobile unit and the network. The cell search procedure consists of a series of synchronization stages by which the UE determines time and frequency parameters that are necessary to demodulate the downlink and to transmit uplink signals with the correct timing. It is also used for the acquisition of the receiver frequency of the downlink channels. The cell detection in LTE is tightly linked to the Primary Synchronization Signal (PSS) and the Secondary Synchronization Signal (SSS) [3, 4].

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Time and frequency synchronization for 3GPP LTE has been investigated in [5], where a method for generating repetitive synchronization signals and detection algorithms are described. Cell search based on these proposed synchronization signals are considered in [6].A detection algorithm which uses peak detection property of signals is proposed in [7] and [8]. However, these papers use the correlation based methods, which are of high complexity. We propose to use digital comparator based method which is faster than the conventional method.

The paper is organized as follows. In Section II the frame Structure of LTE and the position of the synchronization Signals are explained. The Primary synchronization process is Presented in Section III, while in Section IV the method for SSS generation and detection is described. The conclusions are given in Section V.

II. RADIO FRAME

A TDD and FDD frame structures (type 1 and 2 respectively) in LTE, are organized in radio frames units of length 10 msec. Each radio frame is divided into 10 sub frames of length 1msec, which are further divided into two slots of length 0.5 msec. As an example, an FDD frame is illustrated in Figure 1. Each slot contains 7 OFDMA symbols with short CP or 6 OFDMA symbols with long CPs.

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 comparator that detects the peak correlation between the CP and its delayed replica in each OFDMA symbol.

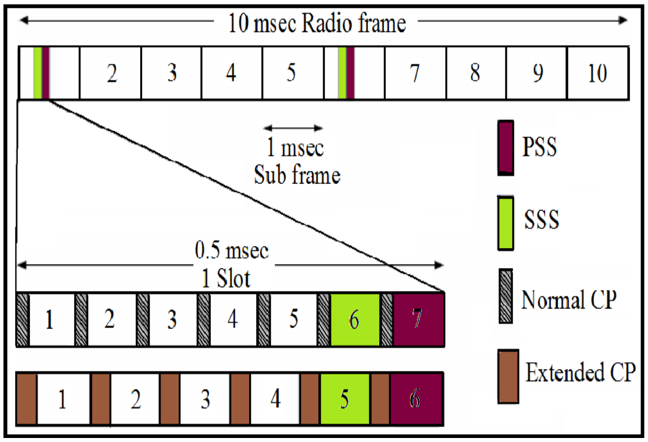

Figure 1. PSS and SSS signals in a FDD Frame.

PSS is used to detect one of three physical layer cell identity represented by $N_{ID}^{(2)} = 0,1,2$. SSS is used to determine physical layer cell identity group between 0 & 167 represented by $N_{ID}^{(1)} = 0,1,\ldots,167$ .The complete cell search procedure consists of two steps to identify the cells' identity after the detection of synchronization sequences by applying the following equation,

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

III. PRIMARY SYNCHRONIZATION SIGNAL

(A) PSS Generation

The PSS is chosen from a class of the polyphase Zadoff-Chu (ZC) sequences [2, 3], which satisfy a Constant Amplitude Zero Autocorrelation (CAZAC) property. These baseband sequences are complex signals defined as,

$$ZC_u^{N_{ZC}} = e^{-j\frac{\pi un(n+1)}{N_{ZC}}} \qquad n = 0,1,2\ldots,N_{ZC}-1 \quad \ldots(2)$$

where, u is the ZC root index relatively prime to N_{ZC}. In particular, $N_{ZC} = 63$ and u is selected from {25, 29, 34} values.

$N_{ID}^{(2)}$	Root Index (u)
0	25
1	29
2	34

Table 1. Root Indices for PSS [9]

The ZC sequence with root u = 29 and u = 34 are complex conjugates of each other. This fact can be employed for efficient detection of the PSS using a correlator.

PSS Signal in frequency domain with root u = 25 is shown in Figure 2. The signal is converted to time domain using IFFT and is used for transmission. From Figure 2 it is clear that all the points of ZC sequence lie on the Unity Circle. Thus it has a Constant Amplitude.

