

A Low Complexity Physical-Layer Identity Detection for 3GPP Long Term Evolution

Hendra Setiawan, Hiroshi Ochi

Computer Science and Electronics, Kyushu Institute of Technology

Kawazu 680-4, Iizuka-shi, Fukuoka-ken, Japan, 820-8502

Email: hendra@dsp.cse.kyutech.ac.jp, ochi@dsp.cse.kyutech.ac.jp

Abstract—Long Term Evolution (LTE) is one of radio access technology that has been intensively studied in 3GPP standard group to support instantaneous downlink and uplink peak data rates of 100Mb/s and 50Mb/s within 20 MHz downlink and uplink spectrum allocations, respectively. Employing OFDMA and scalable bandwidth scheme in downlink access impact on increasing cell search complexity. In this paper we propose low complexity physical layer identity detection as one of cell search step using finite impulse response (FIR) and partial cross-correlation. Our propose scheme is done in time domain instead of frequency to avoid FFT involvement and decrease processing latency. As a result, the proposed scheme just needs 20169 LUTs when implemented in FPGA Virtex-4 XC4VLX200 and can perform physical layer identity detection for SNR 0dB or higher in AWGN channel by probability more than 95%.

I. INTRODUCTION

The LTE, also known as 3.9G, is intended to enhance the 3G and 3.5G systems in order for them to adopt higher peak data rates with extreme high mobility support, [1] [2], [3], [4], and [5]. The LTE PHY employs some advanced technologies that are new to cellular applications. These include Orthogonal Frequency Division Multiplexing (OFDM), Multiple Input Multiple Output (MIMO) data transmission, and scalable bandwidth scheme up to 20 MHz [1] [2], [3], [4], and [5]. In addition, the LTE PHY uses Orthogonal Frequency Division Multiple Access (OFDMA) on the downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) on the uplink.

As in conventional cellular systems, just the user equipment (UE) turn on, UE searching for the base station with the lowest path loss without having any pre-knowledge of the mobile communication environment [1], and [2]. This process is called "initial cell search" aimed at frequency and timing synchronization as well as cell identity recognition. In an OFDMA system, in order to maintain this orthogonally among terminals, tight time and frequency synchronization between the terminal and the base station is required [6].

Cell search in LTE should support a scalable bandwidth of 1.25 MHz to 20 MHz as specified in [1]. However, cell search procedure in 3GPP LTE systems should be completed with low processing complexity at the terminal and within a short time [2].

Unfortunately, overall cell search procedure involves many algorithms that can not be detailed in such of time. Some algorithms regarding synchronization have been discussed in

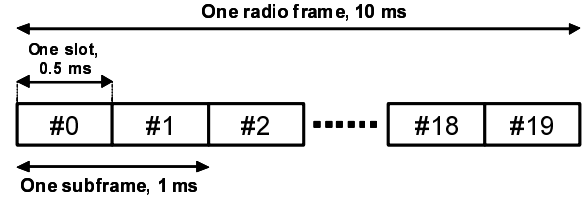


Fig. 1. Frame structure type 1.

[2] and [6]. Cell search procedures for LTE introduced in [2] and [7] use previous specification as main reference. Therefore in this paper we will discuss it based on newest references, i.e. [1] and [8]. We focus on physical layer identity detection as a part of cell search procedures.

This paper will be organized as follow. In section II downlink frame structure for LTE are introduced then followed by detailing physical layer identity in section III. The proposed scheme for physical layer identity detection is served in section IV. Section V discusses about fixed point simulation, and finally conclusions are drawn in section VI.

II. LTE DOWNLINK FRAME STRUCTURE

In the LTE downlink, OFDMA is employed as the multiplexing scheme. Different to OFDM transmission scheme, OFDMA allows the access of multiple users on the available bandwidth. Each user is assigned a specific time-frequency resource. These are referred to as physical resource blocks (PRBs) in the LTE specifications. PRBs thus have both a time and frequency dimension. Before discussing more in this term, better to consider the physical layer frame structure as well.

Two frame structure types are defined in [8] i.e. frame structure type 1 for FDD mode, and frame structure type 2 for TDD mode. For the frame structure type 1, the 10 ms radio frame is divided into 20 equally sized slots of 0.5 ms. A subframe consists of two consecutive slots, so one radio frame contains 10 subframes as illustrated in Fig.1 with sampling period, $T_S = 1/(15000 \times 2048)$ second.

