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Comparative Analysis of Cell Search Schemes in Long Term Evolution Systems

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Abstract- In Long Term Evolution (LTE) systems, cell search is performed by each User Equipment (UE), to detect the cell identity. The received subframe index and radio frame timings in the downlink are also acquired. Cell search is performed using the Primary Synchronization Signal (PSS) and Secondary Synchronization Signal (SSS) in a hierarchical manner.

In this paper we have simulated the schemes for PSS and SSS detection of cell identity and subframe index using Linear Correlation and Circular Correlation. The probability of PSS and SSS detection for both schemes is compared by Monte Carlo Simulation Method.

Keywords- Cell Search, LTE, PSS, SSS, Correlation.

I. INTRODUCTION

Long Term Evolution (LTE) offers transmission rates up to 50 Mbps on the Uplink (UL) and 100 Mbps on the Downlink (DL) [1]. In this system, a scalable transmission bandwidth is designed to allow mobility up to 350 kmph, with slight reduction of performance. LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) for the downlink transmission and Single Carrier Frequency Division Multiple Access (SCFDMA) for the uplink transmission [2-4].

Cell Search is a basic function of any cellular system, during which cell identity of LTE radio cell is obtained. The radio frame timings and the subframe index are also acquired. The cell detection in LTE is tightly linked to the Primary Synchronization Signal (PSS) and Secondary Synchronization Signal (SSS) [2, 3].

A length-63 Zadoff-Chu (ZC) sequence, which occupies the central six resource blocks (RBs) of the system bandwidth, is used to generate the PSS. Since the SSS detection can be performed only after the PSS is successfully identified, the overall DL synchronization performance is therefore heavily dominated by a robust PSS detection. Synchronization and cell search in 3rd Generation Partnership Project (3GPP) LTE systems based on the frequency-domain identification of PSS and SSS are discussed in [5]. In [6], a robust time and frequency synchronization scheme in 3GPP LTE is proposed. The PSS detection depends on a cross-correlation operation performed between the received and local ZC sequences and has a relatively high complexity. In [7] the essential central-symmetric property of the ZC sequences have been exploited to improve the PSS detection performance, and based on this property, high-performance PSS detectors, have been proposed.

Time and frequency synchronization for 3GPP LTE has been investigated in [8], where a method for generating repetitive synchronization signals and detection algorithms are described. Cell search based on these proposed synchronization signals are considered in [9]. The method for detection of PSS and SSS to get cell identity in downlink is described along with improvement in peak detection of frame [10].

This paper compares Linear and Circular Correlation schemes to detect physical layer identity from PSS and physical layer cell identity group from SSS. The probability of PSS detection for channels having varying Signal to Noise Ratio (SNR) and SSS detection for channels with diverse Bit Error Rate (BER) has been computed for both schemes.

The paper is organized as follows. In Section II the frame structure of LTE is explained. The PSS is explained in Section III. Section IV describes SSS generation and SSS detection using linear and circular correlation schemes. The probabilistic analysis for PSS and SSS detection is explained in section V. Finally, the conclusions are drawn in Section VI.

II. LTE RADIO FRAME AND CELL SEARCH

A Time Division Duplex (TDD) and Frequency Division Duplex (FDD) frame structures (type 1 and 2 respectively) in LTE, are organized in radio frames units of length 10 ms. Each radio frame is divided into 10 subframes of length 1 ms, which are further divided into two slots of length 0.5 ms. Each slot either contains 7 OFDMA symbols with short Cyclic Prefix (CP) or 6 OFDMA symbols with long CP.

The synchronization signals are transmitted periodically, twice per 10 ms radio frame. In a FDD frame the PSS is always located in the first and eleventh slots of the slot boundary timing irrespective of the CP length. The SSS is located in the symbol immediately preceding the PSS.

