SSS Detection Method for Initial Cell Search in 3GPP LTE FDD/TDD Dual Mode Receiver

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***Abstract*—In 3GPP Long Term Evolution (LTE) system, initial cell search procedure comprises two steps using primary synchronization signal (PSS) and secondary synchronization signal (SSS). This paper presents SSS detection method for second step of initial cell search. In general, coherent detection using estimated channel frequency response (CFR) at PSS is used for SSS detection, but performance degradation is occurred by difference of channel between PSS and SSS in time division duplex (TDD) mode. Thus we propose non-coherent detection using partial correlation and differential correlation. Moreover, we consider cyclic-prefix (CP) detection algorithm that uses CP and its repetition part of data symbol, and we investigate influence of CP detection in SSS detection process.**

I. INTRODUCTION

3GPP LTE system achieves higher frequency efficiency and user throughput, and provide full IP-based functionalities with low latency and low cost. In the downlink, Orthogonal Frequency Division Multiplexing (OFDM) based radio access was adopted because of its inherent robustness against multipath interference and its affinity to different transmission bandwidth arrangements. 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 ID in addition to the received subframe 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 [1].

In 3GPP LTE system, initial cell search procedure comprises two steps using PSS and SSS as shown in Fig. 1. First, symbol timing and physical-layer ID are detected by PSS in time domain. Second, radio frame timing and cell group ID are detected by SSS in frequency domain [2]. In this paper, we present SSS detection for second step of initial sell search process. In general, coherent detection using estimated channel frequency response (CFR) at PSS is used for SSS detection. In TDD mode, however, performance degradation is occurred by difference of channel between PSS and SSS. This performance degradation is caused by frame structure in TDD mode. Thus we propose non-coherent detection which has stable performance regardless of Doppler frequency. Moreover, we consider influence of CP detection in SSS detection process, because the precise timing of the SSS changes depending on the CP type. CP detection algorithm determines two choices of CP type using correlation between CP and its repetition part of data symbol before SSS detection process.

This paper is organized as follows. Section II describes secondary synchronization signal. The coherent and non-coherent SSS detection are described in Section III. Then, CP detection algorithm is given in Section IV. Simulation results are discussed in Section V. Finally conclusions are given in Section VI.

II. SECONDARY SYNCHRONIZATION SIGNAL

A. PSS and SSS frame structure

In 3GPP LTE systems, downlink and uplink transmissions are organized into radio frames with 10ms duration. Two radio frame structures are supported; Type 1 and Type 2 are applicable to frequency division duplex (FDD) mode and TDD mode, respectively [2].

In FDD mode, the PSS and SSS are multiplexed using time division multiplexing (TDM) into two slots, i.e., #0 and #10 slots within one radio frame as shown in Fig. 2(a). Moreover, the PSS and SSS are multiplexed at the last and second last

