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Optimization of CDMA System by using Hybrid DS-TH Spread Spectrum Technique

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Abstract

The main motivation of this thesis is to optimize the non-coherent detector in code division multiple access (CDMA) communication system. The choice to use non-coherent detection is made because of the fact that non-coherent detectors does not utilize the phase information in receiver side, resulting in lowering detector complexity. In the ultra wideband (UWB) technique both direct-sequence spread spectrum (DS-SS) and time hopping SS (TH-SS) can be combine, since UWB system has ability of combining the advantages of direct-sequence (DS)-CDMA and time-hopping (TH)-CDMA systems and avoiding their disadvantages. This hybrid DS-TH CDMA system can mitigate the channel effect in communication system, naming inter-symbol interference (ISI), multiuser interference (MUI) and multipath fading effects. The correlation detector does not have ability to mitigate these channel effect while linear detector minimum mean-square error (MMSE) has ability to mitigate these channel effect. In single user environment where there is no obstacle between transmitter and receiver and are in line of sight with each other, the correlation detector performance is near optimum and low complexity. However, correlation detector can also be used for multiuser environment if channel effect is ignored.Furthermore, MMSE detector which has ability to tackle channel effect can use hybrid DS-TH UWB system to mitigate channel effect. This novel has three phases, in first phase both correlation and MMSE detector have been simulate in multiuser environment ignoring channel effect, we find out that correlation detector perform well with lower complexity and near ideal BER performance. In second phase channel effect have been introduced and simulate the MMSE for hybrid DS-TH UWB system, result shows MMSE produced good result by varying DS and TH spreading factor of DS-TH CDMA system. However, the complexity for DS-TH CDMA increases for MMSE detector. In third phase, the adaptive detector least-mean square (LMS) is investigated for DS-TH CDMA system in term of their convergence speed, robustness, computational complexity and BER performance. LMS has lower complexity then correlation detector and has BER performance better than MMSE, since it does not require channel estimation. However, LMS result low BER performance in low SNR region.

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List of Symbols

E_b: Energy / Bit
N_c: Number of time slots / chip
T_Ψ: Time hopping slots duration / chip
T_c: Chip duration / time slot
$c_0^k, c_1^k, c_2^k, \ldots\ldots\ldots, c_{M-1}^k$: k_{th} user time-hopped pattern
$d_0^k, d_1^k, d_2^k, \ldots\ldots\ldots, d_{M-1}^k$: k_{th} user spreading sequence
b_i^k: i_{th} data bit transmitted of the k_{th} user (-1 or 1)
d_j^k: k_{th} user assigned binary spread sequence
$\Psi(t)$: Pulse waveform
T_Ψ: Pulse waveform duration
E_Ψ: Pulse waveform energy
K: Total number of users
T_b: Bit duration or bit rate
$s^k(t)$: k_{th} user transmitted signal
$s(t)$: Transmitted signal
$g(t)$: Spreading sequence
$\Phi_1(t)$: Information signal phase
$\propto$: Channel's unknown amplitude
N_0: AWGN single sided power spectral density
$\Psi_{rec}(t)$: Time domain pulse of received signal
$r(t)$: Received signal
$n(t)$: AWGN noise
y_i: Received signal vector
σ^2: Noise variance
$\underline{C_k}$: k_{th} user spreading vector

$\underline{C_i^k}$: i_{th} bit of the k_{th} user's spreading factor

$\underline{H_k}$: Channel matrix of the k_{th} user

h_1: 1^{st} user channel matrix

$e(i)$: Error between desire bit and received estimated bit

μ : Adaptive algorithm step size

$\underline{R_{y_i}}$: y_i auto correlation matrix

r_{y_i}: Cross correlation between b_i and y_i

ω_k: k_{th} user coefficients weights

$\underline{R_{y_i}}$: Matrix y_i Auto correlation

L: Number of multi-path

$\widehat{z_i^k}$: k_{th} user estimated symbols

Chapter 1

Introduction

1.1 Research Background and Motivation

In modern day world, telecommunication is becoming fastest growing and widely used technology, inviting scientist to explorer fastest, secure and reliable ways of telecommunication. Code-division-multiplexing access (CDMA) is now one of the most used communication system, especially in mobile communication where millions of users communicate throughout the world everyday which increases the chances of disturbing users data by interference with other users data and environmental noise.

Motivation of this thesis is to implement a low-complexity receiver with reasonable bit-error-rate (BER) in multi-user (MU) and multipath environment. Ultra wideband (UWB) communication systems attract our focus, since its application in high data rate (HDR) services e.g. third and fourth generation (3G & 4G) communication system. In MU and multipath fading environment one of the main concerns is to mitigate multi-user-interference (MUI) and inter-symbol-interference (ISI), which cause the degradation in BER performance. To mitigate MUI and ISI in multipath fading environment, it is very important to design such a low-complexity receiver which is able to cope multipath with reasonable BER performance.

