Performance of SISID Algorithm for LTE Channel Models

C. Geetha Priya and S. Thilagavathi

***Abstract*—In conventional Long Term Evolution (LTE) cell search, the integer Carrier Frequency Offset (CFO) and sector identity are jointly detected by utilizing the Primary Synchronization Signal (PSS). In order to make an efficient detection of integer CFO and sector identity, Sequential Integer CFO and Sector Identity Detection (SISID) algorithm is proposed. SISID achieves superior detection efficiency mainly by exploiting the symmetric property of the PSS data carried on the positive subcarriers and the negative subcarriers. With this symmetric property, the proposed technique can detect the integer CFO without prior information of the particular PSS that the current cell adopts, making the low-complexity sequential detection possible. The Constant Amplitude Zero Auto Correlation (CAZAC) property of Zadoff–Chu sequence uses the symmetric property of the PSS sequence, which can be exploited to enhance the performance of the cell search. Additionally, the SISID algorithm removes the effect of the channel frequency responses. So the detection accuracy is enhanced.**

***Index Terms*—LTE, SISID, CAZAC.**

I. Introduction

In Device-to-Device (D2D) communications 3GPP LTE-Advanced standard, Synchronization constitutes a challenging task. Especially for out-of-network coverage cases, wherein the devices are not synchronized to any cell and therefore have to synchronize to each other. LTE Direct (LTE-D) was submitted to the 3GPP meeting in 2011 which proposed the study of the service requirement for direct over-the-air LTE D2D discovery and communication. Recent work on LTE D2D device discovery and D2D communication mainly focuses on the technical details, including discovery signal design, resource allocation and scheduling, synchronization mechanism, etc. With proximity discovery, users can discover other users that are in the proximity. Direct communication refers to devices communicating directly, without going via a base station, when they are within reach of each other [1].

The term device-to-device (D2D) communications refers to direct short-range communications between terminals of a mobile network, without the intermediate transmission to a base station (BS). Differing from conventional approaches, such as Bluetooth and WiFi-Direct, D2D communications utilize licensed spectrum with quality of service (QoS) guarantees, while no manual network detection-selection is required. Compared to the very appealing cognitive radio communications, where secondary transmissions are allowed in parallel with cellular (primary) transmissions, D2D communications are established by cellular (primary) users, reaping the benefits of being synchronized and controlled by the BS.

The timing of the transmissions is one of the most important aspects in D2D network as well as in conventional cellular systems since it is necessary to synchronize sender and receiver and to manage interference efficiently. The requirements on the timing accuracy in a slotted communication system depend on the specific system design. LTE-A uses frame transmission with long symbol duration (LTE-A symbol length is 67 µs) and cyclic signal extension (LTE-A has 5 and 17 µs defined), which eases the time synchronization requirements of the frames.

In an LTE network-assisted D2D scenario, the two UEs of the D2D pair are synchronized with the eNB, implying that slot and frame timing as well as frequency synchronization is acquired. Also, other fundamental system parameters (such as cyclic prefix (CP) length and duplexing mode) are known by the UEs. Therefore, the D2D candidates can be assumed to be synchronized to each other prior to D2D bearer establishment (e.g., assuming 5 µs CP and 300 m/µs signal propagation speed, a D2D pair can be assumed to be time synchronized within the CP up to 1,000–1,500 m distance which is significantly greater than what we can assume for the D2D distance).

A pair of D2D communication users must synchronize in space, time and frequency before D2D communication can be initiated. In LTE-Advanced, device discovery is made by transmitting a synchronization signal by one of the devices.