For frame structure type 2, the 10 ms radio frame consists of two half-frames of length 5 ms each. Each half-frame is divided into five subframes of each 1 ms, as shown in Fig.2. There are two special subframes consist of three fields DwPTS (Downlink Pilot Timeslot), GP (Guard Period), and UpPTS (Uplink Pilot Timeslot).

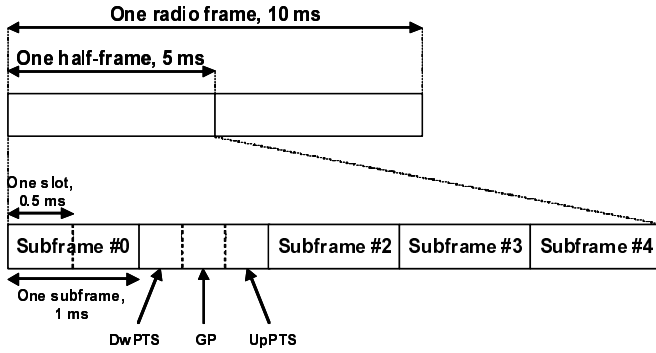


Fig. 2. Frame structure type 2.

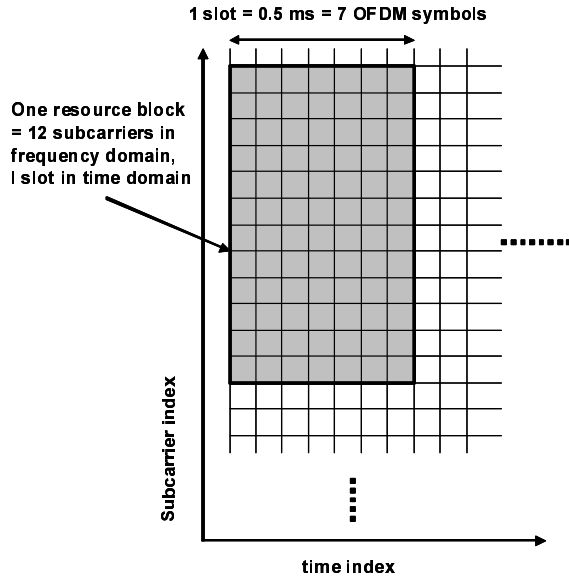


Fig. 3. Physical resource block.

To avoid ambiguousness, type 1 is become the scope of this paper and type 2 frame structures are therefore not considered even though the proposed scheme can be performed in type 2 as well.

As mentioned [1], a slots consist of either 6 or 7 OFDM symbols, depending on whether the short or long cyclic prefix is employed. However, the subcarriers in LTE have a constant spacing of $\Delta f = 15$ kHz. As shown in Fig.3, in the frequency domain, 12 subcarriers form one resource block. The resource block size is the same for all bandwidths. Each box within the resource bloc represents a single subcarrier for one symbol period and is referred to as a resource element.

Physical signals use assigned resource elements. However, unlike physical channels, physical signals do not convey information to/from higher layers. There are two types of physical signals: reference signals used to determine the channel impulse response (CIR) and synchronization signals which convey network timing information. In this paper, we only focus on synchronization signals as a carrier of physical layer identity.

Synchronization signals are classified as primary and sec-

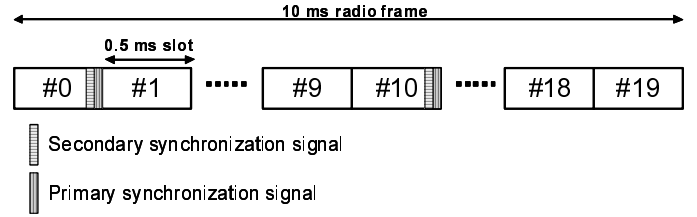


Fig. 4. Synchronization signal structure

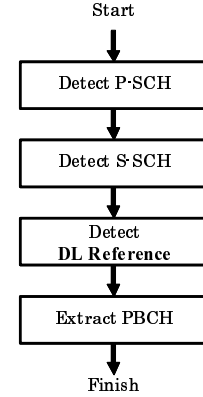


Fig. 5. LTE cell search procedures.

ondary synchronization signals. Both primary and secondary synchronization signals are transmitted on the 64 subcarriers centered around the DC subcarrier during the 0th and 10th slots of a 10 ms frame as shown in Fig.4.