Synchronization is also a major issue in UWB environment, since it has high bandwidth signals with very sharp time resolution. This sharp time resolution causes synchronization process very difficult and slow, also a very fast analog-to-digital converter (ADC) is required to sample receive signal. In addition, the UWB communication characteristic are much more complex then narrowband system. To tackle above mention issues, this thesis propose a hybrid direct-sequence time-hopping UWB (DS-TH UWB) system. This hybrid system combines their advantages at same time avoiding their disadvantage and helps in achieving a reasonable BER performance in Gaussian or multipath fading environments. We focuses to design a low-complexity receiver for DS-TH UWB system, which is practical to implement and does not required channel estimation. Furthermore, these receivers should be capable of achieving reasonable BER performance in MU environment in the presence of MUI, ISI and resolvable multipaths.

1.2 Literature Review

In this section, we review a few papers from literature related to the DS-CDMA and DS-TH CDMA systems. In [2], SS techniques have been discussed in the perspective of their advantages and disadvantages. The authors have presented different types of SS techniques with respect to fading effects introduced by a channel. Furthermore, characteristics of generating pseudorandom code, and methods which can be used for the creation of pseudorandom sequences in a CDMA system have been discussed. Finally, BER performance have been demonstrated using additive white Gaussian noise (AWGN) and Rayleigh fading channels. However, they did not propose any method to overcome the interference introduced by the narrowband and wideband channels. The performance analysis of coherent and non-coherent techniques in a DS-CDMA system have been presented in [3], where the authors discuss the effects of multiple access interference (MAI), and the types of parameters which are required to cancel the effect of MAI in a DS-CDMA system. They used a de-correlating detector to detect the transmitted symbols and a maximum likelihood estimator to estimate the channel in coherent scheme. In non-coherent scheme, a decision feedback equalizer and non-linear multistage detectors were used. A hybrid DS-TH

UWB system is implemented using BPSK modulation in [5]. The authors developed a system model of a DS-TH UWB system. Furthermore, different receiver structures like single user correlation detector and minimum mean square error detector have been used to coherently detect the bits transmitted by the intended user. Furthermore, they evaluated that these detectors are unrealistic due to the requirement of channel information which should be known at the receiver end. For channel estimation different adaptive algorithms like least mean square (LMS), normalized least mean square (NLMS), recursive least square (RLS) have been investigated. Furthermore, they used a correlation detector, that can track the channel variations in the time domain. The performance of the proposed DS-TH UWB system is evaluated using BER curves for different types of fading channels that include Rician, Nakagami, and Rayleigh fading channels. They concluded with the finding that a reduced rank receiver can be used in UWB systems which can improve spectral efficiency of the system and thus enhances the BER performance. However, all their findings are based on using coherent detection schemes only

1.3 Problem Statement

In this thesis, our goal is to implement a low-complexity receiver for DS-TH UWB system capable of achieving a reasonable BER in multipath fading environment in the presence MUI and ISI. For simulating such receiver we will consider differential phase-shift-keying (DPSK) modulation in Rayleigh fading channel model with multipath, their path delays and path gains. We will employed three different types of receivers naming correlation, minimum mean-square error (MMSE) and least mean-square (LMS) detector. Later, their BER performance will be analyzed for single-user and multi-user environment.

1.4 Contribution

This novel propose a hybrid DS-TH UWB system, combines both DS and TH UWB advantages while avoiding their disadvantage at same time. This hybrid system is capable of performing as a pure DS-UWB as well as pure TH-UWB system, which increases it flexibility for UWB system. As one of the main objective of this thesis is to design a low-complexity receiver, we consider correlation detector which is a single user detector without a capability to mitigate MUI and ISI, then MMSE a multi-user detector with capability to mitigate MUI and ISI and in last an adaptive LMS dettector which has lowest complexity with reasonable BER performance.

1.4.1 Single-User Correlation Detector

It is also known as conventional detector and has lowest complexity. Since it is a single user detector with the ability of mitigate ISI and MUI in multi user environment, also its performance gets worst as number of users as well as number of multipath increases. However, correlation detector BER performance can be improved in multiuser environment by increasing signal-to-noise ratio (SNR) and with optimum combination of DS and TH spreading factor in DS-TH UWB system.

1.4.2 Multi-User MMSE Detector

MMSE detector has ability to mitigate ISI and MUI but has higher complexity than correlation detector. Also it has an ability to resolve multipath assuming ideal channel state information and spreading code are known at receiver in TH-DS UWB communication system. By choosing optimum values of TH and DS spreading factor and reasonable SNR, MMSE can achieve even better performance, however increases it complexity if TH spreading factor increases.

In practical, ideal knowledge of channel in UWB system is very hard to achieve. Usually, UWB system has very large number of multipath with low energy this increases MMSE complexity. These complexity issues can be overcome by using adaptive filtering, since adaptive detectors dose not required ideal knowledge of channel. An adaptive detector operates using training sequence even without user signature. In this LMS detector will be applied on DS-TH UWB system and its BER performance will be analyzed.

1.4.3 LMS detector

LMS detector uses training sequence to operate without channel and user signature knowledge making it less complex then correlation detector. Furthermore, the BER performance of LMS detector is near to ideal MMSE detector. However, its BER performance gets worst in low signal-to-ratio (SNR).

