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Performance Analysis of Cell Search Scheme for OFDM Cellular Systems

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Abstract—**OFDM has been a widely accepted technology in high rate and multimedia data service systems, such as 3G Long Term Evolution (3G LTE) system in the 3rd Generation Partnership Project (3GPP). A cell search scheme based on the sequence hopping of Synchronization channel symbols is proposed. The assigned hopping pattern provides cell identification (cell ID) to a mobile station (MS).The synchronization channel structure allows MS to acquire OFDM symbol/frame timing, cell ID in the cell search stage. The detection of the cell for 3G LTE and sequence hopping are compared. Here several sequences are generated for existing LTE cell searching and sequence hopping cell searching. The sequences are transmitted through OFDM block. Using these sequences the bit error rate is calculated. The performance of existing LTE and sequence hopping is compared in terms of bit error rate.**

Index Terms— **OFDM, cell search, synchronization, sequence hopping, 3G long term evolution**

Introduction

DUE to its inherent robustness to the multipath fading, no intra-cell interference and granular resource allocation capability, orthogonal frequency division multiplexing (OFDM) techniques have been widely adopted for many high data rate applications, such as DAB/DVB (digital audio and video broadcasting) system, high-rate WLAN (wireless local area networks) such as IEEE802.11a, HIPERLAN II and Terrestrial DMB (digital multimedia broadcasting) system. Also, for a smooth migration toward 4G, 3G LTE (Long Term Evolution) plan was announced recently to apply OFDM techniques for downlink transmission in the 3G LTE cellular network. The design of a synchronization channel (SCH) for supporting an efficient cell search in mobile station (MS) is one of the most important topics in standardization (1). Currently, the working assumption for 3G LTE cell search is to use two SCHs; a primary synchronization channel (P-SCH) and a secondary synchronization channel (S-SCH). Basically, the cell search scheme in 3G LTE is based on the hierarchical cell search scheme of WCDMA system with two types of SCH, which is known to be beneficial in asynchronous cellular Systems. The P-SCH and the S-SCH are code multiplexed. In WCDMA, while in LTE, they are time multiplexed in adjacent symbol positions. In LTE, the P-SCH and the S-SCH are transmitted twice in every 10 msec radio frame (4). Three different P-SCH signals are used to distinguish three sector cells within a base station (BS) and 170 different SSCH signals are used to differentiate 170 BSs so that 510 cell identities (cell IDs) can be specified by the combination of the P-SCH signals and the S-SCH signals. The P-SCH and the S-SCH occupy centered 1.25 MHz frequency band among the total system bandwidth.

The cell search procedure consists of two steps: In the first step, an MS finds P-SCH sequence index and P-SCH symbol timing (5 msec timing) using three time domain matched filters which correspond to the P-SCH sequences. In the second step, the MS detects S-SCH sequence index and 10 msec frame timing based on frequency domain correlation using 340 S-SCH sequences.

One drawback of the current 3G LTE cell search scheme is the computational burden in the first step since matched filter operation requires a large number of complex multiplications. Another drawback is that the complexity in detecting a tower. In this paper, as an alternative method, we propose an efficient cell search scheme based on a sequence hopping technique. The performance of proposed scheme is compared with that of 3G LTE scheme under the 3G LTE simulation environment.

SCH Transmission Bandwidth

Scalable multiple transmission bandwidths are specified such as 1.25, 2.5, 5, 10, 15, and 20 MHz .The SCH is transmitted in the center of cell transmission bandwidth with the constant bandwidth of 1.25MHz regardless of the overall transmission bandwidth of the cell.

Block Diagram of OFDM

The OFDM transmitter and receiver is as shown in figure1. The Fast Fourier Transform (FFT) transforms a cyclic time domain signal into its equivalent frequency spectrum. The amplitude and phase of the sinusoidal components represent the frequency spectrum of the time domain signal. The IFFT performs the reverse process, transforming a spectrum (amplitude and phase of each component) into a time domain signal. At the output of the transmitter OFDM output is generated and at the receiver the original data comes out.