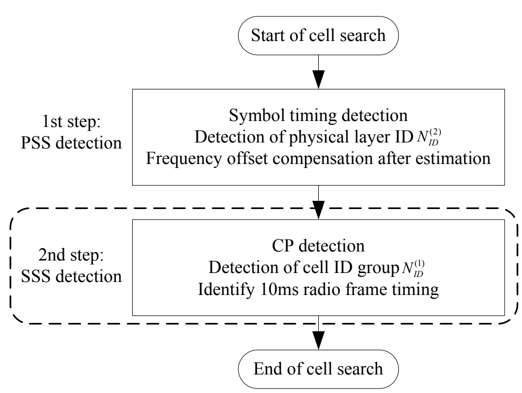


Fig. 1. Flow of initial cell search procedure

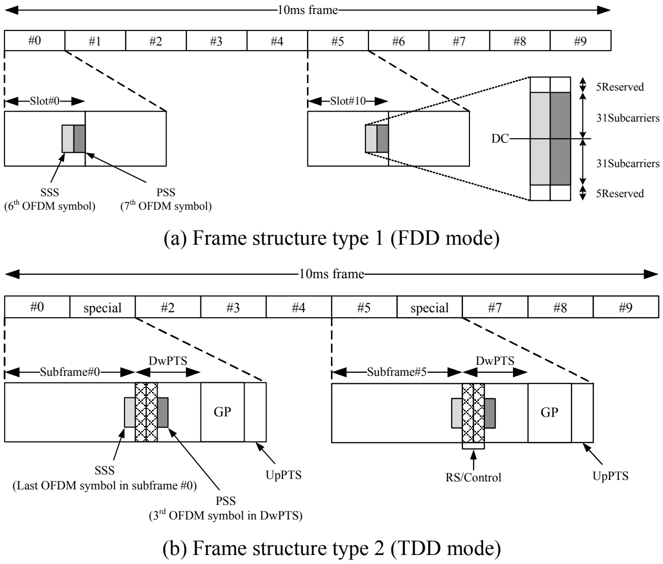


Fig. 2. PSS and SSS frame structure in time domain

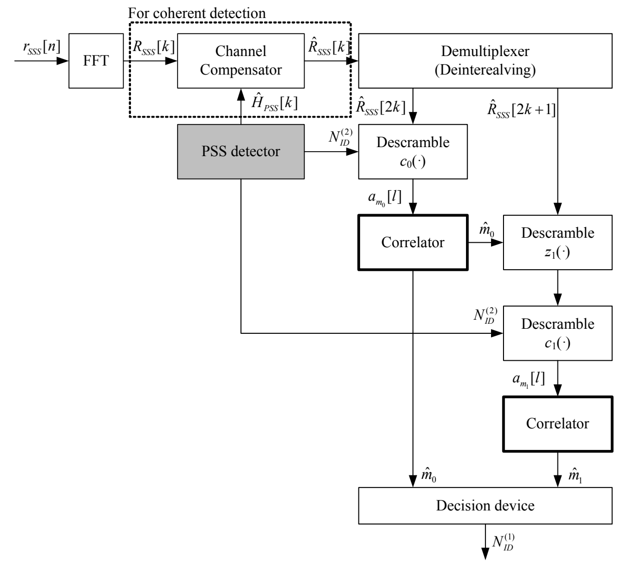


Fig. 3. Structure of SSS detection

OFDM symbol positions of the two slots, i.e. SSS is placed in adjacent PSS. In TDD mode, however, PSS is placed in the third OFDM symbol positions of Downlink Pilot Time Slot (DwPTS) as shown Fig. 2(b). The PSS increase the distance between the SSS and the PSS, from being sent in adjacent symbols to being three symbols apart. If the PSS and SSS are further separated in time the channel will change more between these two symbols, in particular at high Doppler frequencies, and one may argue that an effect of this will be degraded cell search performance in coherent detection [3].

B. SSS sequences

The SSS is organized into an interleaved concatenation of two length-31 binary sequences [2]. To randomize the interference from the neighboring cells, the concatenated sequence is scrambled with a scrambling sequence given by the PSS [4]. The combination of two length-31 sequences defining the SSS differs between subframe 0 and subframe 5 according to

$$d(2n)=\begin{cases} s_0^{(m_0)}(n)c_0(n) & \text{in subframe 0}\\ s_1^{(m_1)}(n)c_0(n) & \text{in subframe 5}\end{cases}$$
$$d(2n+1)=\begin{cases} s_1^{(m_1)}(n)c_1(n)z_1^{(m_0)}(n) & \text{in subframe 0}\\ s_0^{(m_0)}(n)c_1(n)z_1^{(m_1)}(n) & \text{in subframe 5}\end{cases} \quad (1)$$

where $s(n)$ is SSS sequence , and $c(n)$ and $z(n)$ are scrambling sequence. The indices m_0 and m_1 are derived from cell ID group $N_{ID}^{(1)}$.

III. SSS Detection Algorithms

Both coherent and non-coherent detection may play a part in the initial cell search procedure: in the case of the PSS, non-coherent detection is used, while for SSS detection, coherent or non-coherent method can be used. Fig. 4 shows structure of SSS detection, and channel compensator is only used for coherent detection. Each algorithm is applied to correlator block in Fig. 3. The received SSS in frequency domain can be expressed as

$$R_{SSS}[k]=d[k]H_{SSS}[k]+W[k] \quad (2)$$

where $d[k]$ is SSS in frequency domain, $H_{SSS}[k]$ is CFR at SSS, and $W[k]$ is the additive white Gaussian noise (AWGN).