1.5 Thesis Organization

Chapter 2 presents an overview of different spread spectrum techniques the perspective of their advantages and disadvantages. In fact, we present the complete system model of a generic DS-CDMA system and detailed structure of a DS-TH CDMA system. Chapter 3 discuses several detector structures and their mathematical equations are analyzed in non-coherent detection schemes to detect the transmitted bits at the receiver side. Chapter 4 presents simulation results for a DS-TH CDMA system using non-coherent detection schemes in a single user correlation receiver, MMSE receiver and adaptive LMS receiver. The non-coherent detection schemes were simulated to compare their performance in different channels. Finally in chapter 5 we conclude the thesis with a brief description of the possible future work.

Chapter 2

Spread Spectrum in CMDA System

Spread spectrum (SS) techniques are widely used in modern wireless communication system. These techniques increase the bandwidth of data to be transmitted than the minimum required bandwidth. SS techniques can also be used as multiple-access (MA) where users shared scarce communication resources e.g. time and bandwidth. To uniquely identify each user, a unique spreading sequence is assigned to each user. These spreading sequences are orthogonal so that data merging could be avoided. The basic transmitter receiver structure for SS system can be seen in Fig. 2.1.

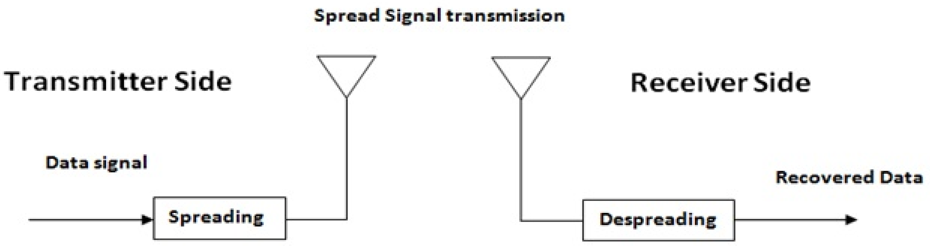

Figure 2.1: Spread spectrum transmitter and receiver structure [1].

Spreading code required to fulfill following properties [1].

- After each period of sequence, number of 1's and 0's should be different.

- Every sequence should be unique. Total number of bits per sequence known as run length, where every run length must have half of bits of length 1,while 1/4 of length 2 and so does the next run lengths.

- Total number of auto-correlation and cross-correlation should be not exceed than cyclic shift single count.

One of the major parameter that effect SS is processing gain, which is a ratio of transmission and information bandwidth. It can be represent mathematically as [4]

$$P_g = \frac{BW_{tra}}{BW_{info}} \tag{2.1}$$

Where P_g is the spreading factor, BW_{tra} is transmission bandwidth, and BW_{info} information bandwidth. Tradeoff exit between these two bandwidths, increasing P_g allows more users to transmit their data which leads to decrease in multipath interference, also provide anti-jamming capability but increases detector complexity.

2.1 Direct Sequence Spread Spectrum

Direct sequence (DS) is one of the widely used SS technique. In Fig. 2.2, DS-SS transmitter and receiver structure can be seen [2]. Where $x(t)$ is data signal multiplied with spreading code $g(t)$ with unit of symbol per second also known as chip rate R_{ch}, causes data signal to spread. This signal is now can be transmit through channel. Now when signal received at receiver, this signal is multiplied with $g(t)$ again to despread. By filter of bandwidth R, these undesired signal can be removed.

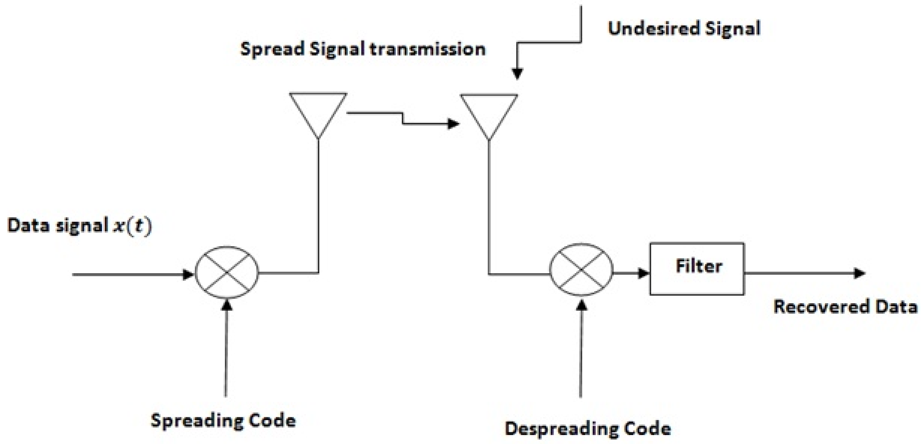

Figure 2.2: DSSS transmitter receiver structure[2]