III. PHYSICAL LAYER CELL IDENTITY

Physical-layer cell identity is a parameter which is used to differentiate between the signals of different radio cells. Based on [8], there are 504 unique physical-layer cell identities. The physical layer cell identities are grouped into 168 unique physical layer cell identity groups, each group containing three unique identities. The grouping is such that each physical layer cell identity is part of one and only one physical layer cell identity group. A physical-layer cell identity (N_{ID}^{cell}) is thus uniquely and defined by,

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

where $N_{ID}^{(1)}$ representing the physical-layer cell-identity group within the range of 0 to 167, and $N_{ID}^{(2)}$ representing the physical-layer identity within the physical-layer cell-identity group in the range of 0 to 2.

Physical-layer identity is recognized within cell search procedure as well as acquiring time and frequency synchronization. Cell search procedure for LTE consists of four steps as shown in Fig.5. First, subscriber must detect primary synchronization channel (P-SCH) that always exists each 5 ms. The result of this process is 5 ms cyclic timing reference [1] as well as physical-layer identity. Second is secondary synchronization channel (S-SCH) detection to get slot numbering and physical layer cell identity group. For further cell parameters,

TABLE I
ROOT INDICES FOR THE PSS

$N_{ID}^{(2)}$	root index u
0	25
1	29
2	34

subscriber have to get downlink reference signals and extract Physical Broadcast Channel (PBCH).

As mentioned above, physical-layer identity can be detected in primary synchronization signal (PSS). Therefore we discuss PSS deeply below and regardless secondary synchronization signal.

A. PSS Generation

The sequence PSS is generated from a frequency-domain Zadoff-Chu sequence [8] according to,

$$d_u(n) = \begin{cases} e^{-j \frac{\pi u n(n+1)}{63}} & n = 0, 1, \dots, 30 \\ e^{-j \frac{\pi u (n+1)(n+2)}{63}} & n = 31, 32, \dots, 61 \end{cases} \quad (2)$$

where the Zadoff-Chu root sequence index (u) is given by Table.I

Fig.6 show three possibilities of PSS based on Eq.2. For simplification reasons, we can combine signal pattern for $N_{ID}^{(2)} = 1$ and $N_{ID}^{(2)} = 2$ since they are conjugated each others in frequency domain as well as time domain. It means we save 33% of resource than before.

B. PSS Mapping

The mapping of the sequence to resource elements depends on the frame structure. For frame structure type 1, the PSS shall be mapped to the last OFDM symbol in slots 0 and 10. For frame structure type 2, the PSS shall be mapped to the third OFDM symbol in subframes 1 and 6.

In order for the terminal to acquire timing and frequency offset in a short time, a synchronization channel is transmitted using central 1.25 MHz bandwidth, regardless of the system bandwidth of the cell [1] as shown in Fig.7. The central 1.25 MHz corresponds to 76 subcarriers with subcarrier spacing of 15 kHz. Index number in Fig.7 belong to n in the Eq.2. There are 5 subcarriers in right and left side of synchronization signal reserved to zero padding.

IV. PHYSICAL-LAYER IDENTITY DETECTION SCHEME

A. Proposed Scheme

Our proposed scheme to extract physical layer identity from PSS is based on states below.