A. Coherent detection

In 3GPP LTE system, the PSS and SSS are closely located in time to enable the coherent detection [5]. For coherent detection, the UE estimates the CFR $\hat{H}_{PSS}^{*}[k]$ by using the received PSS sequence. From the point of view of the UE, the SSS detection is done after the PSS detection, and the channel can therefore be assumed to be known based on the PSS sequence. In frequency domain, channel compensated SSS is given by

$$\hat{R}_{SSS}[k]=R_{SSS}[k]\hat{H}_{PSS}^{*}[k] \quad (3)$$

After channel compensation, deinterleaved and descrambled signal can be expressed as

$$a_{m_0}[l]=\hat{R}_{SSS}[2k]c_0[k] \quad (4)$$

$$a_{m_1}[l]=\hat{R}_{SSS}[2k+1]c_1[k]z_1^{(\hat{m}_0)}[k] \quad (5)$$

Correlation output of coherent detection is cross-correlation between descrambled signal and cyclic shift of an SSS sequence, and can be represented as

$$\hat{m}_0 = \arg\max_i \left| \sum_{l=0}^{30} a_{m_0}[l] s^{(i)}[l] \right|^2 \quad (6)$$

$$\hat{m}_0 = \arg\max_i \left| \sum_{l=0}^{30} a_{m_0}[l] s^{(i)}[l] \right|^2 \quad (7)$$

where $\hat{m}_0$ and $\hat{m}_1$ are i-th SSS sequence. The identified $\hat{m}_0$ and $\hat{m}_1$ indicated the frame timing and cell ID group $N_{\mathrm{ID}}^{(1)}$.

B. Non-coherent detection

We consider two non-coherent detection algorithms that are differential correlation based and partial correlation based algorithms. Structure of non-coherent detection is the same Fig. 3 except for channel compensator, and deinterleaved and descrambled signal can be expressed as

$$\beta_{m_0}[l] = R_{SSS}[2k] c_0[k] \quad (8)$$

$$\beta_{m_1}[l] = R_{SSS}[2k+1] c_1[k] z_1^{(\hat{m}_0)}[k] \quad (9)$$

Differential correlation is used for coarse frequency synchronization, and it can be used for non-coherent detection of SSS [6]. Correlation output of differential correlation is complex conjugate multiply between adjacent descrambled signals, and correlation output is given by

$$\hat{m}_0 = \arg\max_i \left| \sum_{l=1}^{30} \beta_{m_0}[l] \beta_{m_0}^*[l-1] s^{(i)}[l] s^{*(i)}[l-1] \right|^2 \quad (10)$$

$$\hat{m}_1 = \arg\max_i \left| \sum_{l=1}^{30} \beta_{m_1}[l] \beta_{m_1}^*[l-1] s^{(i)}[l] s^{*(i)}[l-1] \right|^2 \quad (11)$$

Differential correlation based non-coherent detection is robust frequency selective fading channel, because $\beta_{m_0}[l]\beta_{m_0}^*[l-1]$ can reduce channel effect. But this operation induces SNR loss due to squaring loss of complex conjugate multiply.

Cross-correlation uses all sequence between received signal and reference signal. In partial correlation, however, the integration range of the correlation is divided into the number of small blocks [7]. The partial correlation output is summation of correlation value which is individually obtained at each block, and can be written as

$$\hat{m}_0 = \arg\max_i \sum_{j=0}^{M-1} \left| \sum_{l=jN_M}^{(j+1)N_M - 1} \beta_{m_0}[l] s^{(i)}[l] \right|^2 \quad (12)$$

$$\hat{m}_1 = \arg\max_i \sum_{j=0}^{M-1} \left| \sum_{l=jN_M}^{(j+1)N_M - 1} \beta_{m_1}[l] s^{(i)}[l] \right|^2 \quad (13)$$

where M is the number of blocks, and N_M is the number of sample in the small block. M can be defined as a fundamental design parameter and should be chosen according to the coherence bandwidth of multipath fading channel, and this paper sets up M=3.

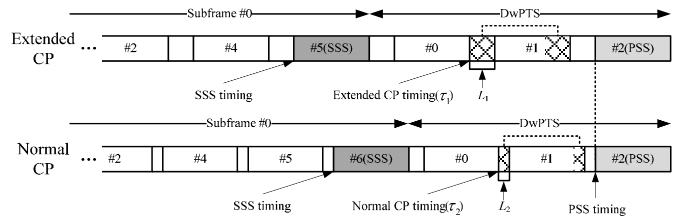


Fig. 4. Structure of CP detection

IV. CP DETECTION

3GPP LTE system supports normal CP and extended CP type considering channel environment. The precise timing of the SSS changes depending on the CP type as shown in Fig. 4. Before SSS detection process, the CP type is unknown a priori to the UE, and it is therefore blindly detected by checking for the SSS at the two possible positions [8]. However, we consider a simple algorithm for determining the CP type, before SSS detection process. This algorithm is based on the principle developed by Van de Beek. Correlation between CP and its repetition part of data symbol is determined for two choices of CP type [9]. This correlation is normalized with their power, because integration range of the correlation varies with CP type. Correlation term and normalize term are represented as