2.2 DS-CDMA System

Direct-Sequence CDMA (DS-CDMA) uses unique PN codes assigned to each user to differentiate between multiple users, commonly used in 3rd generation (3G) communication system. DS-CDMA allows multiple user to transmit their data simultaneously by sharing resources. CDMA system gives users an ability of sharing scarce resources such as time and frequency. CDMA system shown its application in security fields, since these spreading code are random and only receiver side has these code and cannot be used illegal access of these codes. While multiple user transmitting their data simultaneously, ISI and MUI makes recovering original data of users difficult by only using spreading codes. These interference can be minimized by utilizing channel knowledge with RAKE-receiver. Such system can be seen in Fig. 2.3. [2]. Channel coding is applied at transmitter side to convert data into codes. This coded data is then modulated by using baseband modulator, where this modulated data is than multiplied with spreading code before transmission. These spreading codes are usually Walsh or Hadamard codes [4]. At receiver side, the received signal first despread by multiplying it with spreading code and then demodulated and channel decoded to recover original data. For multi-user DS-CDMA, unique spreading code $g_i(t)$ has been assigned to each user before it multiplexed. In Fig. 2.4. MU DS-CDMA structure can be

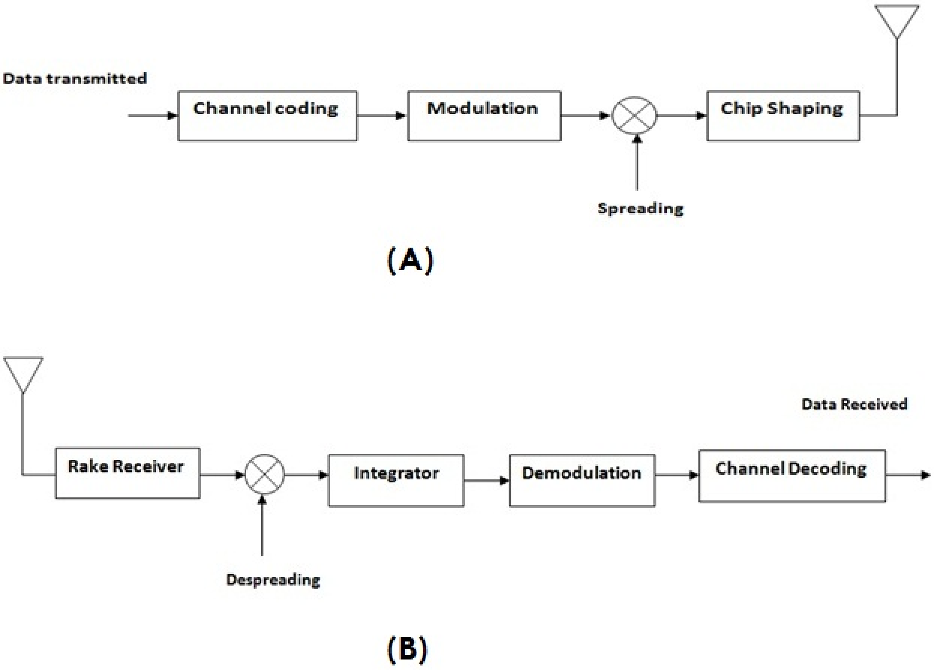

Figure 2.3: (A)Transmitter and (B) receiver section in DS-CDMA system[2].

seen [1]. In Fig. 2.4., each i_{th} user data is modulated with carrier $Acos\omega_o t$ to generate modulated data $s_i(t)$ for each user.

$$s_i(t) = Acos[\omega_o t + \theta_i(t)], fori = 1, 2, \dots, N \tag{2.2}$$

These modulated signal is then multiplied with $g_i(t)$ and resulted signals multiplexed to transmit it over channel. Mathematically this multiplex signal can be present as

$$g_1(t)s_1(t) + g_2(t)s_2(t) + \dots\dots. + g_N(t)s_N(t), \tag{2.3}$$

At receiver, the received signal is multiplied with spreading code $g_i(t)$, where in Fig. 2.4. suppose 1^{st} user want to received data, thus spreading code $g_1(t)$ is correlated then we get

$$g_1^2(t)s_1(t) + g_1 g_2(t)s_2(t) + \dots\dots. + g_1 g_N(t)s_N(t), \tag{2.4}$$

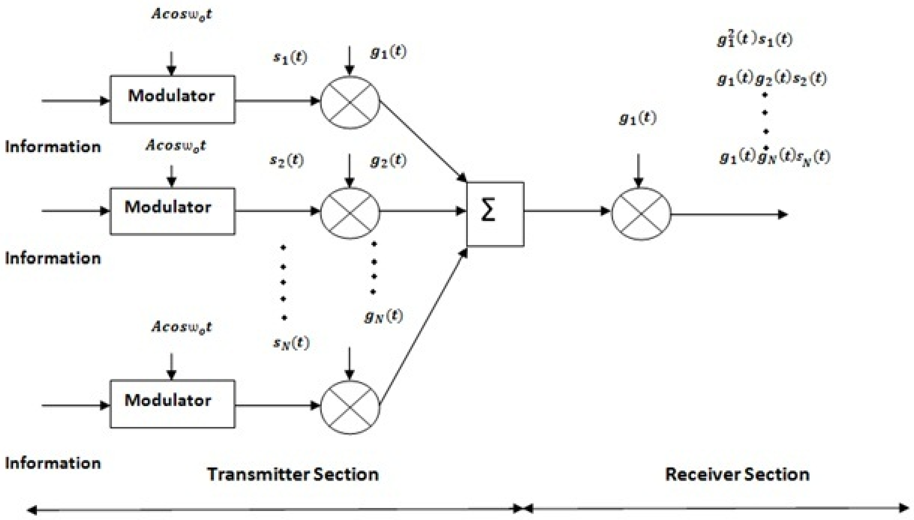

Figure 2.4: Multi-user DS-CDMA system [1].