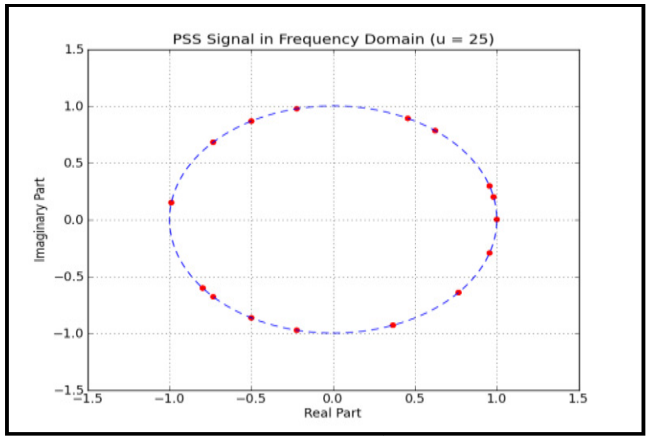

Figure 2. PSS in frequency domain with root u = 25

(B) PSS Detection

In particular, ZC sequences have a low sensitivity to Doppler frequency-offset, defined as the ratio of the maximum undesired autocorrelation peak in the time domain to the desired correlation peak computed at a certain frequency offset. This characteristic allows a certain robustness of the PSS detection during the initial synchronization. The Figure 3 and 4 shows the correlation of the transmitted PSS signal with unknown root with ZC signal of roots u = 25 and u = 29 respectively.

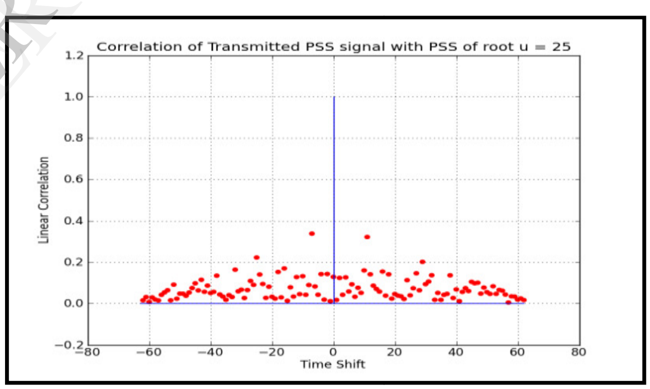

Figure 3. Correlation of PSS signal with PSS of root u=25

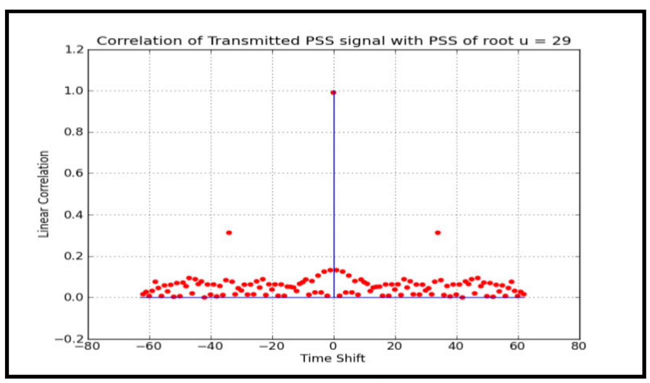

Figure 4. Correlation of PSS signal with PSS of root u=29

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From Figure 4, we can see that there is a local maximum at time lag = 0, thus from Table 1, we can say that, the physical layer cell identity = 1.

IV. SECONDARY SYNCHRONIZATION SIGNAL

(A) SSS Generation

After the UE has detected the physical layer cell identity, the second step is to obtain the physical layer cell identity group. This information can be found from the SSS. The sequence used for the secondary synchronization signal (SSS) is an interleaved concatenation of two length-31 bi-level sequences. The concatenated sequence is scrambled with a scrambling sequence given by $N_{ID}^{(2)}$. The interleaving of two length-31 sequences defining the secondary synchronization signal differs between sub frame 0 and sub frame 5 according to:

$$
\left.\begin{array}{l}
d(2n) = \begin{cases} S_0^{(m_0)}(n)c_0(n) & \text{in slot } 0 \\ S_1^{(m_1)}(n)c_0(n) & \text{in slot } 10 \end{cases} \\
d(2n+1) = \begin{cases} S_1^{(m_1)}(n)c_1(n)z_1^{(m0)}(n) & \text{in slot } 0 \\ S_0^{(m_0)}(n)c_1(n)z_1^{(m1)}(n) & \text{in slot } 10 \end{cases}
\end{array}\right\} \quad \ldots (3)
$$

The indices m_0 and m_1 are derived from $N_{ID}^{(1)}$ according to [2] and $c_0(n)$ and $c_1(n)$ are derived from $N_{ID}^{(2)}$. Figure 5 shows SSS generated by simulation.