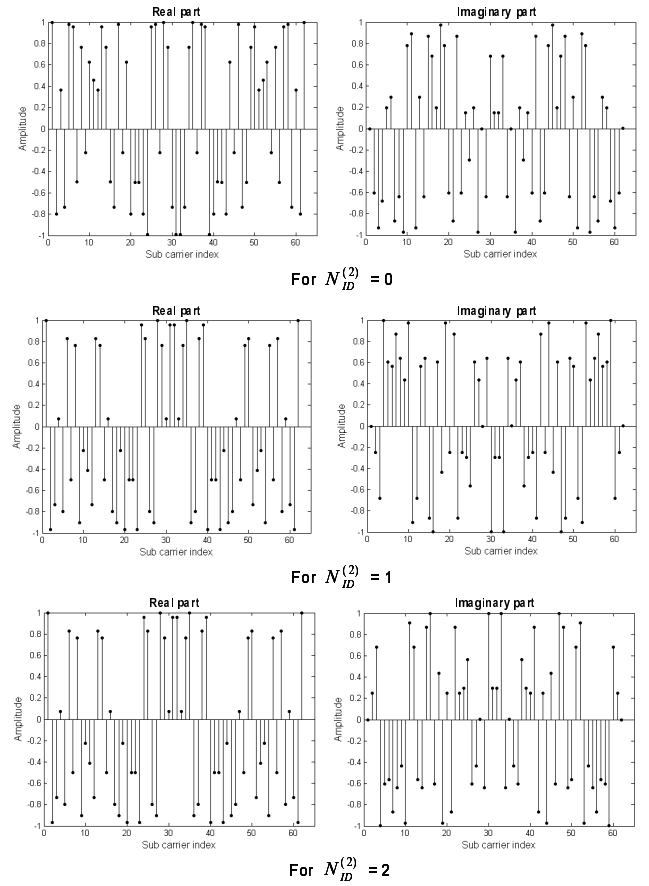


Fig. 6. PSS in frequency domain

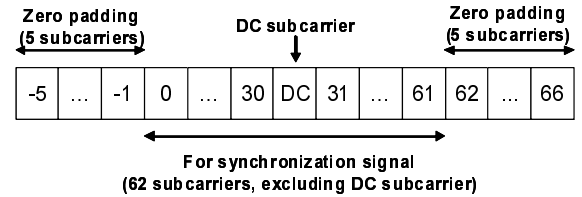


Fig. 7. PSS arrangement in frequency domain

1) *Detect Synchronization Signal in Time Domain:* Synchronization sequence is mapped to the central band of entire bandwidth due to the OFDMA based downlink air interface. However, the terminal does not know the downlink timing of the system at the beginning of the cell search; hence, frequency domain processing (e.g., DFT) based timing detection at each sample will make the cell search processing complexity too high for the terminal [2]. Therefore, we want to avoid DFT involvement that occupied large of computation resources by time domain detection instead of frequency domain detection.

2) *Take the Center of Frequency using Finite Impulse Response (FIR):* As mentioned above, synchronization sequence is mapped to the central 1.25 MHz bandwidth. To extract this sequence, we propose finite impulse response (FIR) because of stability and linearity of phase response. The passband is within 31 subcarriers and stopband is 36 subcarrier from the central of bandwidth. Since the subcarrier spacing is 15

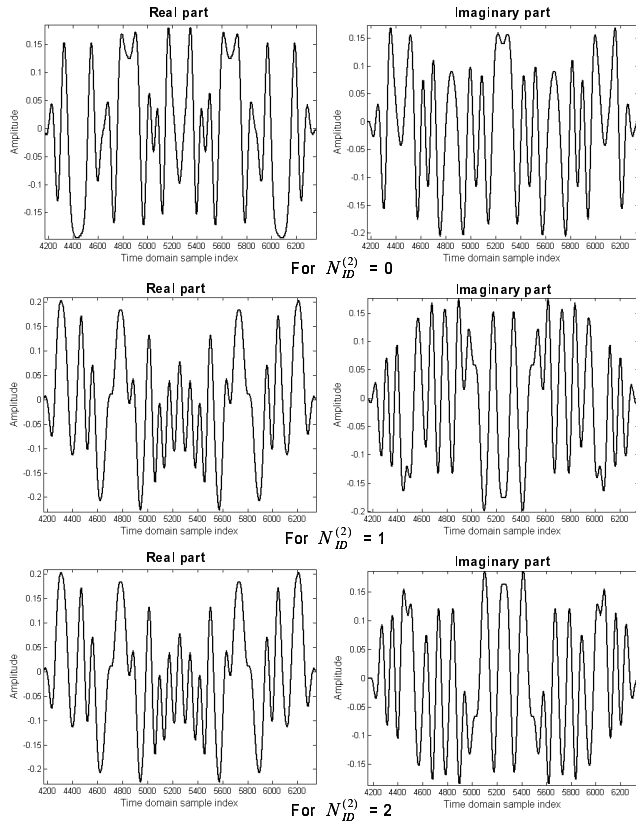


Fig. 8. PSS in time domain after filtering

kHz, we can derive passband frequency 465 kHz and stopband frequency 540 kHz.