Where g_1^2 (t) $s_1(t)$ is wanted signal with highest correlation while rests are unwanted signal with zero correlation, which will be canceled out due to zero correlation.

2.3 Multipath Fading

Fading arise due to rapid change in amplitude, received signal delays due to scattering objects during transmission. Due to fading, transmitted signal in CDMA signal reaches through direct as well as others paths called multipath cause by signal reflection from different scattering objects as shown in Fig. 2.5. [1]. Three major reason which cause fading [2].

- Moving object affected by Doppler shift.
- Due to change in travelled distance, signal power change.
- Due to multipath, propagation delay in signal.

At receiver, received signal with delays in multipath with respect to direct path. Total combine energy of multipath and direct path is equal to energy

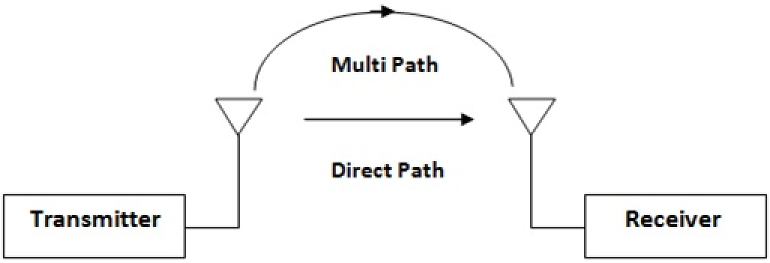

Figure 2.5: Multipath between transmitter and receiver [1].

of signal when it is transmitted. If delay in multipath is greater than R_{ch} then multipath effect can be mitigate. Thus, by using DS-SS multipath effect can be mitigate.

2.4 Time Hopping Spread Spectrum

In time-hopping SS (TH-SS), a delayed train of pulses modulated with transmitted data to introduced time shift. The delayed pulse train also known as TH pattern. There are two categories of TH-SS.

- Slow TH-SS
- Fast TH-SS

In STH-SS, each frame assigned a same TH code and symbols are transmitted in these frames. While in FTH-SS, each frame assigned a different code and symbols are transmitted in these frames.

2.5 Hybrid DS-TH CDMA System

Hybrid DS-TH CDMA system combines the advantages of both DS and TH CDMA system, while at same time avoiding their disadvantages. Non-coherent detection can be used for DS-TH CDMA system.

2.5.1 Non-Coherent DS-TH CDMA System

In this detection, information of phase does not utilize to detect original data at receiver side [1]. It works without any knowledge of reference phase, thus minimize receiver complexity but more prone to error than coherent detection. Differential phase-shift-keying (DPSK) can be used for non-coherent detection. DPSK modulation can be represent mathematically as

$$b_i(t) = \sqrt{\frac{2E}{T}} cos(\omega_0 t + \theta_i(t)), \qquad (0 \leq t \leq T)(i = 1, \ldots, M) \tag{2.5}$$

Differential coding scheme can be used to decode received data at receiver side. Each current waveform is then multiplied with their predecessor waveform to re-generate encoded waveform, this encoded waveform in not in-phase with the original waveform. [1].

2.5.2 Transmitter Section

Hybrid DS-TH CDMA system uses both DS and TH mechanism. Pulses are generated with different time hopped but same probability at transmitter site. DS-TH CDMA system's transmitter block diagram can be seen in Fig 2.6. [5]. Where b^k are data bits for k_{th} user modulated with DS spreading sequence d_j^k by N_c number of chips. These modulated bits are then transmitted by N_Ψ pulses sequences. These N_Ψ patterns are determined by TH pattern

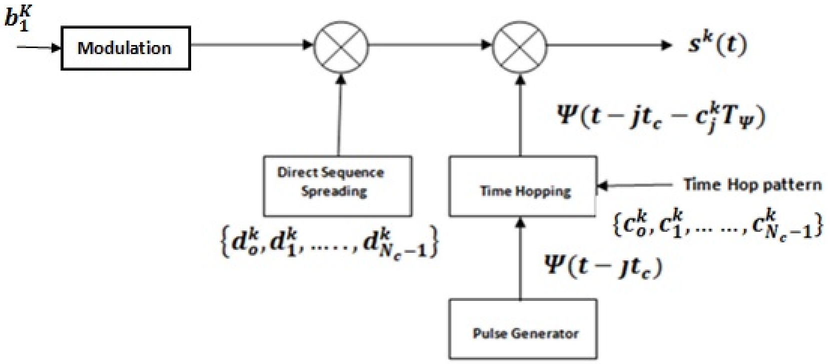

Figure 2.6: Non-coherent DS-TH CDMA system transmitter [5].

assigned to the k_{th} user. Symbol transmitted by k_{th} user be represented as

$$s^k(t) = \sqrt{\frac{E_b}{N_c T_\psi}} \sum_{j=0}^{\infty} b^k_{\frac{j}{N_c}} \; d_j^{(k)} \Psi[t - jT_c - c_j^{(k)} T_\Psi] \tag{2.6}$$

Here $\Psi(t)$ is time domain pulse which has width of T_Ψ.

