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Spectral Analysis of SSS detection Schemes in Long Term Evolution Systems

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Abstract: **- In the present scenario, mobile communication is ruling the world with advanced technologies. Long Term Evolution (LTE) is one such advanced high-speed technology. Cell search is done using the Primary Synchronization Signal (PSS) and Secondary Synchronization Signal (SSS), in LTE Systems. PSS is generated from frequency domain Zadoff-Chu (ZC) sequence which has zero autocorrelation property. SSS corresponds to a cell-specific scrambling code, given by Pseudo-Noise (PN) sequence. Detection of cell identity in LTE systems is done by using correlation. In this paper, we have proposed detection of the physical layer cell identity group from SSS using linear and circular correlation schemes. We also extended our work to estimate the spectral analysis for the detection of physical layer cell identity group. We have compared probabilistic analysis of correlation schemes with spectral analysis and results are validated and justified.**

***Index Terms*— LTE, SSS, Spectral Analysis, Probabilistic Analysis.**

I. INTRODUCTION

The beyond 3G system in 3rd Generation Partnership Project (3GPP) is called evolved Universal Terrestrial Radio Access (evolved UTRA) and is also widely referred to as LTE. The objective of LTE is to provide a high-data-rate, low-latency and packet-optimized radio access technology supporting flexible bandwidth deployments. It offers transmission rates up to 50 Mbps on the Uplink (UL) and 100 Mbps on the Downlink (DL) [2]. 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. LTE uses a hierarchical cell-search procedure in which LTE radio cell is identified by a cell identity. The cell detection in LTE is tightly linked to PSS and SSS [2, 3]. PSS is a length-62 sequence generated from a frequency-domain ZC sequence, and has Constant Amplitude Zero Autocorrelation (CAZAC) property. SSS is organized into an interleaved concatenation of two length-31 binary sequences. In time-domain, the synchronization signals are transmitted twice per 10ms radio frame. 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 issue is described by design considerations of PSS, SSS and synchronization channel in [6]. A low complexity algorithm to detect the position of PSS and SSS is described in [7]. The method for detection of PSS and SSS to get cell identity in downlink is described in [8] along with improvement in peak detection of frame. In [9], SSS detection schemes are compared with probabilistic analysis. The paper is organized as follows. In Section II cell search in LTE is explained. The PSS is explained in Section III. Section IV describes generation and detection of SSS along with probability of its detection using linear and circular correlation. Spectral analysis of received SSS for proposed schemes is performed in Section V. Finally, the conclusions are explained in Section VI.

II. CELL SEARCH IN LTE

LTE consists of 504 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 two steps to identify the cells' identity after the detection of synchronization sequences by applying the equation [2],

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

primary synchronization signal

The PSS is chosen from a class of the polyphase ZC sequences [2, 3], which satisfies 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 [2].

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

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

Where NZC = 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 [9].

IV. SECONDARY SYNCHRONIZATION SIGNAL

SSS corresponds to a cell-specific scrambling code, given by Pseudo-Noise (PN) sequence. The physical layer cell identity group can be extracted from the SSS. The purpose of the SSS is to provide the terminal with information about the cell ID, frame timing properties and the cyclic prefix (CP) length.
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],

$$d(2n) = \begin{cases} s_0^{(m_0)}(n).\, c_0(n) \ldots \text{in slot } 0 \\ s_1^{(m_1)}(n).\, c_0(n) \ldots \text{in slot } 10 \end{cases} \quad (3)$$

$$d(2n+1) = \begin{cases} s_1^{(m_1)}(n).\, c_1(n).\, z_1^{(m_0)}(n) \ldots \text{in slot } 0 \\ s_0^{(m_0)}(n).\, c_1(n).\, z_1^{(m_1)}(n) \ldots \text{in slot } 10 \end{cases} \quad (4)$$

where $0 \le n \le 30$
The indices m_0 and m_1 are derived from $N_{ID}^{(1)}$ according to [2]. Figure 1 shows block diagram of step by step procedure used for SSS Detection [9]. It consists of important blocks such as, Sign Filter, Deinterleaving, Descrambling, Correlator and Extraction process.