In frequency domain, PSS have symmetrical pattern as shown in Fig.6. Since they are mapped to the subcarriers around the central frequency, after filtering in time domain, the symmetrical property still exist. Fig.8 show the PSS after passed FIR for three possibilities.

3) *Detect Physical Layer Identity using cross-correlation:* Common method to detect physical layer identity is cross-correlation based on equation below,

$$P_{cc}(n) = \sum_{k=0}^{N-1} p^*(k) \cdot r(k-n) \quad (3)$$

where $p(k)$ is the PSS pattern at k -th tap, and N denote cross-correlation signal length or number of tap.

Since there are three root indices for the PSS, three cross-correlations must be involved to detect all PSS possibilities at the same time. However, $N_{ID}^{(2)} = 1$ and $N_{ID}^{(2)} = 2$ are conjugate each other, thus we can reduce number of cross-correlation. Moreover, we must consider 2048 tap cross-correlation as a worst case due to scalable point of IFFT from 128 to 2048. Fortunately, PSS just occupy same number of subcarriers regardless number of IFFT point. Therefore we can take smallest number of IFFT point i.e. 128 to reduce number of tap of cross-correlation.

Furthermore, to minimize the number of multiplier and

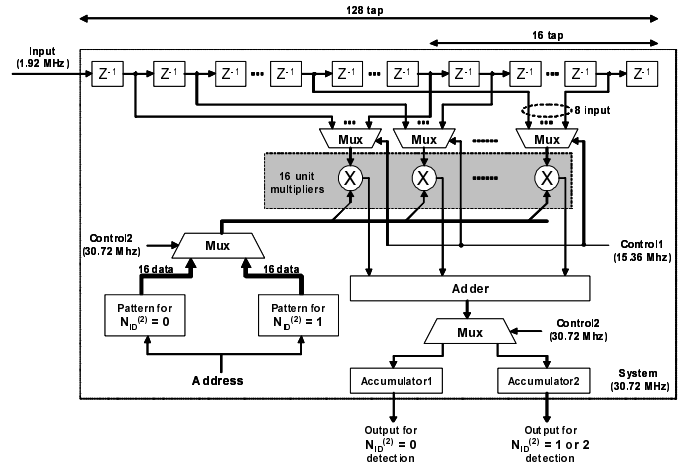


Fig. 9. Partial cross-correlation computation

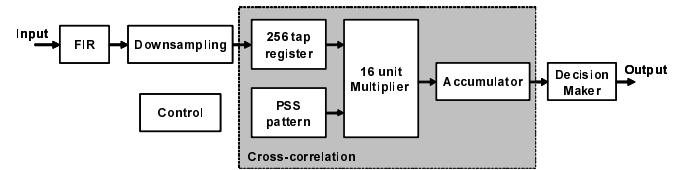


Fig. 10. Block diagram proposed system

adder in the cross-correlation, we introduce partial cross-correlation as shown in Fig.9. So far, it can be implemented due to the computational clock is higher than input data sampling. Since computational clock is 16 times higher than input data sampling, the number of multiplier can be reduced from 128 to 8 units. However, we need 16 units multiplier due to two different patterns for $N_{ID}^{(2)} = 0$ and $N_{ID}^{(2)} = 1$ should be separately computed.

B. System Architecture

We develop the proposed system using model-based RTL design to get many advantages[9]. Synplify DSP computer aided design (CAD) tool has been involved to develop our system. Fig.10 show the block diagram of proposed system that implemented in Fig.11 using model-based RTL design.

The proposed system consists of three main functions: filtering, cross-correlation and decision maker. FIR, for filtering function, is built using filter design and analysis tool (FDATool) available in Synplify DSP. Some parameters belong to filter design are given in Table.II

Cross-correlation implementation is based on partial cross-correlation that mentioned before, consists of four main components: 356 tap register, PSS pattern, multiplier, and accumulator. Dissimilar with general cross-correlation that consist of 128 multipliers for 128 tap cross-correlation, our proposed cross-correlation consists only 16 multiplier. Since number of multiplier is reduced, number of adder will reduce automatically. The only overhead for the proposed partial cross-correlation is a controller and multiplexers as a manifestation of time scheduling.