$$R_i = \sum_{n=0}^{L_i - 1} r^*(n+\tau_i) r(n+\tau_i+N) \quad (14)$$

$$P_i = \sum_{n=0}^{L_i - 1} \left| r(n+\tau_i+N) \right|^2 \quad (15)$$

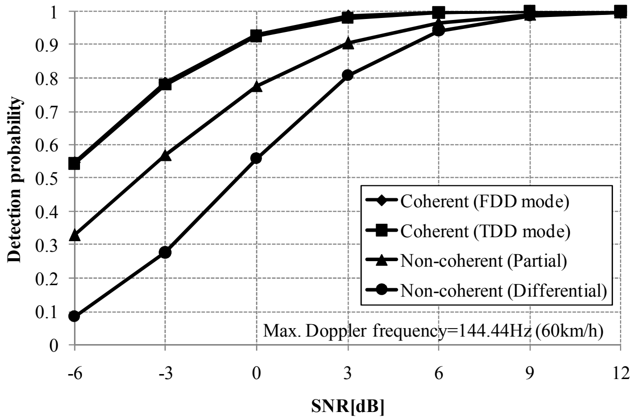
where τ_1 and τ_2 represent the normal CP timing and extended CP timing, respectively. L_1 and L_2 represent the corresponding CP length as shown in Fig. 4.

The CP type corresponding to the normalized correlation with the maximum value indicates the CP type.

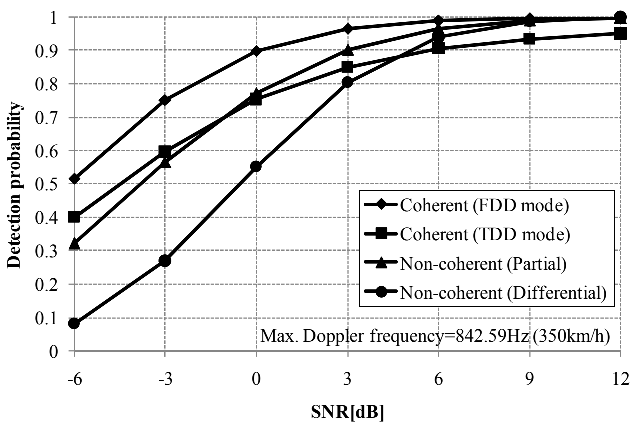
$$M_i = \frac{\mathrm{Re}\{R_i\}}{P_i}, \quad \begin{cases} \text{if } M_1 > M_2 \text{ , then extended CP} \\ \text{if } M_1 < M_2 \text{ , then normal CP} \end{cases} \quad (16)$$

TABLE I.
SIMULATION PARAMETERS

Parameters	Value
Center frequency	2.6 GHz
Bandwidth	1.25MHz
CP type	Normal CP
PSS sequence	ZC sequence ($N_{ID}^{(2)} = 0$)
SSS sequence	m-sequence based ($N_{ID}^{(1)} = 101$)
Channel model	Extended TU
Max. Doppler frequency	144.44Hz / 842.59Hz



(a) Low Doppler frequency environment



(b) High Doppler frequency environment

Fig. 5. SSS detection probability (Detection time=5ms)