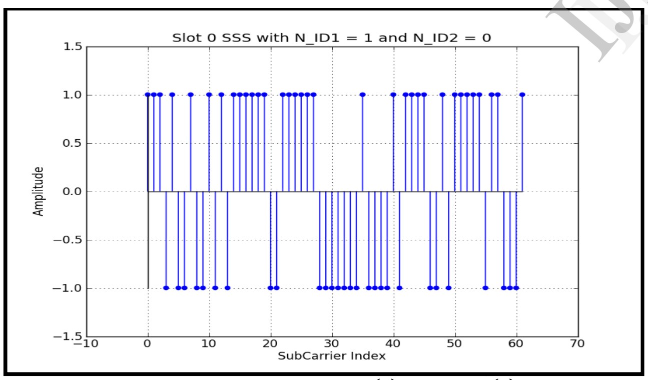

Figure 5. Slot 0 SSS with $N_{ID}^{(1)}$=1 and $N_{ID}^{(2)}$=0

(B) SSS Detection

The SSS detection is done after the PSS detection, and the channel can therefore be assumed to be known.

The sequence decoder block for the SSS in the receiver contains the following blocks: Deinterleaving, De-scrambling, and Extraction process.

Taking in consideration the known $N_{ID}^{(2)}$obtained in the PSS detection, the process of detection of $N_{ID}^{(1)}$ is shown in Figure 6.

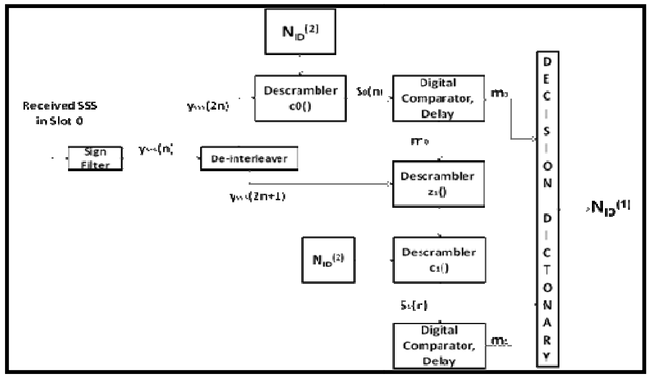

Figure 6. Block diagram of SSS detector

In SSS detector a digital comparator and circular shift delay is used for checking the equality of the received and the reference signal. Thus the values of m_0 and m_1 can be detected. From these values the Physical Layer Cell Identity Group can be determined.

Figure 7 – 11. show the graphical representation of SSS detection.