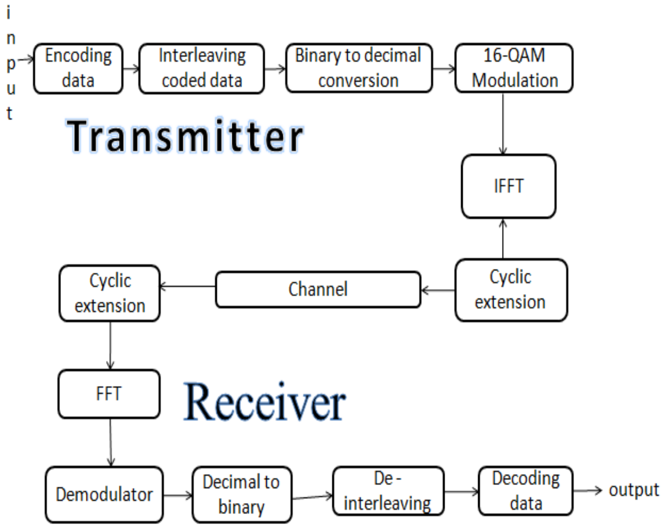

Fig1.OFDM Block Diagram.

SCH Signals and Cell Identities

This hierarchical cell search procedure is performed in two steps using two signals:

1. Primary Synchronization Signal and
2. Secondary Synchronization Signal.

The synchronization signals have 72 subcarriers reserved for them, but they use only 62 of the 72 subcarriers. The reason only 62 subcarriers are used is because it enables the UE to perform 64 point FFT and lower sampling rate.(5)

The Primary Synchronization signal first determines one of three cell identities (0, 1, 2), also represented by $N^{(2)}ID$ as shown in figure 2.

Then the secondary synchronization signal, is used to determine a cell ID between 0 and170 represented by $N^{(1)}$ ID. The primary signal is based on Zadoff-Chu sequence which is a Constant Amplitude Zero Auto Correlation (CAZAC) sequence. A Zadoff-Chu sequence is a complex-valued mathematical sequence which exhibits the useful property that cyclically shifted versions of it are orthogonal to each other. (1)

The complex value at each position (n) of each root Zadoff–Chu sequence (u) given by,

$$x_u(n) = e^{-j}\frac{\pi un(n+1)}{N_{ZC}}$$

Where 0 <=n<=NZC-1, NZC = length of sequence.

1. Primary synchronization signal: The Primary Synchronization Signals are modulated using one of three different frequency domain Zadoff-Chu sequence. (2)

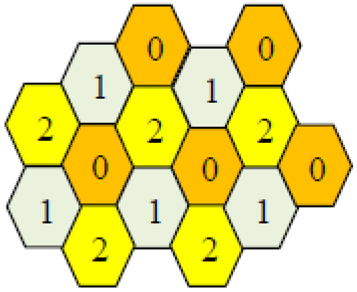

Fig2.Pattern Reuse for 3 P-SCH Sequences.

Sequence generation:

The sequence *d* (*n*) used for the primary synchronization signal is generated from a frequency-domain Zadoff-Chu sequence according to:

$$d_u(n) = e^{-j}\frac{\pi un(n+1)}{63} \quad \text{For n=0, 1,…..30}$$

$$d_u(n) = e^{-j}\frac{\pi u(n+1)(n+2)}{63} \quad \text{For n=31, 32….61}$$

Where the Zadoff-Chu root sequence index *u* is given by

$N^2{}_{ID}$	Root index u
0	25
1	29
2	34

2. Secondary synchronization signal: The secondary synchronization signal is generated using the interleaved concatenation of two binary sequences (8).

Sequence generation:

The sequence d(0)..........d(61) used for the second synchronization signal is an interleaved concatenation of two length-31 binary sequences. The concatenated sequence is scrambled with a scrambling sequence given by the primary synchronization signal.

The combination of two length-31 sequences defining the secondary synchronization signal differs between sub frame 0 and sub frame 5 according to:

$$d(n) = \{s_0{}^{(m_0)}(n)c_0(n) \quad \text{In sub frame 0}$$

$$d(n) = \{s_1{}^{(m_1)}(n)c_0(n) \quad \text{In sub frame 5}$$

$$d(2n+1) = \{s_1{}^{m_1}(n)c_1(n)z_1{}^{m_0}(n) \quad \text{In sub frame 0}$$

$$d(2n+1) = \{s_0{}^{m_0}(n)c_1(n)z_1{}^{m_1}(n) \quad \text{In sub frame 5}$$

Where 0<=n<=30.