LTE uses a hierarchical cell-search procedure in which LTE radio cell is identified by a cell identity. It consists of 504 unique physical layer cell identities. To accommodate and manage this large amount, the cell identities are divided into 168 unique cell layer identity groups. Each group further consists of three physical layer identities.

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 and 167 represented by $N_{ID}^{(1)} = 0, 1, \ldots ,167$.

The complete cell search procedure consists of calculating the cell's identity, after the detection of synchronization sequences, by applying the equation,

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

III. PRIMARY SYNCHRONIZATION SIGNAL

- 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. A ZC sequence is a complex-valued mathematical sequence which exhibits the useful property that cyclically shifted versions of it is orthogonal to each other.

The sequence used for the primary synchronization signal is generated from a frequency-domain ZC sequence according to the equation,

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

Where $N_{ZC} = 63$, is the length of the sequence,

u is the root index selected from the set {25, 29, 34}.

This set of roots for the ZC sequences was chosen to obtain good periodic autocorrelation and cross-correlation properties. The three values of $N_{ID}^{(2)} = 0, 1, 2$ are represented by the PSS with three different ZC root indices u = 25, 29, 34 respectively.

Figure 1 represents the real and imaginary parts of the sequence used in PSS with root index of 25 in Frequency Domain.

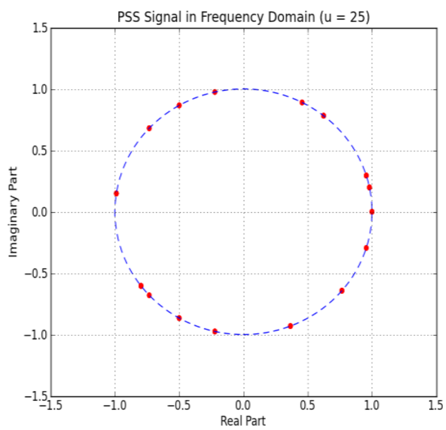

Figure 1. ZC (Frequency Domain) sequence with length 63 and root u = 25.

From Figure 1 it is evident that all points lie on the unity circle. Thus the amplitude of the signal is constant.

- PSS DETECTION

The PSS signal is transmitted in Time Domain. To obtain time domain sequence IDFT is applied to the generated ZC signal. The transmitted signal gets distorted due to noise present in the channel. The channel is modeled as Additive White Gaussian Noise (AWGN).

The time domain PSS used for transmission and the PSS received from a channel with SNR of 6 dB is demonstrated in Figure 2.

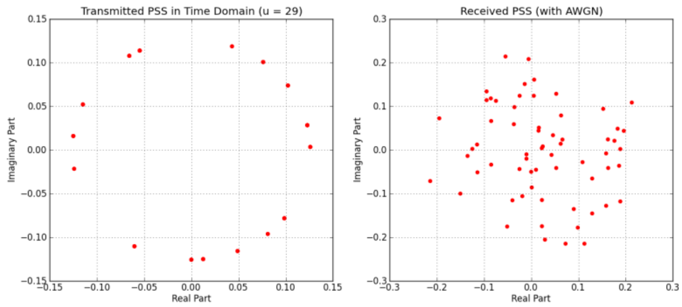

Figure 2. Transmitted and Received PSS.

To detect the physical layer identity, the received PSS is correlated with the three ZC sequences of each of the above mentioned roots. This can be implemented using Linear as well as Circular correlation.

Linear Correlation is given by the following equation,

$$r_{xh}(k) = \sum_{n=0}^{N-1} x(n-k).h^*(k) \quad (3)$$

Where k = Time Lag, and
N = length of the sequence.

Circular Correlation is defined by the equation,

$$\tilde{r}_{xh}(k) = \sum_{n=0}^{N-1} x\big((n-k) mod\ N\big).h^*(k) \quad (4)$$

Where k = Time Lag, and
N = length of the sequence.

Figure 3 shows linear correlation of the received signal with the ZC sequence of roots u = 25 and 29.