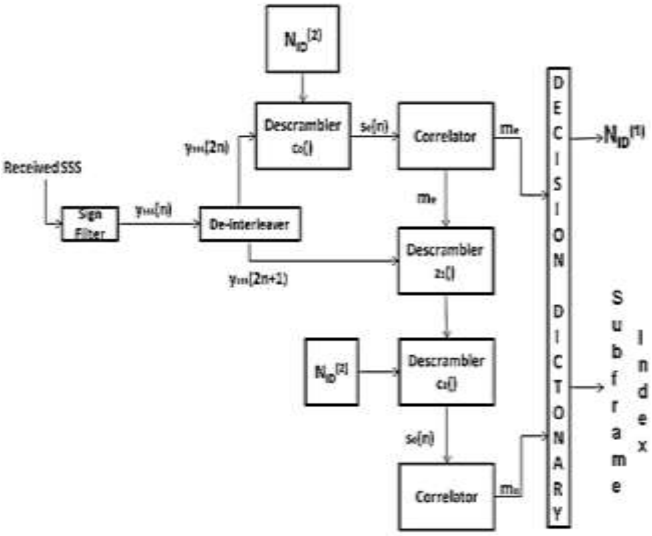


Figure 1. Block diagram of SSS detector [9]

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 De-interleaver 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). The extraction process is performed using decision dictionary, which links the values of m0 and m1 to $N_{ID}^{(1)}$. Correlator block in SSS detector can be implemented using Linear as well as Circular correlation.

A. Linear Correlation

Linear Correlation is given by the following equation,

$$r_{xh}(k) = \sum_{n=0}^{N-1} x(n-k).\, h^*(k) \quad (5)$$

Where k is the Time Lag and N is the length of the sequence. Figure 2 shows the linear correlation of errorless SSS with predefined sequence.

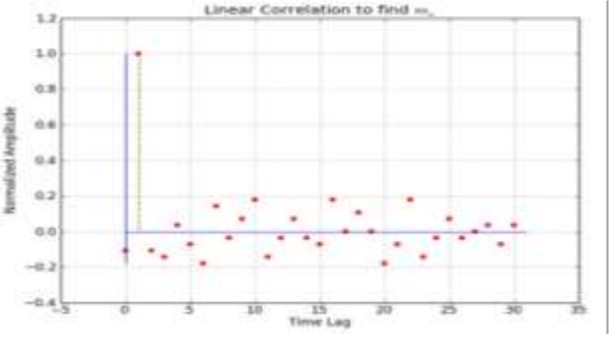


Figure 2. SSS detection using Linear Correlation

B. Circular Correlation:

Circular Correlation is defined by the equation,

$$\tilde{r}_{xh}(k) = \sum_{n=0}^{N-1} x\big((n-k) \bmod N\big).h^*(k) \quad (6)$$

Where k is the Time Lag and N is the length of the sequence. Figure 3 show simulation results using circular correlation.

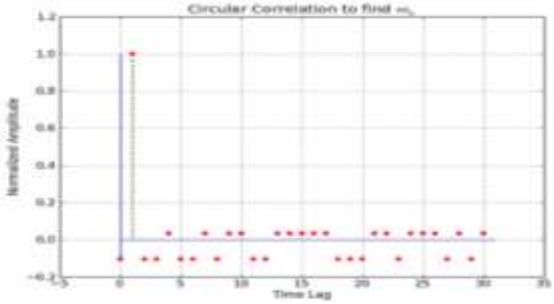


Figure 3. SSS detection using Circular Correlation

From Figures 2 and 3, the peak is detected at Time Lag = 1. Thus, the value of me = 1. Similar analysis is carried out to find value of mo from $s_o(n)$. The value of mo is equal to 2. To detect subframe index, the tuple (me, mo) is given to the decision dictionary as shown in Figure 1. As (me, mo) exists in the keys of the dictionary, the SSS is present in slot 0. Thus, the subframe index = 0. $N_{ID}^{(1)}$ = 1 is returned by the dictionary. Thus, the physical layer cell identity group is detected correctly. [9] The cell identity group detection using the proposed schemes has been simulated for noisy channel. The channel can cause errors in the bits in the received signal. Simulation has been made for channel having different values of BER. Monte Carlo simulations using 10000 trials were used to estimate the probability of detection for each BER, for each scheme.

The probability of successful SSS detection has been shown in Figure 4.