The values m0 and m1 are derived from the physical layer cell identity group $N^1{}_{ID}$ according to:

$$m_0 = m^{'} \bmod 31$$

$$m_1 = (m_0 + [m^{'}/31] + 1) \bmod 31$$

$$m^{'} = N^1{}_{ID} + q(q+1)/2$$

$$q = \frac{N^1{}_{ID} + q^{'}(q^{'}+1)/2}{30}$$

$$q^{'} = N^1{}_{ID}/30$$

Search Algorithm of LTE Scheme

In this subsection, we briefly mention the search algorithm of 3G LTE scheme [7]. In the current working assumption for the SCH in 3G LTE, both the P-SCH and the S-SCH occupy all subcarriers in the centered band and the number of subcarriers for SCH is 64 within 1.25 MHz. Zadoff-Chu (ZC) sequences are used for 3 P-SCH sequences and concatenated two binary sequences of length 32 are mapped to 64 subcarriers of S-SCH (1). When we use two binary sequences of length 32 in an S-SCH symbol, we can generate 1024 (32x32) sequences among which 340 sequences are used for S-SCH sequences. At the first step, matched filter operations corresponding to three P-SCH sequences are performed and resulting P-SCH symbol timing and P-SCH sequence index is used at the second step. The cell group ID (one among 170) and 10 msec frame boundary are detected in the second step based on the frequency domain correlations of the candidate S-SCH sequences. The second step detection scheme under current discussion in 3G LTE is based on the coherent frequency domain correlation of S-SCH sequences. Using the channel estimate of P-SCH symbol which is located just after the S-SCH symbol.

The cell search procedure is done in two steps:
1. PSS Detection (primary synchronization signal).
2. SSS Detection (secondary synchronization signal).

1. PSS Detection: UE (User Equipment) is powered on. UE monitors the central part of the spectrum regardless of its bandwidth capability. The UE has in its memory a copy of the three possible Primary Synchronization signals. The first step that a UE has to perform before proceeding with further signals processing is the determination of the symbol start.(6)The UE performs this detection by using a sliding window method with a delay length of symbol length. Now the UE has to match the received signal to one of the three sequences it knows.

For simulation, it was assumed that the PSS with root 25, 29 and 34 is the transmitted signal from the radio cell. The correlation amplitude maximum is obtained only when the received sequence matches with one of the sequences.

After simulation $N^1{}_{ID} = 0$ since the root 25 is detected.

2. SSS Detection: In our simulation (8), say m0=25 and m1=26.

1. Channel effects are removed from the SSS and any frequency offset determined earlier is corrected.
2. The received signal is de-interleaved into the odd part and the even part, i.e. d (2n) and d (2n+1).Since $N^{(2)}$ID is known from the PSS, the scrambling code c0(n) is already known to the UE and can be descrambled from the received signal. So, $d(2n) = s_0{}^{(m_0)}(n)c_0(n)$ has only one unknown m0 in $s^{(m0)}$0(n). So the UE now correlates the descrambled signal with 30 copies of s $^{(m0)}$0(n) to determine a match.
3. The UE has determined m0 or m1, but since it does not know which sub frame it is in, let us denote it by M. In our case, M is determined to be 25.
4. Now, s1 can be correlated with the 30 sequences at the receiver to obtain the right match and this gives m1=26.

$$N^1{}_{ID} = 25$$

CELL ID= $3N_{ID}{}^1 + N_{ID}{}^2$=3*25+0=75

Since the P-SCH signal has no time domain repetition property, the frequency offset estimation scheme is based on the correlation of the received signal and the time domain waveform of frequency domain P-SCH sequence as

$$\Delta_F = \frac{R_S}{\pi N_S} \arg\{\sum_{p=0}^{P-1}\{\sum_{n=0}^{\frac{N_S}{2}-1} r_p(n)s^*(n)\}\}*$$
$$\{\sum_{n=\frac{N_S}{2}}^{N_S-1}\{r_p(n)s^*(n)\}\}\}$$

Where *r* (*n*) is the time domain sample of received signal at sample point *n* in the P-SCH symbol position and *s* (*n*) is the time domain waveform of the P-SCH sequence.