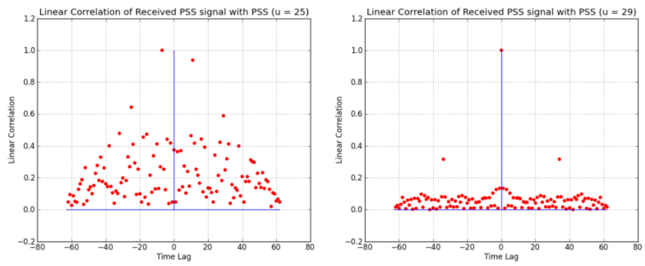

Figure 3. PSS Detection using Linear Correlation.

From Figure 3 it is seen that an auto-correlation peak is detected, for sequence with root u = 29, at Time Lag = 0. Figure 4 shows similar results of PSS detection using circular correlation.

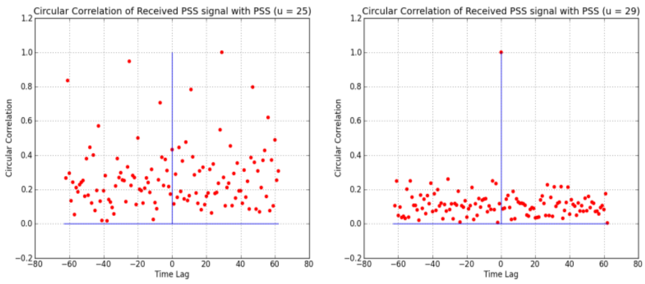

Figure 4. PSS Detection using Circular Correlation.

Thus the physical layer identity detected from the received PSS is 1.

IV. SECONDARY SYNCHRONIZATION SIGNAL

- SSS GENERATION

The physical layer cell identity group can be extracted from the SSS. The sequence used for the SSS is an interleaved concatenation of two length-31 bi-level sequences. The sequence is scrambled with a scrambling sequence, $c(n)$ which is dependent on $N_{ID}^{(2)}$. The SSS differs between slot 0 and slot 10 according to the following equations [2],

$$d(2n) = \begin{cases} s_0^{(m_0)}(n).\,c_0(n) \text{ ... in slot 0} \\ s_1^{(m_1)}(n).\,c_0(n) \text{ ... in slot 10} \end{cases} \tag{5}$$

$$d(2n+1) = \begin{cases} s_1^{(m_1)}(n).\,c_1(n).\,z_1^{(m_0)}(n) \text{ ... in slot 0} \\ s_0^{(m_0)}(n).\,c_1(n).\,z_1^{(m_1)}(n) \text{ ... in slot 10} \end{cases} \tag{6}$$

where $0 \le n \le 30$.

The two length-31 binary sequences $s_0^{(m_0)}(n)$ and $s_1^{(m_1)}(n)$ are defined as two different cyclic shifts of the m-sequence $\tilde{s}(n)$

$$\begin{aligned} s_0^{(m_0)}(n) &= \tilde{s}((n+m_0) \bmod 31) \\ s_1^{(m_1)}(n) &= \tilde{s}((n+m_1) \bmod 31) \end{aligned} \tag{7}$$

where $\tilde{s}(i) = 1 - 2x(i)$, $0 \le i \le 30$ with $x(i)$ given as,

$$x(j+5) = (x(j+2) + x(j)) \bmod 2,\ 0 \le j \le 25 \tag{8}$$

with initial conditions $x(0) = 0$, $x(1) = 0$, $x(2) = 0$, $x(3) = 0$, $x(4) = 1$.

The expression $(1 - 2x(i))$ converts binary 0 and 1 in $x(i)$ to $+1$ and -1 respectively. The sequences are defined and indices m_0 and m_1 are derived from $N_{ID}^{(1)}$ according to [2].