II. Literture Review

Paper *A New Cell Search Scheme in 3GPP Long Term Evolution Downlink, OFDMA Systems* presents a cell search procedure in 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) downlink systems [2]. The cell search operation done by three steps. Either the time-domain properties or the frequency-domain properties of signals conveyed in synchronization channels can be utilized for startup synchronization and cell search. However, the carrier frequency offset severely destructs the performance of time domain matched-filter based detection. Therefore, frequency domain cell search procedure is approached. In the conventional mode detection, symbol timing detection and fractional carrier frequency offset (CFO) estimation methods are adopted so that frequency-domain signal processing can be performed subsequently. Secondly, a joint detection method for integer carrier frequency offset and sector cell index information is proposed, which is shown to

Manuscript received August 4, 2015; revised January 13, 2016.
C. Geetha Priya is with Electronics and Communication Engineering, Kamaraj College of Engineering and Technology, Virudhunagar, Tamil Nadu, India (e-mail: geethapriyaece@kamarajengg.edu.in).
S. Thilagavathi is with Electronics and Communication Engineering, V.V. College of Engineering, Tisaiyanvilai, Tirunelveli, Tamil Nadu, India.

be capable of resisting symbol timing error. After the joint detection in the second step is completed, the third step is to find the cell ID group information and the frame timing by the SSS. So a coherent detection approach is proposed. The channel estimates derived from PSS are then applied to compensate the SSS signals. However, highly time-selective fading channels are disadvantageous to the coherent detection for the time division multiplexed PSS and SSS. Thus, this paper is used to detect the cell ID group without PSS channel estimates.

In paper *A Closed Concept for Synchronization and Cell Search in 3GPP LTE Systems*, the authors have investigated the time and frequency synchronization as well as the sector and cell search for the 3GPP LTE downlink [3]. The algorithms rely on the synchronization and cell-specific reference signals and are hence compliant to most recent 3GPP specifications.

The objective of synchronization is to retrieve OFDM symbol timing and to estimate the CFO. Time and (fractional) frequency offset coarse synchronization are performed in the time domain with the cyclic prefix based autocorrelation, while the sector and cell as well as the integer frequency offset are estimated in the frequency domain by using the primary and secondary synchronization signals. To improve the cell detection reliability, the estimated cell is afterwards confirmed through the cell-specific reference signal. All algorithms are evaluated under multipath channel conditions and an initial carrier frequency mismatch.

Paper *Two Symbol Timing Estimation Methods Using Barker and Kasami Sequence as Preamble for OFDM Based WLAN Systems* discusses about the various training sequences used as preamble in the data aided method for symbol timing estimation for OFDM based WLAN system [4]. The estimation of the exact point of the start of the symbol is significant as the OFDM system is very sensitive to symbol errors. The Barker and Kasami sequences have good autocorrelation properties. It performs well in no noise and channel distortion condition and also under low SNR. The simulation results show that the proposed scheme eliminates the side lobes present in earlier methods and therefore suitable for timing synchronization of OFDM WLAN system even in worst channel conditions. The proposed scheme develops a simple preamble structure and gives more accurate estimate of symbol timing. The proposed algorithm has good performance even in a Rayleigh fading channel with frequency offset.

Paper *Low-complexity Cell Search Algorithm for Interleaved Concatenation ML-sequences in 3GPP-LTE Systems* describes that 3GPP-LTE downlink system includes two synchronization signals: PSS and SSS [5]. The former is a Zadoff-Chu sequence carrying sector ID information while the latter consists of two maximal-length (ML)-sequences that relate to the cell identity group index. To avoid the so-called double collision problem, the SSS adopts interleaved concatenation of two ML sequences, which are allocated at even and odd subcarriers in subframe 0 and subframe 5. Considering all their possible combinations, detection of the cyclic shifts of these two ML sequences becomes a non-trivial task. Conventionally, the detection algorithms can be classified into two categories. In the first category, the respective cyclic shifts of the ML-sequences are detected sequentially and separately, which discards one half of the SSS and thus sacrifices certain performance. The second category finds the cyclic shifts of the ML-sequences simultaneously to gain performance by testing all the hypotheses, and thus requires much higher complexity. SSS detection algorithm which not only tries to take advantage of the interleaved pattern to enhance detection performance but also exploit the properties of the cyclic-shift indices of the two ML sequences to reduce detection complexity. The SSS detection algorithm, called quantized double correlation (QDC), with the following features:

1) Differential correlation to remove channel responses.
2) Quantized cross-correlation to simplify arithmetic computation.
3) Utilization of interleaved pattern of ML sequences to increase detection reliability.
4) Exploiting the relationship between two indices to reduce the search range.

In paper *A Low Complexity Architecture for the Cell Search Applied to the LTE Systems*, a low-complexity, high-speed, and high performance architecture was proposed for both steps of the cell search in the LTE systems: sector ID detection and cell ID group detection [6].