The decision metric of the second step can be defined by

$$v(i) = \sum_{p=0}^{P-1}\sum_{k=0}^{N_S-1} r_p{}^{'}(k)c_p{}^{i}(k)^*\alpha_p(k)^* \quad \text{i=0,1,....339}$$

The normalized maximum decision metric is defined by

$$v(i)_{nor\_\max} = \frac{\mathrm{Re}(v(i))_{\max}}{\frac{1}{339}\sum_{i=0}^{339}\mathrm{mod}(v(i)}$$

Search Algorithm of sequence hopping

The cell search algorithm of the proposed scheme is also composed of two steps as in [8], but it differs in that the same SCH signal is utilized in both the first step and the second step. Since the SCH symbol occupies only even numbered subcarriers, its time domain signal waveform has repetition property. The new sequence is proposed in this algorithm which is the pseudorandom sequence .The length of this sequence is reduced to 32 and another sequence which is zadoff chu sequence of length 32 .As in the case of LTE primary synchronization signal consists of zadoff chu sequence of length 32 and the secondary synchronization signal consists of pseudorandom noise sequence of length 32.The algorithm process is same as the LTE. These sequences are passed through the OFDM transmitter and receiver(4). At the output of the receiver the cell tower is detected.

Radio Frame Structure

The frame format of the proposed structure is as same as the 3G LTE as shown in fig 3.The length of a radio frame is 10 msec and one radio frame is composed of 20 time slots.(3) For convenience, we define a “sync block”, which is composed of 5 time slots resulting in a radio frame with 4 sync blocks. Each slot consists of 7 or 6 OFDM symbols in case of short or long CP, respectively. Each sync block has one SCH symbol. Thus the resource occupation of the proposed SCH remains the same as the one of the current 3G LTE SCH structure. An SCH sequence is allocated to each SCH symbol in the frequency domain and the SCH sequence is used as Fourier coefficients at the occupied sub-carrier frequencies. The SCH sequence in a symbol is composed of two types of binary sequences.

The zadoff-Chu sequence of length 32 and a new sequence which is pseudorandom sequence of length 32.The hopping sequence $h_g = (h_g(0), h_g(1), h_g(2), h_g(3))$ is used for hopping the PN Sequence.

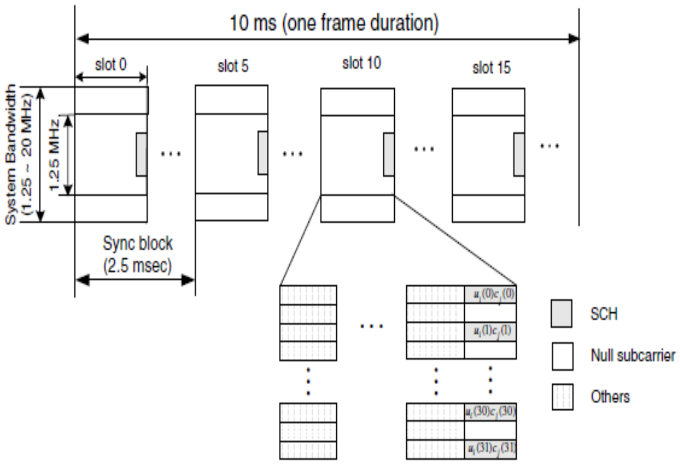

Fig.3.Downlink frame structure of proposed scheme.

The PN Sequence Generator block generates a sequence of pseudorandom binary numbers using a linear-feedback shift register. A pseudorandom sequence can be used in a pseudorandom scrambler and descrambler. It can also be used in a direct-sequence spread-spectrum system.

1. PSS Detection: In the PSS detection the steps in detecting a cell is same as 3G LTE except the sequence length is reduced to 32 bit. The sequence used here is zadoff Chu sequence.Three sequences are used in detecting primary cell. The procedure used in detecting the primary signal is same as in the 3G LTE except the sequence is reduced to 32 bit. By reducing to 32 bit the complexity in detecting the cell is reduced.

2. SSS Detection: In the SSS detection the sequence used is pseudorandom sequence of length 32.the sequences are cyclically shifted to 1 bit and then it is sent through OFDM transmitter and at the receiver one sequence is detected among all. Here the sequences used are 10 sequences. These 10 sequences are cyclically shifted to 1 bit.