The SSS generated by simulation is shown in Figure 5

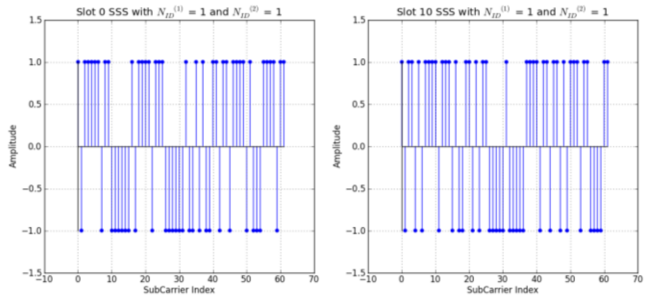

Figure 5. SSS with $N_{ID}^{(1)}$=1 and $N_{ID}^{(2)}$=1.

- SSS DETECTION

Figure 6 shows Block Diagram for SSS Detector. It uses the following blocks: Sign Filter, Deinterleaving, De-scrambling, Correlator and Extraction process.

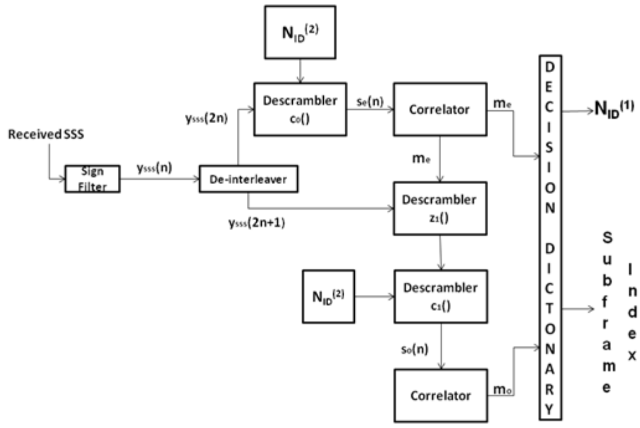

Figure 6. Block diagram of SSS detector.

The received SSS is affected by the Additive White Gaussian Noise (AWGN) present in the channel. This noise can be filtered using a Sign Filter. The mathematical function of a sign filter is given as follows,

$$y_{sss}(n) = \begin{cases} -1;\ for\ x(n) < 0 \\ \ \ 1;\ for\ x(n) \ge 0 \end{cases} \tag{9}$$

Where $x(n)$ is the input and $y_{sss}(n)$ is the output of the filter respectively.

The Deinterleaver separates the signal into even and odd parts. The even and odd parts are processed individually. The Descrambler is used to invert the process used in SSS generation. The Correlator returns the correlation of the received and predefined sequences, given by equations (3) and (4). Extraction process is performed using Decision Dictionary, which links the values of m_0 and m_1 to $N_{ID}^{(1)}$.

The transmitted SSS is received as shown in Figure 7.

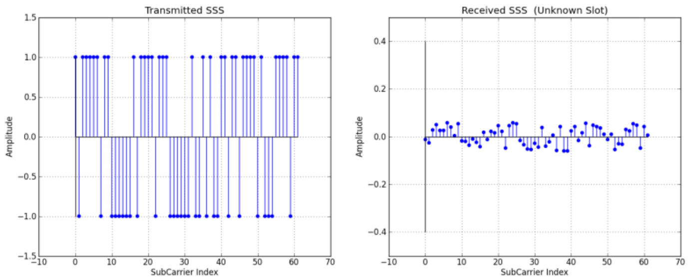

Figure 7. Transmitted and Received SSS.

The User Equipment (UE) is unaware of the subframe index of the received SSS. Thus the binary sequence $s_e(n)$ is extracted from the even part of received SSS according to Block Diagram. The sequence $s_e(n)$ thus obtained is shown in Figure 8.