In Fig 2.6., where each data bit b_k^i is divided into N_c chips having duration T_c. N_c chips can also be referred as pseudo random sequences. The N_Ψ can be determined by using TH pattern and each chip can be corresponds to different N_Ψ.

2.5.3 Receiver Section

Assuming Rayleigh distribution channel, the signal received can be presented as [5, 12]

$$r(t) = w(t) + n(t) \tag{2.7}$$

Here

$$w(t) = \sqrt{\frac{E_b}{N_c T_\psi}} \sum_{k=1}^{k} \sum_{l=0}^{L-1} \sum_{j=0}^{\infty} h_l^{(k)} b^k_{\frac{j}{N_c}} \; d_j^{(k)} \Psi_{rec}[t - jT_c - c_j^{(k)} T_\Psi - T_0 - lT_\Psi - \tau_k] \tag{2.8}$$

By substituting (2.7) and (2.8), it yields

$$r(t) = \sqrt{\frac{E_b}{N_c T_\psi}} \sum_{k=1}^{k} \sum_{l=0}^{L-1} \sum_{j=0}^{\infty} h_l^{(k)} b^k_{\frac{j}{N_c}} \; d_j^{(k)} \Psi_{rec}[t - jT_c - c_j^{(k)} T_\Psi - T_0 - lT_\Psi - \tau_k] + n(t) \tag{2.9}$$

Here n(t) is additive white Gaussian noise (AWGN) which add up through channel with transmitted signal $w(t)$ with power spectral density N_0. In (2.8), The transmitted signal $s(t)$ of each user, is convoluted with $h_l^{(k)}$ corresponds to channel response [5, 13]. In Fig 2.7., the received signal $r(t)$ is filtered using matched filter(MF). It can be used to increase SNR for each bit. MF can be sampled at rate $1/T_\Psi$. To detect M data bits of received signal, the detector received $MN_cN_\Psi + L - 1$ samples, where N_c, N_Ψ and

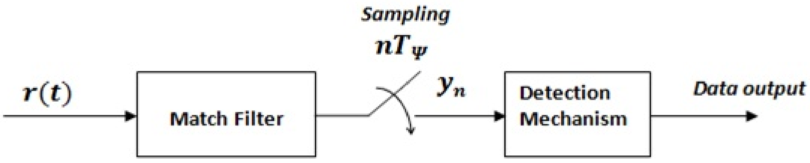

Figure 2.7: Receiver block diagram for DS-TH system [5].

$L-1$ represents spreading sequence, time hopping components, resolvable multipaths respectively. Output of MF is sampled at $T_0+(n+1)T_\Psi$ to obtain n_{th} sample, mathematically it can be represent as

$$y_n = \frac{1}{\sqrt{\frac{E_b T_\Psi}{N_c}}} \int_{T_0+nT_\Psi}^{T_0+(n+1)T_\Psi} r(t)\Psi^*_{rec}(t)dt, \qquad n = 0,1,2,3,...MN_cN_\Psi + L - 2 \tag{2.10}$$

2.5.4 Linear Equation form of the Received Signal

Uncorrelated noise and linear equation for MF output can be represented as [5]

$$y = [y_0, y_1, ..., y_{MN_cN_\Psi+L-2}]^T \tag{2.11}$$

$$n = [n_0, n_1, ..., n_{MN_cN_\Psi+L-2}]^T \tag{2.12}$$

The MF output can be sampled at $T_0+(h+1)T_\Psi$, which can be represent mathematically as [5]

$$n_h = \frac{1}{\sqrt{\frac{E_b T_\Psi}{N_c}}} \int_{T_0+hT_\Psi}^{T_0+(h+1)T_\Psi} n(t)\Psi^*_{rec}(t)dt, \qquad h = 0,1,2,3,...MN_cN_\Psi + L - 2 \tag{2.13}$$