The detection is done by combing the primary and secondary signal sequences. The zadoff chu sequence of length 32 and cyclically shifted pseudorandom sequence of length 32 are combined and send through the OFDM transmitter and at the receiver one sequence is detected by doing the cross correlation of 10 sequences.

Compared to 3G LTE the detection is easy since the sequences are reduced.

Simulation Results

Simulations were carried out to evaluate the proposed sync and cell search algorithms in 3gpp LTE systems and sequence hopping. If continuous matched filtering is not performed, then oversampling can be used. Oversampling is also performed to measure its effect on the probability of correct cell identification in single cell and multi cell scenarios. Therefore, the total number of useful subcarriers is 72 subcarriers occupying the central 1.25 MHz it should be noted that the corresponding bandwidth for 72 subcarriers is 1.08 MHz In the case of sequence hopping the detection of PSS is same except the bits are reduced to avoid complexity.

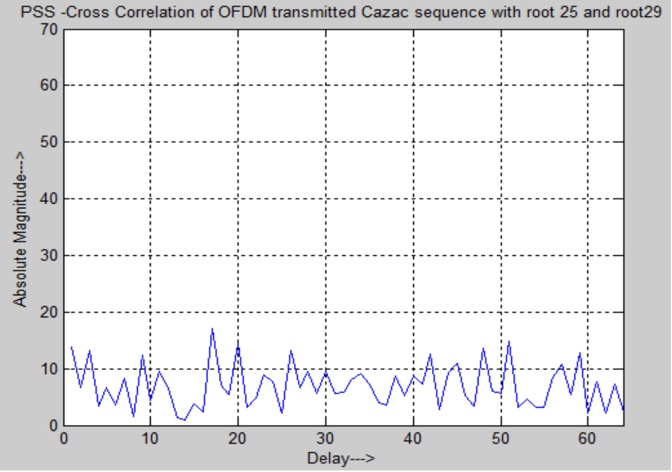

Fig.3.1 Correlation between received signal and sequence with root 29.

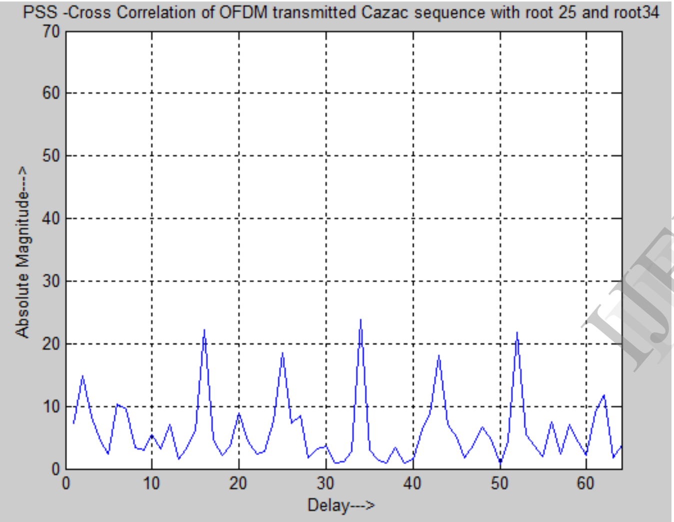

Fig.3.2.Cross Correlation between received signal and sequence with root 34 at UE.

The PN sequence is used in SSS Detection. The process in detecting a tower is easy compared to 3G LTE cell search scheme.

The above figure shows the correlation results at the receiver when there is no exact match.

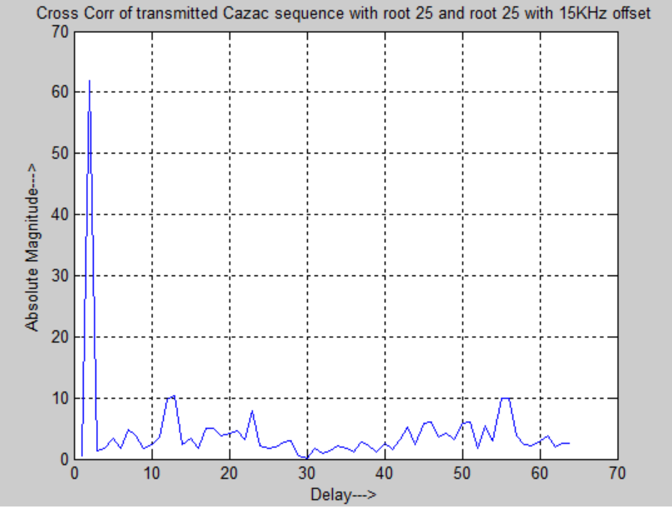

Fig.3.3.Cross correlation of PSS sequence with itself.