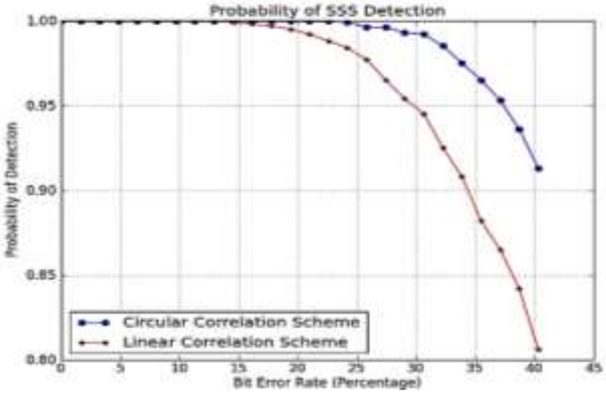


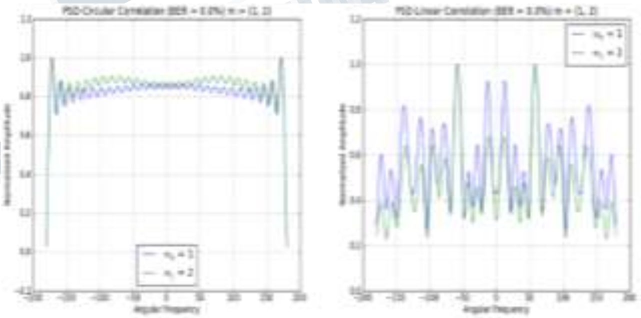
Figure 4. Probability of SSS Detection

The result shows that the correlation 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.

spectral analysis The correlation used to detect the SSS is performed in time domain. The energy distribution of SSS detection in the frequency domain can be studied by spectral analysis. To study the spectral analysis of linear and circular correlation schemes, Fourier Transform has been carried out. Figure 5. Shows spectrum of the received SSS under ideal conditions.

V. SPECTRAL ANALYSIS

The correlation used to detect the SSS is performed in time domain. The energy distribution of SSS detection in the frequency domain can be studied by spectral analysis. To study the spectral analysis of linear and circular correlation schemes, Fourier Transform has been carried out. Figure 5. Shows spectrum of the received SSS under ideal conditions.



(a) (b)

Figure 5. Power Spectral Density (PSD) of ideal received SSS.

Figure 5a and 5b shows the energy content of circular correlation and linear correlation respectively. It is seen that the energy content of circular correlation is more than the energy content of linear correlation for ideal received SSS. The spectral analysis is performed on received signal under channels of varying noise density. BER is directly affected by noise density. The PSD for received SSS with BER = 15% and BER = 30% are shown in Figures 6 and 7 respectively.

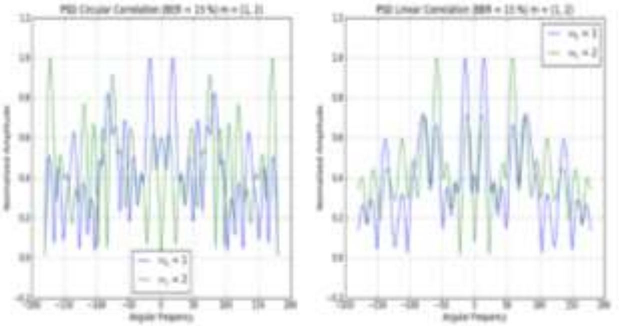


Figure 6. PSD of received SSS with BER = 15%.

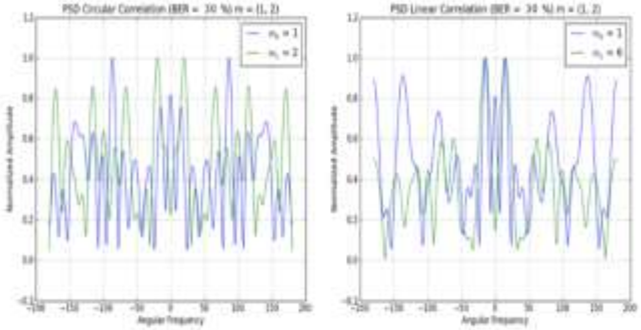


Figure 7. PSD of received SSS with BER = 30%.

From Figures 6 and 7, it can be inferred that, as the BER increases, the area under the PSD curve reduces. Thus, the energy content of both the correlation schemes lessens with increase in noise power. It is also observed that, the rate of reduction in energy of circular correlation is less than that of linear correlation scheme. Figures 5 and 6 shows accurate detection of m0 and m1 from the received SSS using both the schemes. In Figure 7 the linear correlation scheme fails to detect the correct value of m1 from the received SSS with BER = 30%, whereas circular correlation successfully detects the same from received SSS. This justifies the fall of linear correlation scheme in probability of SSS detection, as shown in Figure 4.

VI. CONCLUSION

In this paper, we have presented SSS detection schemes in LTE systems. The linear and circular correlation schemes for SSS detection are implemented. The probability of detection for both schemes is compared by Monte Carlo simulation method. The result shows that the correlation schemes are equally effective till a BER of 15%. 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. The spectral analysis shows the energy content of the received signal. The area under the PSD curve reduces with the increase in BER. As BER crosses the threshold of 15%, the linear correlation scheme fails to detect the received SSS more frequently than circular correlation scheme. This justifies the better performance of circular correlation scheme over linear correlation scheme for SSS detection.

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