An algorithm based on the Maximum Likelihood Sequence Detection (MLSD) called "sign bit MLSD". Simulations show that the proposed methods result in more than 90% reduction in area compared to the state-of-the-art.

Joint Sector Identity And Integer Part Of Carrier Frequency Offset Detection By Phase-Difference In Long Term Evolution Cell Search Process [7]. An innovative algorithm for detecting the sector ID and ICFO together via the PSS-matching process is presented in this paper. Detection error rate of sector ID and ICFO is simulated for various SNR values. To accomplish this cell search process, two synchronisation signals, the primary synchronisation signal (PSS) and the secondary synchronisation signal, are periodically broadcasted from base stations in the LTE system.

Multicarrier Offset Estimation in LTE System [8]. In COMP-OFDM systems, the multiple transmitters must be synchronized to prevent mutual interference. Applying COMP transmission, a receiver must estimate multiple CFO corresponding to the multiple receiving signals for compensation. Impact of failure in LTE network performance will be severe loss, since large investment in small cells has been made in LTE networks to increase capacity and coverage. When synchronization fails, both objectives are lost. The objective of designing training sequence set is to apply orthogonal sequences which achieve the zero mutual interference. Constant Amplitude Zero Auto Correlation sequence used at the K-th BS is circular shifting version of Z by right shifting Dk. The multiple fractional frequency offset are estimated considering single BS, 2 BSs and 3BSs respectively using ML function. The optimum time shift index D2, D3 are also determined simulating the mutual interference measure.

III. System Model [9]

In the LTE system, the Primary Synchronization Sequence takes the form of the Zadoff–Chu sequence with length 62:

$$x_u(m) = \begin{cases} e^{\frac{-j\pi um(m+1)}{63}} & m = 0,\dots,30. \\ e^{\frac{-j\pi u(m+1)(m+2)}{63}} & m = 31,\dots.,61. \end{cases} \quad (1)$$

where the root index u adopted for the PSS is $u\epsilon\{25,29,34\}$, corresponding to three sector identities $N_{ID}^{(2)} \epsilon \{0,1,2\}$. The autocorrelation function is having a spike like response at the time index 62 which is the length of Zadoff Chu Sequence as in Fig. 1.

The symmetry property of the transmitted PSS and the cyclic cross correlation which is constant and equal to $0.126\left(\frac{1}{\sqrt{N_{zc}}}\right)$ is simulated and validated as in Fig. 2.

The auto correlation of a prime length Zadoff–Chu sequence with a cyclically shifted version of itself is zero, i.e., it is non-zero only at one instant which corresponds to the cyclic shift as simulated in Fig. 3.

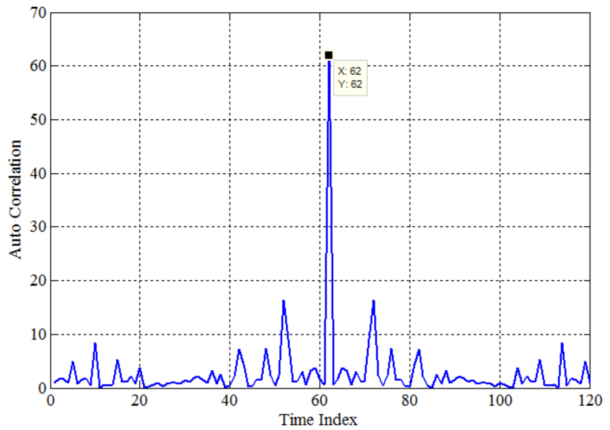

Fig. 1. Absolute value of the auto-correlation functions for the primary D2D synchronization signal in LTE-Advanced.