Figure3.3. Shows the correlation results at the receiver when there is an exact match in sequence and there is no frequency offset.

From these figures that the correlation amplitude maximum is obtained only when the received sequence matches with one of the sequences.

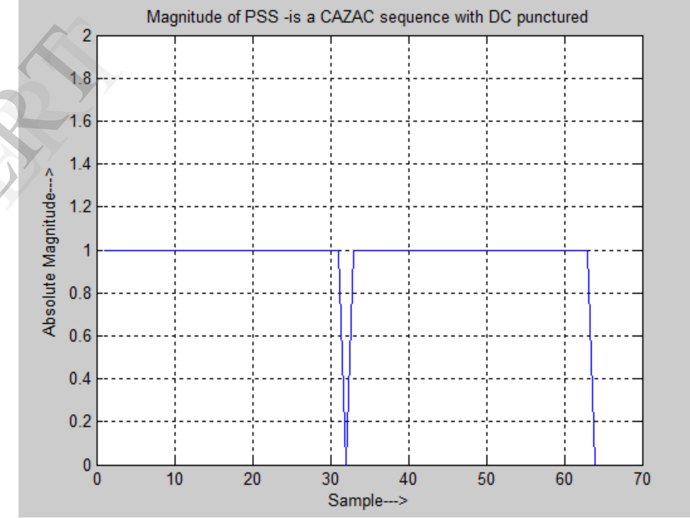

Fig.3.4. Constant magnitude of PSS.

It can be seen that the three sequences with different roots have constant amplitudes, but at different phases. The magnitude of the CAZAC sequence is represented by Figure 3.4. It can be seen that the amplitude is constant for all the points except DC.

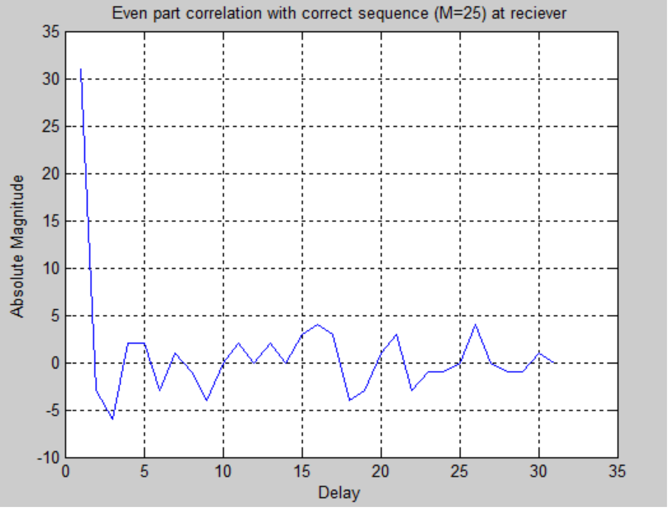

Fig.3.5.Correlator output with the correct matching sequence for the even part.

Figure3.5. shows the correlator output with the correct matching sequence for the even part s0.

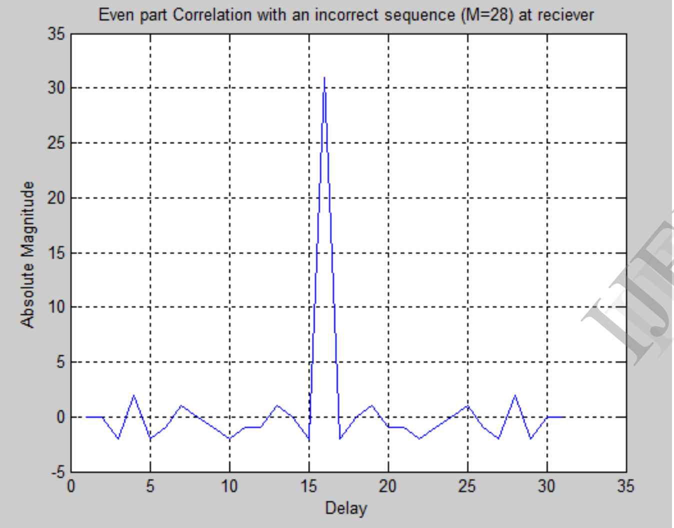

Fig.3.6.Correlator output with the incorrect matching sequence for the even part

Figure3.6. shows the correlator output with incorrect matching sequence for s0.