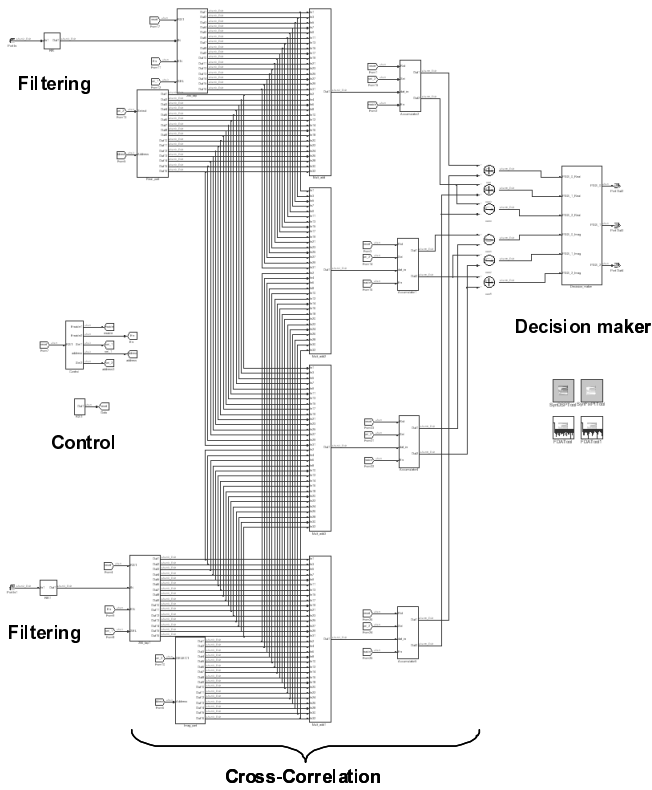


Fig. 11. The proposed system in model based RTL

TABLE II
FILTER PARAMETERS FOR FDATAOOL

Filter type	Lowpass
Design method	FIR Equiripple
Filter order	Minimum order
Density factor	32
Frequency sampling	30.72 MHz
Frequency passband	0.465 MHz
Frequency stopband	0.54 MHz
Attenuation magnitude	60dB

The last function of our proposed system is a decision maker. This function consists of two processes to decide the physical layer identity number within a PSS, i.e. peak detector and decision logic. As mentioned before cross-correlation output consists of two stream for three $N_{ID}^{(2)}$ possibilities. First stream is used for $N_{ID}^{(2)} = 0$ identifying, that easy to recognize from the peak existence. The second steam is used for $N_{ID}^{(2)} = 1$ and $N_{ID}^{(2)} = 2$. To distinguish them, we consider the peak polarity. Since they are conjugated each other, they will have difference peak polarity i.e. positive and negative. Therefore, we use peak and polarity as reasons to recognize $N_{ID}^{(2)} = 1$ and $N_{ID}^{(2)} = 2$.

TABLE III
SIMULATION PARAMETER IN MODEL BASED RTL

$N_{ID}^{(2)}$	0, 1, 2
IFFT point of received signal	2048
number of used subcarrier	1200
frequency sampling	30.72 MHz
Channel model	AWGN
SNR	-5 to 15 dB
sample per slot	15360