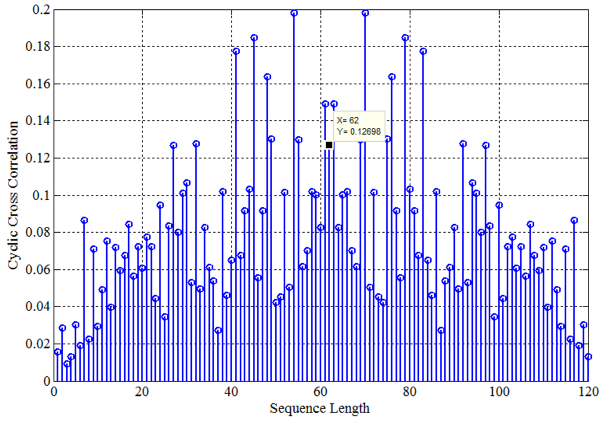

Fig. 2. From this plot, cyclic cross correlation is constant and equal to 0.126 $\left(\frac{1}{\sqrt{N_{zc}}}\right)$ for root index 25 & 29.

The Zadoff–Chu sequence has constant amplitude zero autocorrelation (CAZAC) property and the symmetric property of the PSS sequence, which can be exploited to enhance the performance of the cell search. The mapping between the Zadoff–Chu sequence index m and the subcarrier index n is given by

$$m = \begin{cases} n+31, & n = -1,\dots,-31. \\ n+30, & n = 1,\dots\dots.,30. \end{cases} \quad (2)$$

where the DC subcarrier is skipped. Replacing m by n in (1), the transmitted PSS data at the nth subcarrier takes the form of

$$D_u(n) = \mathrm{e}^{\frac{-j\pi u(n^2+31.32)}{63}} - j\pi un, n = \pm1,..,\pm3 \quad (3)$$

The transmitted PSS data on the negative subcarriers and on the positive subcarriers are symmetric. At the receiver side, the received PSS data are not only contaminated by channel fading and noise, but are also corrupted by the CFO due to the Doppler effect and frequency mismatch between the transmitter and receiver oscillators. The corrupted frequency-domain received signals are shifted by the CFO. For example, if the frequency mismatch of the oscillators is ±15 ppm, the resulting CFO can be up to ±2.5 subcarrier spacings when the center frequency is 2.5 GHz. After compensating the fractional CFO and obtaining the coarse timing information, the frequency-domain received PSS sequence takes the form of

$$z(n) = H(n)D_u(n-\varepsilon) + V(n), \quad n = -31,\dots,-1,1,\dots,31 \quad (4)$$

where $H(n)$ and $V(n)$ respectively denote the channel frequency response and the additive Gaussian noise at the nth subcarrier. $D_u(n-\varepsilon)$ denotes the transmitted PSS data with the root index u and the integer CFO ε.

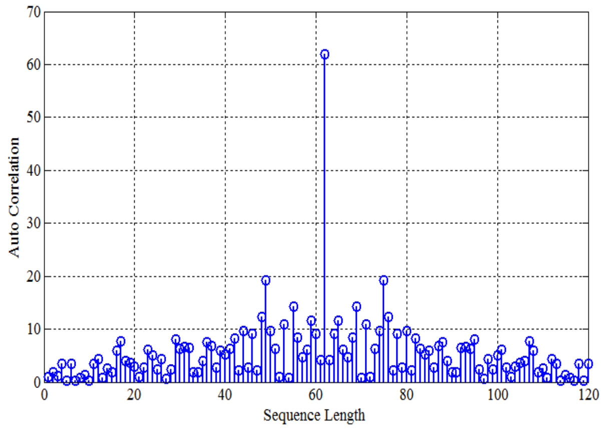

Fig. 3. The auto correlation of a prime length Zadoff–Chu sequence with a cyclically shifted version of itself is zero, i.e., it is non-zero only at one instant which corresponds to the cyclic shift.

IV. SISID Algorithm [9]

SISID technique consists of three steps:

1) Differential correlation of the normalized frequency-domain PSS data for each pair of neighboring subcarriers is done to remove the effect of channel fading.
2) Using symmetry property of the transmitted PSS in (3), integer CFO is detected without knowing the sector identity.
3) With the detected integer CFO compensated, the sector identityis detected easily by computing the correlation between the received PSS and the transmitted PSSs with different root indices.