Substituting (2.9) in (2.10), it yields [5]

$$y = \sum_{k=1}^{K} \underline{C_k H_k} b_k + n \tag{2.14}$$

Where $\underline{C_k}$, b_k and $\underline{H_k}$ represents the spreading matrix having dimension$(MN_cN_\Psi + L - 1 \times ML)$, i bits and impulse response of the channel respectively. If M is the number of information bits i.e. transmitted by n_{th} user, now b_k can be represent as matrix

$$b_k = \{b_0^k, b_1^k, b_2^k, ..., b_{M-1}^k\}^T \tag{2.15}$$

Also H_k for k_{th} user can be represent mathematically as [5]

$$\underline{H_k} = diag\{h_k, h_k, h_k, ..., h_k\} \tag{2.16}$$

In (2.16), h_k can be represent as

$$h_k = [h_0^k, h_1^k, h_2^k, ..., h_{L-1}^k]^T \tag{2.17}$$

$\underline{C_k}$ for the k_{th} user can be represent in matrix form as

$$C_k = \begin{bmatrix} C_0^{(k)} & 0 & 0 & 0 & 0 \\ 0 & C_1^{(k)} & 0 & 0 & 0 \\ 0 & 0 & \ddots & \cdots & 0 \\ \vdots & \vdots & \cdots & 0 & \vdots \\ 0 & 0 & 0 & C_{M-2}^{(k)} & 0 \\ 0 & 0 & 0 & 0 & C_{M-1}^{(k)} \end{bmatrix} \tag{2.18}$$

Where C_k is in Toeplitz structure.
A slot of length N_Ψ will be assign for each chip in DS-TH CDMA system. Suppose with spreading factor $N_c = 4$ and time hopped factor $N_\Psi = 3$, the i_{th} bit of k_{th} user is spread and distributed in time slots, with total $L = 3$ multipaths. N_Ψ has value 0,1,2 with equal probability. Consider $M = 3$ total number of bits. In this scenario, the spreading matrix C_i^k can be represent as (2.19). Suppose in other scenario for j_{th} bit of k_{th} user, assume $N_c = 4$,

$N_\Psi = 1$ and $L = 3$. Now the spreading matrix C_j^k can be seen in (2.20).

$$C_k = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
d_0^k & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & d_0^k & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
d_1^k & 0 & d_0^k & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & d_1^k & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & d_1^k & 0 & 0 & 0 & 0 & 0 & 0 \\
d_2^k & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & d_2^k & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & d_2^k & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
d_3^k & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & d_3^k & 0 & d_4^k & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & d_3^k & 0 & d_4^k & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & d_4^k & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & d_5^k & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & d_5^k & 0 & 0 & 0 \\
0 & 0 & 0 & d_6^k & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & d_6^k & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & d_6^k & 0 & 0 & 0 \\
0 & 0 & 0 & d_7^k & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & d_7^k & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & d_7^k & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & d_8^k & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & d_9^k & d_8^k & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & d_9^k & d_8^k \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_9^k \\
0 & 0 & 0 & 0 & 0 & 0 & d_{10}^k & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & d_{10}^k & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_{10}^k \\
0 & 0 & 0 & 0 & 0 & 0 & d_{11}^k & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & d_{11}^k & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_{11}^k \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix} \tag{2.19}$$

$$C_k = \begin{bmatrix} d_0^k & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_1^k & d_0^k & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_2^k & d_1^k & d_0^k & 0 & 0 & 0 & 0 & 0 & 0 \\ d_3^k & d_2^k & d_1^k & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & d_3^k & d_2^k & d_4^k & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & d_3^k & d_5^k & d_4^k & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & d_6^k & d_5^k & d_4^k & 0 & 0 & 0 \\ 0 & 0 & 0 & d_7^k & d_6^k & d_5^k & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & d_7^k & d_6^k & d_8^k & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & d_7^k & d_9^k & d_8^k & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & d_{10}^k & d_9^k & d_8^k \\ 0 & 0 & 0 & 0 & 0 & 0 & d_{11}^k & d_{10}^k & d_9^k \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_{11}^k & d_{10}^k \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_{11}^k \end{bmatrix} \tag{2.20}$$

$$C_k = \begin{bmatrix} d_0^k & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_1^k & d_0^k & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_2^k & d_1^k & d_0^k & 0 & 0 & 0 & 0 & 0 & 0 \\ d_3^k & d_2^k & d_1^k & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & d_3^k & d_2^k & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & d_3^k & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & d_4^k & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & d_5^k & d_4^k & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & d_6^k & d_5^k & d_4^k & 0 & 0 & 0 \\ 0 & 0 & 0 & d_7^k & d_6^k & d_5^k & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & d_7^k & d_6^k & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & d_7^k & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & d_8^k & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & d_9^k & d_{10}^k & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & d_{10}^k & d_9^k & d_8^k \\ 0 & 0 & 0 & 0 & 0 & 0 & d_{11}^k & d_{10}^k & d_9^k \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_{11}^k & d_{10}^k \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_{11}^k \end{bmatrix} \tag{2.21}$$

By analyzing (2.19) and (2.20), it can be observed if number of multipath L is larger than N_Ψ, then strong inter-chip interference is observed. By assigning different time slot for each user, ICI can be mitigate.

To optimize system performance, zero padding can be introduced. With the aid of zero padding, ICI can be minimized between two data bits, i_{th} and j_{th}

for k_{th} user as shown in (2.21).

After introducing zero padding, the spreading matrix C_k and channel matrix H_k become complex. Adding zero padding cause the dimension of C_k modified to $((M(N_c N_\Psi + L - 1)) \times ML)$, and channel matrix H_k dimensions become $(ML \times M)$.