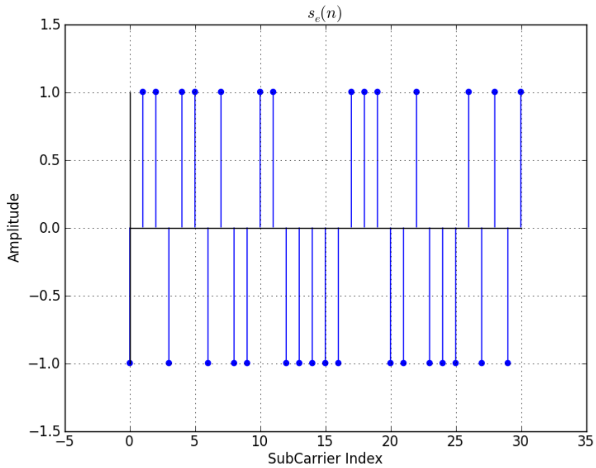

Figure 8. Descrambled even part of SSS

The value of m_e can be obtained by correlating $s_e(n)$ with the sequence $\tilde{s}(n)$ as defined in [2].

From equation (5), it is clear that, if the received SSS belongs to slot 0, then $m_e = m_0$, else $m_e = m_1$

The results of applying linear and circular correlation for SSS detection are shown in Figures 9 and 10 respectively.

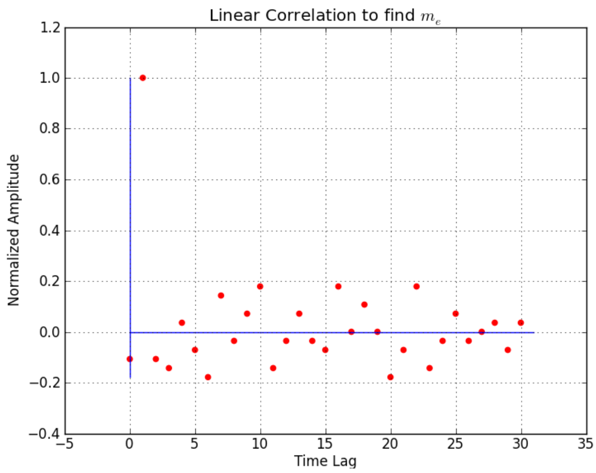

Figure 9. SSS detection using Linear Correlation.

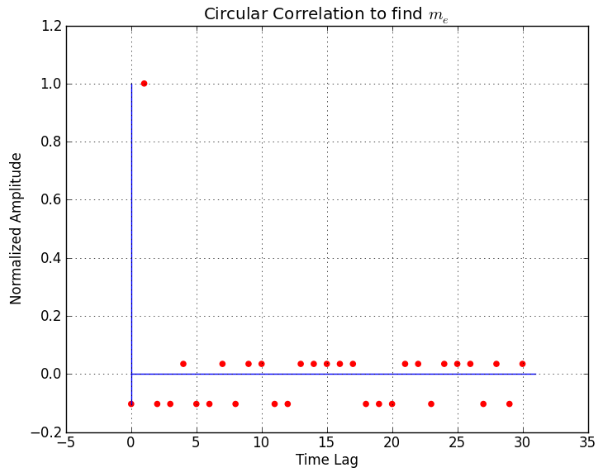

Figure 10. SSS detection using Circular Correlation.

From Figures 9 and 10, the peak is detected at Time Lag = 1. Thus the value of m_e = 1. Value of m_o = 2 can be obtained using a similar procedure from $s_o(n)$.

To detect subframe index, the tuple (m_e, m_o) is given to the decision dictionary. As (m_e, m_o) exists in the keys of the dictionary, the SSS is present in slot 0. If the tuple (m_o, m_e) would be present in the keys of dictionary, the SSS would have been present in slot 10. Thus the detected subframe index = 0. $N_{ID}^{(1)}$ = 1 is returned by the dictionary. Hence the SSS is detected correctly.

V. PROBABILISTIC ANALYSIS

The cell identity detection using the proposed schemes has been simulated for noisy channels. Monte Carlo simulations using 10000 trials were used to estimate the probability of detection for a range of noisy channels, for each scheme.