By using (4), the normalized received PSS can be expressed as

$$\hat{Z}(n) = \frac{Z(n)}{|Z(n)|}$$
$$= \frac{H(n)D_u(n-\varepsilon)}{|H(n)D_u(n-\varepsilon)+V(n)|} + \frac{V(n)}{|H(n)D_u(n-\varepsilon)+V(n)|}$$
$$\approx e^{j\theta_H(n)} D_u(n-\varepsilon) \quad (5)$$

where $\theta_H(n)$ is the phase of the complex channel frequency response $H(n)$. Then, to eliminate this channel phase $\theta_H(n)$, the coherence bandwidth is assumed to be sufficiently large such that the channel frequency responses at consecutive subcarriers are similar. Under this assumption, the differential correlations of the normalized PSSs at the consecutive subcarriers are formulated as

$$G(n) = \hat{Z}(n)\hat{Z}^*(n+1)$$
$$\approx e^{(j\theta_H(n)-\theta_H(n+1))} D_u(n-\varepsilon) D_u^*(n+1-\varepsilon)$$
$$\approx D_u(n-\varepsilon) D_u^*(n+1-\varepsilon) \quad (6)$$

where $(.)^*$denotes the complex conjugate operation.

The objective function $f_{\varepsilon,\mu}(\hat{\varepsilon})$ of the integer CFO detection as follows:

$$f_{\varepsilon,u}(\hat{\varepsilon}) \triangleq \frac{1}{30} \sum_{n=-31}^{-2} G(n+\hat{\varepsilon})\, G(-n-1+\hat{\varepsilon})$$
$$f_{\varepsilon,\mu}\widehat{(\varepsilon)} \approx \frac{1}{30} \sum_{n=-31}^{-2} \big(D_u(n+\hat{\varepsilon}-\varepsilon) D_u^*(-n+\hat{\varepsilon}-\varepsilon)\big) \cdot$$
$$\big(D_u(-n-1+\hat{\varepsilon}-\varepsilon) D_u^*(n+1+\hat{\varepsilon}-\varepsilon)\big) \quad (7)$$

Thus, the channel frequency responses are approximately removed. When $\hat{\varepsilon} = \varepsilon$, (7) becomes,

$$f_{\varepsilon,u}(\varepsilon) \approx \frac{1}{30} \sum_{n=-31}^{-2} \big(D_u(n) D_u^*(-n)\big)$$
$$\cdot \big(D_u(-n-1) D_u^*(n+1)\big)$$
$$= \frac{1}{30} \sum_{n=-31}^{-2} |D_u(n)|^2 |D_u(n+1)|^2 = 1 \quad (8)$$

where (8) is due to the symmetry of the PSS as specified in (3). The criterion of the integer CFO detection is defined as below and is simulated as in Fig. 4.

$$\hat{\varepsilon}^* = \underset{\hat{\varepsilon}^*=0,\pm1,\pm2,\pm3}{\operatorname{argmin}} |f(\hat{\varepsilon}) - 1|$$

where $|\ \cdot|$is the absolute operation and $\hat{\varepsilon}^*$is the detection result of the integer CFO.

After the integer CFO detection, the sector ID is detected by reusing $G(n+\hat{\varepsilon}^*)$

$$g_{\hat{\varepsilon}^*,\varepsilon,u}(\hat{u}) \triangleq \sum_{n=-31}^{-2} \big(G(n+\hat{\varepsilon}) + G^*(n-1+\hat{\varepsilon}^*)\big)$$
$$\times \big(D_{\hat{u}}^{\ *}(n) D_{\hat{u}}(n+1)\big)$$
$$\approx \sum_{n=-31}^{-2} \big(D_u(n) D_{\hat{u}}^{\ *}(n) D_u^*(n+1) D_{\hat{u}}(n)\big) \cdot$$
$$\big(D_u(-n) D_{\hat{u}}^{\ *}(n) D_u^*(-n-1) D_{\hat{u}}(n+1)\big) \quad (10)$$

The detection criterion of the sector identity is defined as $\hat{u}^*$ and is simulated as in Fig. 5.

$$\hat{u}^* = \underset{\hat{u}\ \epsilon\{25,29,34\}}{\operatorname{argmax}} g_{\hat{\varepsilon}^*,\varepsilon,u}(\hat{u}) \quad (11)$$