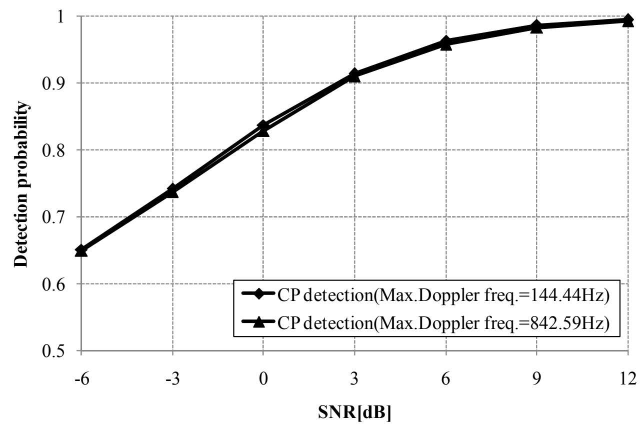


Fig. 6. CP detection probability versus SNR

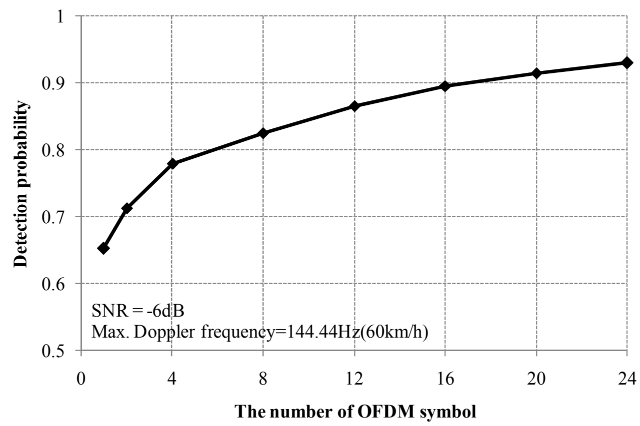


Fig. 7. CP detection probability versus the number of symbol accumulation

Main advantage of this algorithm is that correlation value can be accumulated by using OFDM symbol within one radio frame in order to improve CP detection performance at low SNR. In addition to, this algorithm can reduce the computational complexity compared with blind CP detection using SSS detection at the two possible positions.

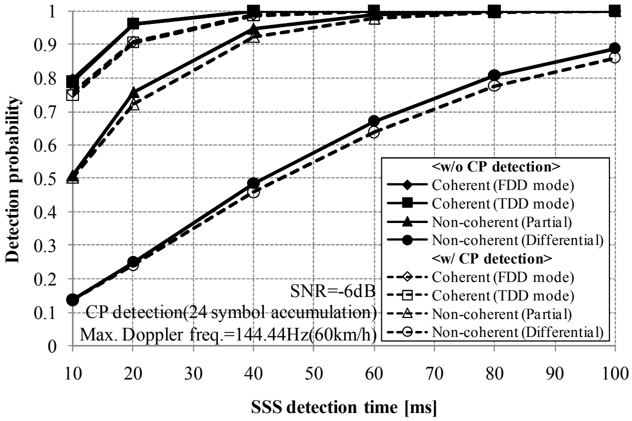
V. SIMULATION RESULTS AND DISCUSSION

The major simulation parameters are based on LTE standards as represented in Table I [2]. For the multipath fading channel environments, the extended typical urban (TU) model which is recommended by 3GPP is considered [10]. To evaluate the SSS detection performance, we assumed that PSS detection is perfect and CFR of PSS is known for coherent detection.

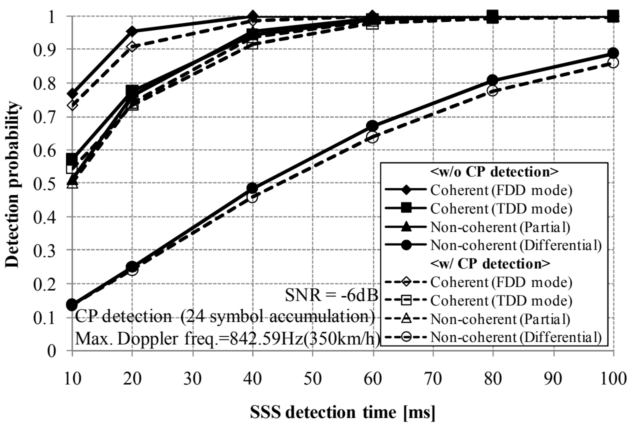
Figs. 5(a) and 5(b) show the SSS detection probability during one half-frame (5ms). Regardless of FDD/TDD mode, coherent detection outperforms non-coherent detection in low Doppler frequency. In high Doppler frequency, however, coherent detection has performance degradation induced by channel difference between PSS and SSS. Even if CFR is known at PSS, coherent detection is lower than partial based non-coherent detection in TDD mode. If practical channel estimation is adopted, the performance of coherent detection is lower than these results. Unlike coherent detection, partial correlation based non-coherent detection has stable performance regardless of Doppler frequency. Differential correlation based non-coherent detection has performance degradation about -3dB compared with partial correlation based. This performance degradation is caused by squaring operation of differential correlation.