- PSS DETECTION PROBABILITY

The probability of PSS detection using both the schemes is shown in Figure 11.

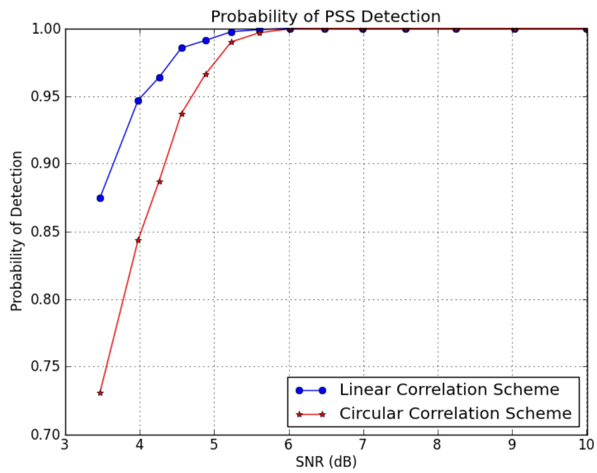

Figure 11. PSS Detection Probability.

Figure 11 shows that the probability of PSS detection is same for linear and circular correlation schemes up to SNR of 6 dB. As SNR reduces, linear correlation proves to be more effective than circular correlation.

- SSS DETECTION PROBABILITY

The probability of SSS detection is shown in Figure 12. The result shows that the schemes are equally effective till a BER of 15%. The performance of Linear Correlation scheme degrades rapidly as compared to Circular Correlation scheme for channels with higher AWGN. The probability of detection for circular correlation scheme does not fall below 0.9 even for a BER of 40%. Thus circular correlation is superior to the linear correlation scheme for successful SSS detection.

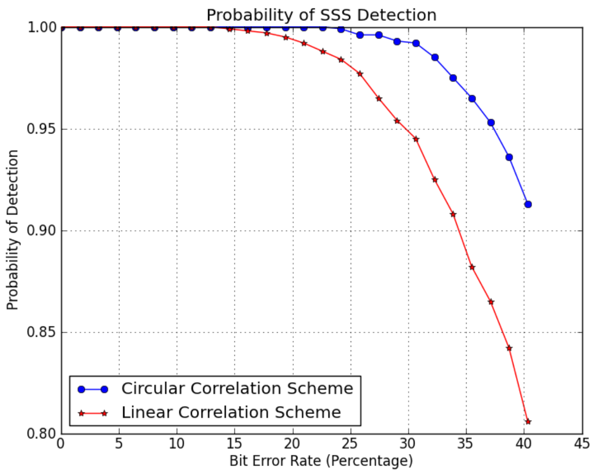

Figure 12. Probability of SSS Detection.

The computation of linear correlation requires appending of zeros to the received signal. In circular correlation algorithm, a periodic extension of the received signal is used for computation. The number of complex additions and complex multiplications for both the correlations remains the same. Thus complexity of both the schemes is equivalent.

VI. CONCLUSION

In this paper we have described and implemented the schemes for generation and detection of PSS and SSS for LTE systems. We have used polyphase Zadoff Chu (ZC) sequences for PSS generation and interleaved concatenation of two length-31 bi-level sequences for SSS generation. PSS detection algorithm is designed to determine the physical layer identity correctly and SSS detection algorithm is designed to determine physical layer cell identity group. The PSS and SSS detection algorithm is implemented by using linear and circular correlation. The performance of PSS detection is evaluated by calculating probability of detection for various SNR values. We observed that the linear correlation scheme is more effective for channels with SNR value below 6 dB. Similarly the SSS detection is carried to determine the physical layer cell identity group and the current sub frame index correctly. The simulation for SSS detection shows that the circular correlation scheme gives better results for SSS detection for channels with BER of 15%.

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