The symmetric property of the PSS is also used in (10) to reduce the computation complexity. Moreover, the transmitted PSSs with root indices 29 and 34 are conjugate with each other

$$D_{29} = D_{34}^*(34), \quad n=\pm1,\ldots,\pm31 \quad (12)$$

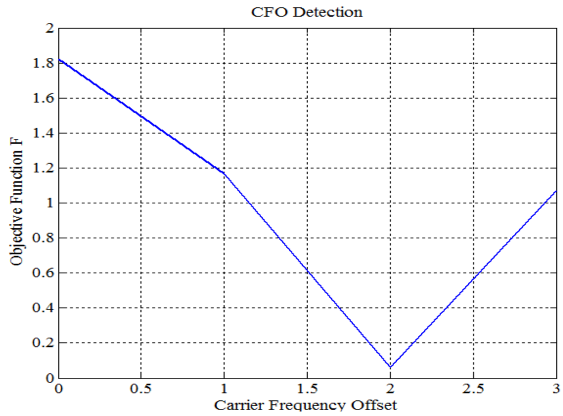

Fig. 4. Detected CFO value is 2. For the root index 25, when $\varepsilon = \hat{\varepsilon}$, the objective function $f_{\varepsilon,u}(\varepsilon)$ becomes minimum.

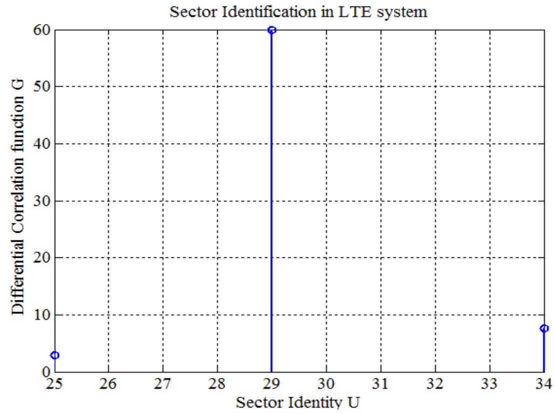

Fig. 5. Differential Correlation function G for the sector identity detection U is chosen to be 29 from the set of three sector Identities {25, 29, 34}.

V. Simulation Results and Discussion

International Telecommunication Union (ITU) defines three extended channel models for LTE system. They are, Extended Pedestrian A model (EPA), Extended Vehicular A model (EVA), Extended Typical Urban model (ETU). The Power Delay Profile for the LTE models are tabulated.Comparison of the performance of SISID Algorithm under AWGN and the LTE channel models like EPA, EVA and ETU is simulated in Fig. 6.

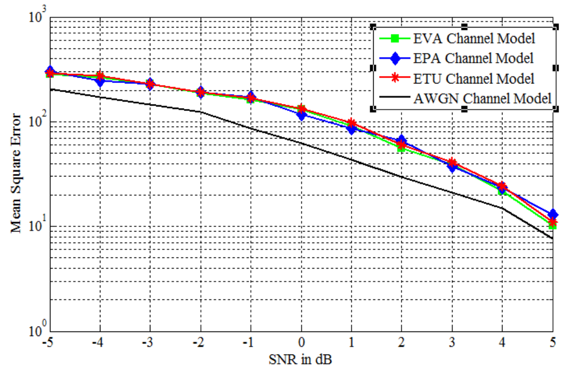

Fig. 6. Comparison of the performance of SISID Algorithm under AWGN and the LTE channel models like EPA, EVA and ETU.

TABLE I: EPA CHANNEL — POWER DELAY PROFILE

Excess Delay(ns)	Relative Power(dB)
0	0
30	-1
70	-2
90	-3
110	-8
190	-17.2
410	-20.8

TABLE II: EVA CHANNEL — POWER DELAY PROFILE

Excess Delay(ns)	Relative Power(dB)
0	0
30	-1.5
150	-1.4
310	-3.6
370	-0.6
710	-9.1
1090	-7.0
1730	-12.0
2510	-16.9

TABLE III: ETU CHANNEL — POWER DELAY PROFILE

Excess Delay(ns)	Relative Power(dB)
0	-1
50	-1
120	-1
200	0
230	0
500	0
1600	-3
2300	-5
5000	-7