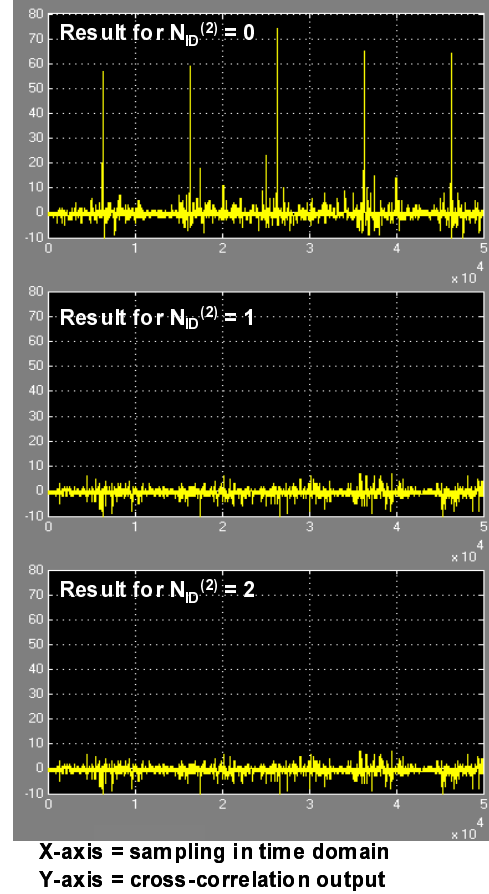


Fig. 12. Simulation snapshot for SNR = 1 dB

V. SIMULATION AND SYNTHESIS RESULT

Simulation is performed based on some parameters mentioned in Table.III. Fig.12 show simulation snapshot in case of SNR 1dB and $N_{ID}^{(2)} = 2$ has been sent from transmitter.

Furthermore, the performance of the proposed system for various SNR is given in Fig.13. The results are taken by 500 radio frames that consist of 1000 PSSs. As shown in Fig.13, for SNR = 0dB or higher, more than 95% of physical layer identity can be recognized correctly.

Regarding to the complexity, we use number of look up table (LUT) needed to implement it in such of FPGA as a reference. Synthesis result for Virtex-4 xc4vlx200 implemen-

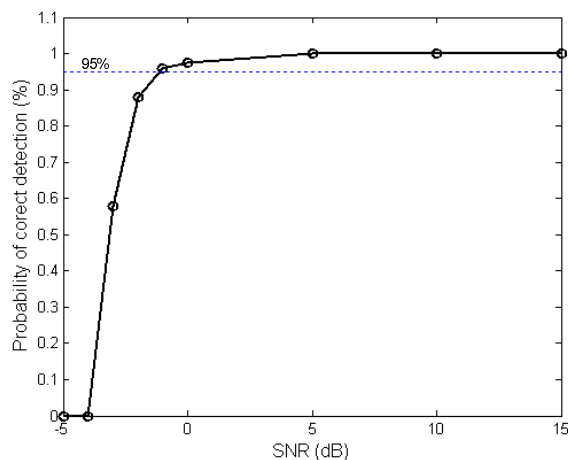


Fig. 13. Proposed system performance in various SNR

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Mapping to part: xc4vlx200ff1513-10
Cell usage:
FDE          240 uses
FDR           8 uses
FDRE        8726 uses
GND           15 uses
MULT_AND     1027 uses
MUXCY        126 uses
MUXCY_L     9266 uses
MUXF5        640 uses
MUXF6        320 uses
VCC           16 uses
XORCY       8895 uses
LUT1         905 uses
LUT2        9411 uses
LUT3        2659 uses
LUT4        1959 uses

SRL primitives:
SRL16E       240 uses

I/O Register bits:          0
Register bits not including I/Os:  8974 (5%)
Total load per clock:
    clk: 9214

Mapping Summary:
Total LUTs: 15174 (8%)

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Fig. 14. Proposed system synthesis result

tation shown in Fig.14. Our proposed system needs around 20169 LUTs that distributed on FIR (35%), cross-correlation (55%) and others (10%). As comparator, it is around 24.8% of 2048 point FFT implementation using the same target device. Therefore, time domain detection will save resources compare with frequency domain detection. As addition, using the target device, our proposed system can work up to 37.2 MHz clock rate that satisfy for 30.72 MHz required clock.

VI. CONCLUSION

Employing OFDMA and scalable bandwidth scheme in LTE downlink access impact on increasing complexity in search procedure such as physical layer identity recognition. However, we propose time domain instead of frequency domain detection to reduce complexity by avoiding FFT involvement. Partial cross-correlation also introduces to minimize computational resources.

In this paper we also have done fixed point simulations in AWGN channel with various of SNR. As a result, more than 95% physical layer identity can be detected correctly in case of SNR = 0 dB or higher. As additional, for FPGA implementation, proposed design only requires around 20169 LUTs in virtex-4 xc4vlx200. It is only 24.8% of 2048 point FFT implementation in those FPGA that might be required if we detect physical layer identity in frequency domain.

ACKNOWLEDGMENT

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