Fig. 6 depicts the CP detection probability using one OFDM symbol. We can see that the CP detection probability is 63% at SNR -6dB. From this result, performance degradation of SSS detection can be induced by CP detection error, and we consider symbol accumulation for improvement of CP detection performance.

Fig. 7 represents CP detection probability versus the number of symbol accumulation at SNR -6dB. Maximum of accumulation symbol sets 24, because minimum of downlink subframe is 2 at uplink-downlink configuration #0 in TDD mode. We can see that the CP detection probability of approximately 92% is achieved with 24 symbols accumulation at SNR -6dB. From this result, performance



(a) Low Doppler frequency environment



(b) High Doppler frequency environment

Fig. 8. SSS detection time comparison

degradation of SSS detection due to CP detection error can reduce using symbol accumulation CP detection.

Fig. 8(a) and 8(b) show the SSS detection time to achieve target performance in high and low Doppler frequency environment, respectively. Target performance is 99% detection probability at SNR -6dB, and CP detection is performed using 24 OFDM symbols accumulation due to minimize CP detection error. Coherent detection achieves a much faster SSS detection time than non-coherent detection in low Doppler frequency environment. In TDD mode, however, coherent SSS detection time is increased by channel difference between PSS and SSS at high Doppler frequency. SSS detection time to achieve target performance is the same coherent detection and partial correlation based non-coherent detection. Since these results assumed that CFR is known at PSS, if practical channel estimation is adopted then coherent detection time is slower than non-coherent detection. In case of considering CP detection, SSS detection has performance degradation until 60 ms, this is influenced by CP detecion error. We can see that effect of CP detection error is little for SSS detection, and SSS detection time to achieve target performance is increased by 80 ms.

VI. CONCLUSION

In this paper, we compared coherent and non-coherent SSS detection method for second step of initial cell search in 3GPP LTE system. Coherent detection considering TDD mode has performance degradation induced by frame structure in high Doppler frequency environment. However, partial correlation based non-coherent detection has stable performance regardless of Doppler frequency. Consequently, partial correlation based non-coherent detection is suitable for TDD/FDD dual mode receiver. Furthermore, we investigated influence of CP detection in SSS detection process. SSS detection has little performance degradation using CP based CP detection algorithm.

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REFERENCES

[1] Satoshi Nagata, Yoshihisa Kishiyama, Motohiro Tanno, and Mamoru Sawahshi, "Investigation on Transmit Diversity for Synchronization Channel in OFDM Based Evolved UTRA Downlink," VTC 2008-Fall, Sept. 2008.

[2] 3GPP TS 36.211 v8.5.0, "Physical Channel and Modulation," Dec. 2008.

[3] 3GPP TSG-RAN WG1 #52 R1-080873, "On the design of DwPTS," Ericsson, Feb. 2008.

[4] 3GPP TSG RAN WG1 50bis R1-074143, "Secondary SCH Mapping and Scrambling," Texas instruments, Oct. 2007.

[5] H.-G. Park, I.-K. Kim, and Y.-S. Kim, "Efficient coherent neighbor cell search for synchronous 3GPP LTE system," *ELECTRONICS LETTERS* Vol.44 No.21, Oct. 2008.

[6] Zheng Du, Jinkang Zhu, "Improved Coarse Frequency Synchronization Algorithm with Extended Differential Detection," *Proc. WCNC'03*, Vol. 1, pp. 470-477, 2003.

[7] Young-Hwan You, Jong-Ho Paik, Cheol-Hee Park, Min-Chul Ju, Ki-Won Kwon, and Jin-Woong Cho, "Low-complexity Coarse Frequency-offset Synchronization for OFDM Applications," *IEEE ICC 2001*, vol. 8, pp. 2494-2498, 2001.

[8] 3GPP TSG RAN WG1 LTE TDD Ad Hoc R1-071884, "P-SCH/S-SCH design in alternative TDD frame structure," Samsung, April. 2007.

[9] K. Pushpa, Ch. Nanda Kishore and Y. Yoganandam, "Estimation of Frequency Offset, Cell ID and CP Length in OFDMA mode of WMAN," *IEEE TENCON*, Nov. 2008.

[10] 3GPP TS 36.101 v8.4.0, "User Equipment radio transmission and reception," Dec. 2008.