TABLE IV: ADOPTED EXTENDED ITU CHANNEL MODELS

Model	Channel taps	Delay spread (ns)	Maximum excess tap delay (ns)	Doppler frequency (Hz)
EPA	7	45	410	5
EVA	9	357	2510	70
ETU	9	991	5000	300

VI. CONCLUSION

The symmetry property of the transmitted PSS and the cyclic cross correlation which is constant and equal to $0.126\left(\frac{1}{\sqrt{N_{zc}}}\right)$ is simulated and validated.Thus the properties of the ZC sequence which were used to identify the sector and the CFO is simulated. Using the proposed algorithm, it is simulated in MATLAB for the root index of 25, when = $\hat{\varepsilon}$, the objective function $f_{\varepsilon,u}(\varepsilon)$ becomes minimum and the CFO value is estimated as 2. The Differential Correlation function G is simulated forthe sector identity detection U which is chosen to be 29 from the set of three sector Identities {25, 29, 34}. Using the Power Delay Profile values from the Tables I-IV, the performance of the SISID algorithm in the LTE channel was found using MATLAB for AWGN, EPA, EVA and ETU models.

REFERENCES

[1] S. Mumtaz and J. Rodriguez, *Smart Device to Smart Device Communication*, Springer International Publishing, 2014.

[2] P.-Y. Tsai and H.-W. Chang, "A new cell search scheme in 3GPP long term evolution downlink, OFDMA systems," in *Proc. Int. Conf. WCSP*, Nov. 2009, pp. 1–5.

[3] K. Manolakis, G. Estevez, V. Jungnickel, W. Xu, and C. Drewes, "A closed concept for synchronization and cell search in 3GPP LTE systems," in *Proc. IEEE WCNC*, Apr. 2009, pp. 1–6.

[4] C. G. Priya and M. Suganthi, "Two symbol timing estimation methods using barker and kasami sequence as preamble for OFDM–based WLAN systems," *Signal Processing*, vol. 90, no. 7, pp. 2177-2189, 2010

[5] C.-C. Liao, P.-Y. Tsai, and T.-D. Chiueh, "Low-complexity cell search algorithm for interleaved concatenation ML-sequences in 3GPP-LTE systems," *IEEE Wireless Commun. Lett.*, vol. 1, no. 4, pp. 280–283, Aug. 2012.

[6] A. Golnari, G. Sharifan, Y. Amini, and M. Shabany, "A low complexity architecture for the cell search applied to the LTE systems," in *Proc. 2012 19th IEEE International Conference on Electronics, Circuits and Systems (ICECS)*, 2012, pp. 300-303.

[7] S.-L. Su, Y.-C. Lin, and Y.-J. Fan, "Joint sector identity and integer part of carrier frequency offset detection by phase-difference in long term evolution cell search process," *Communications, IET*, vol. 7, no. 10, pp. 950–959, 2013.

[8] C. G. Priya and S. K. Susee, "Multicarrier offset estimation in LTE system," *International Journal of Applied Engineering Research*, vol. 9, no. 24, pp. 28655-28663, 2014.

[9] C.-Y. Chu, I.-W. Lai, Y.-Y. Lan, and T.-D. Chiueh, "Efficient sequential integer CFO and sector identity detection for LTE cell search," *Wireless Communications Letters*, vol. 3, no. 4, pp. 389-392, Aug. 2014.

C. Geetha Priya is working as a professor/ECE, with the Kamaraj College of Engineering and Technology, Virudhunagar, Tamil Nadu, India. She has academic teaching experience of 17 years. She has completed her B.E degree (ECE), M.E degree (communication systems), which were both first class with distinction in 1997 and 1999, respectively. She has been awarded the Ph.D. (wireless communication) under the Faculty of Information and Communication in 2010. More than 30 of her research articles have been published in high impact factor journals and conferences of international status. She has been the guest of honour in the Institute of Engineers forum. She is a life member of ISTE and IETE.

S. Thilagavathi is an assistant professor in the Department of Electronics and Communication Engineering, VV College of Engineering, Tisaiyanvilai. She received her M.E. degree from Anna University, Chennai. She has 10 years' experience and published 7 papers in national conferences, 1 paper in international conference and 4 papers in international journal.