We see that the peak for both is almost the same, but the peak for the sequence with correct match is at the beginning of the sequence and there is an offset for all other correlations.

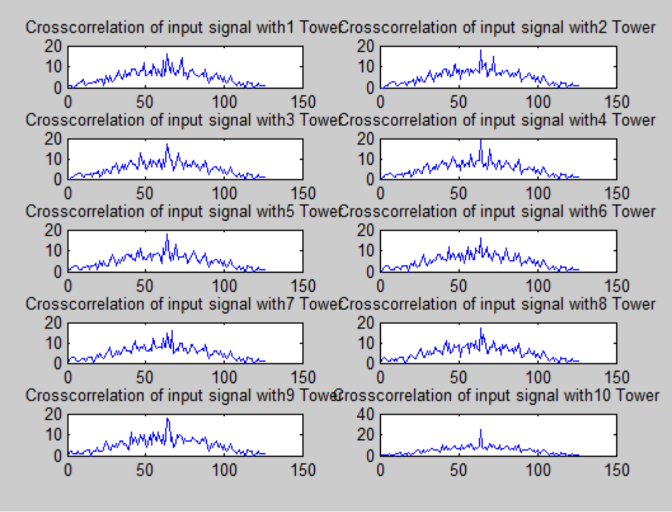

Fig.3.7.Cross correlation of input signal with all towers.

Figure3.7. Shows the correlation results at the receiver detecting one tower among all.

At the receiver one tower is detected. From the above figure tower10 is detected. Each time the simulation is done one tower is detected. There is less variations in curve for tower 10 compared to others. So the tower `10 is detected.

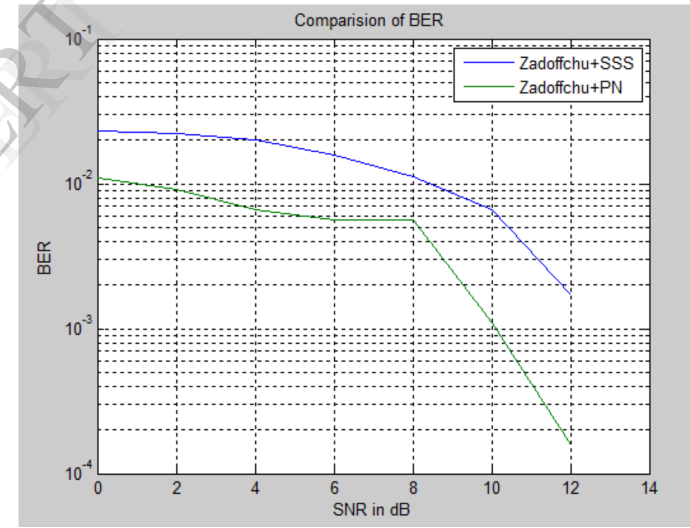

Fig.3.8.3G LTE and sequence hopping graph.

Figure.3.8 shows the bit error rate verses signal to noise ratio graph. As the signal to noise ratio increases the bit error rate decreases the maximum bit error rate is 10^-2b/sec.

In the case of sequence hopping the pseudorandom noise sequence and Zadoff Chu sequence are passed through the OFDM transmitter and receiver as shown in fig1. The BER verses SNR graph is plotted. The maximum bit error rate is less for sequence hopping compared to 3G LTE.

Conclusion

In this paper, a cell search scheme based on the sequence hopping technology for OFDM based cellular system is proposed. The detection of the cell for 3G LTE and sequence hopping are compared. The complexity in detecting a cell is reduced compared to 3G LTE Downlink frame format including the proposed SCH signal and the receiver structure was presented. The cell search performance of the proposed scheme is compared with that of the cell search scheme based on the current 3G LTE working assumption. The bit error rate for sequence hopping is less compared to 3G LTE.

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