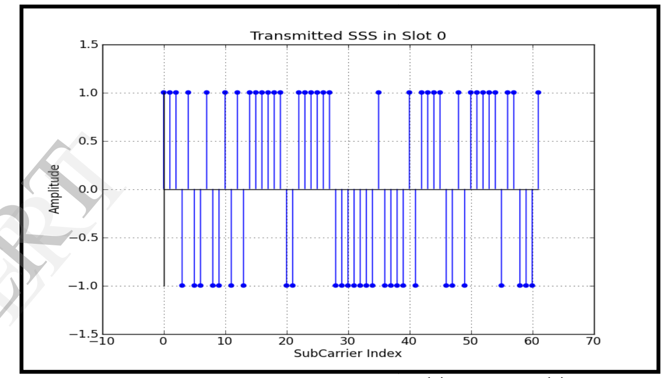

Figure 7. Transmitted SSS with $N_{ID}^{(1)}$=1 and $N_{ID}^{(2)}$=2

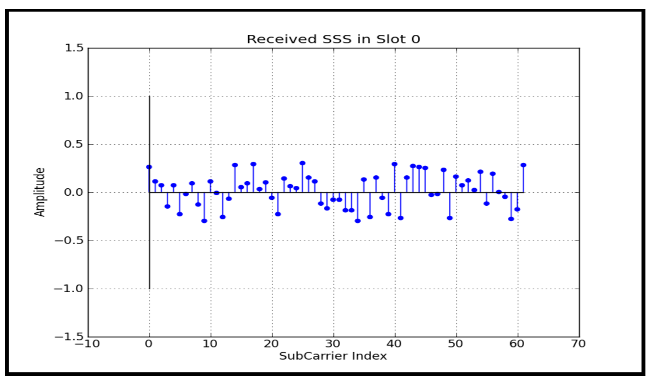

Figure 8. Received SSS (with AWGN)

Figure 8 shows the received SSS signal. The received signal is attenuated because of the white noise present in the enviornment. It can be removed by passing the signal through a Sign Filter. The output of a sign filter is shown in Figure 9. Figures 10 and 11 show descrambled $S_0(n)$ and $S_1(n)$ respectively.

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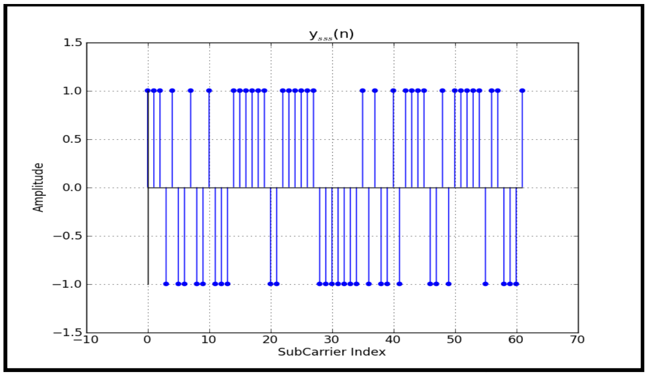

Figure 9. Filtered SSS

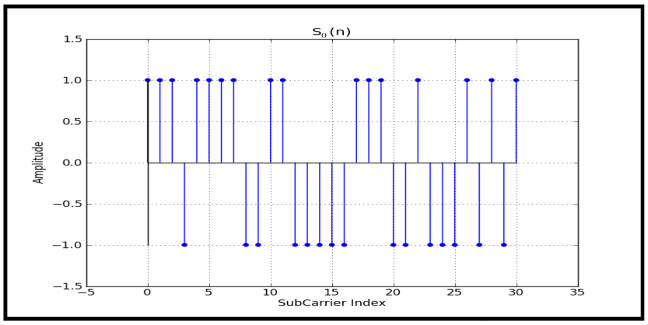

Figure 10. Descrambled even part of SSS

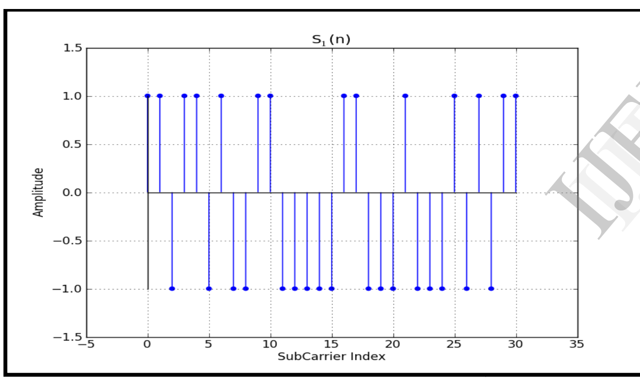

Figure 11. Descrambled odd part of SSS

The values of m_0 and m_1 are detected from the Descrambled even and odd parts of SSS using the Digital comparator and the delay block shown in Figure 6. Thus the value of Cell Identity is calculated successfully.

V. CONCLUSION

This paper describes the process of the cell search in the LTE system. The SSS detector using digital comparator is designed to determine correctly the cell identity group. The complete procedure enables a robust connection to the base station. The complexity of the algorithm is reasonable compared to the conventional methods using properties of correlation.

VI. REFERENCES

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