Now the received signal y has dimension, $((M(N_c N_\Psi + L - 1)) \times 1)$, also this zero padding modified the dimension of noise, since it added through AWGN channel and has same dimension as y.

2.6 Summary

In this chapter, spread spectrum and its technique direct-sequence SS and time -hop SS has been discussed. The block diagram for each technique and their mathematical equations are analyzed in depth. CDMA system has been employed to combine with DS-SS and TH-SS and their block diagram has been examined on the basis of their advantages. The block diagram of transmitter and for hybrid DS-TH CDMA system is also analyzed with the help of their mathematical equations. Spreading matrix, channel impulse response and user data matrix are also visualized for DS-TH CDMA system. In the end different scenarios has been discussed for pure DS-SS CDMA system and hybrid DS-TH CDMA system to analyzed effect of ISI and ICI for spreading matrix.

Chapter 3

Detection in DS-TH CDMA System

The major problem in wireless communication system is to detect data bits accurately which are transmitted from transfer side. To detect data bits accurately, first receiver have to find out whether received signal is corrupted by noise or not. In wireless communication system, hypotheses have to decide by received waveform analysis [14].
DS-TH CDMA system will be observed under multipath and white noise and will be tested by CDMA system techniques. Now to accurately detect information bits from corrupted signal, an efficient detector have to be employed in non-coherent detection schemes to recover original data bits.

3.1 Non-Coherent Signal Detection

Here the received signal and transmitted signal are not in same phase. Since multi-user environment is considered, the detector should have ability to mitigate MUI, ISI and multipath effect. If detector is sampled at $N_c N_\Psi + L - 1$ for detecting i_{th} bit of k_{th} user, then it can be represent mathematically as [15]

$$y_i = \underline{C_i^1} h_1 b_i^1 + \sum_{k=2, i \neq j}^{K} \underline{C_i^k} h_k b_i^k + n(t) \tag{3.1}$$

Wanted signal of 1^{st} user is $\underline{C_i^1}h_1b_i^1$ and MUI and ISI is represent by $\sum_{k=2,i\neq j}^{K}\underline{C_i^k}h_kb_i^k$ between 1^{st} and the n_{th} user. DS-TH CDMA performance can be investigated by three detectors as follow

- Correlation detector (Single-user detector)
- Multi-user minimum mean-square-error (MMSE a multi-user linear detector)
- Adaptive least mean-square (LMS)

3.1.1 Correlation Detector

It is a single-user detector without the ability to mitigate MUI and ISI, but has low complexity. In correlation detector, the i_{th} bit of k_{th} user is reshaped. It also acts as conventional MF. A bank of MF is used to demodulate the receive signal. Single MF for each user, used to maximize the SNR by convolving it with its respective spreading sequence. Correlation detector treats each user data bits independently. Correlation detector should have information of channel response $\underline{H_k}$ and spreading matrix $\underline{C_k}$ for k_{th} user. Block diagram of correlation detector can be seen in Fig. 3.1.

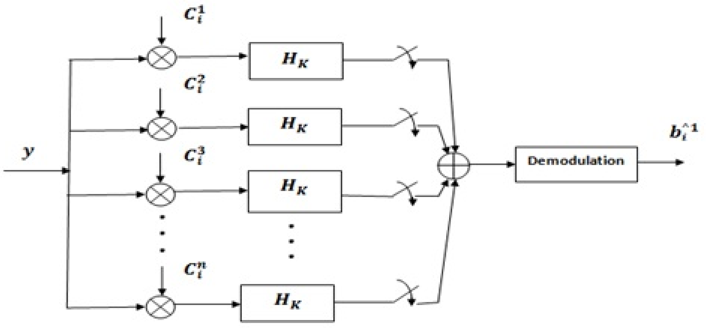

Figure 3.1: Block representation of correlation detector [17].

The product of received waveform and PN sequence $\underline{C_i^1}$ assigned to the i_{th} bit of k_{th} user to detect, and filtered by multiplying it with impulse response of channel h_1^T [17].

$$z_i^1 = h_1^T \underline{(C_i^1)}^T y_i \tag{3.2}$$

Substituting (3.1) in (3.2), it yields

$$z_i^1 = h_1^T \underline{(C_i^1)}^T (\underline{C_i^1} h_1 b_i^1 + \sum_{k=2,i\neq j}^{K} \underline{C_i^k} h_k b_i^k + n(t)) \tag{3.3}$$

Output for i_{th} bit of 1^{st} user can be mathematically expressed as [5,17]

$$\widehat{b_i^1} = sgn(z_i^1) \tag{3.4}$$

By analyzing (3.3), is can be seen that that correlation detector suffers from MUI as well as ISI.

3.1.2 Minimum Mean-Square-Error

MMSE can mitigate MUI, ISI and fading effect. However, correlation detector is less complex then MMSE. [18].

MMSE detector have to adjust its weights w_i^1 to get its optimum weight w_i^1 of the 1^{st} user to detect i_{th} bit of 1^{st} user, it can be done by [5, 19, 20]

$$w_i^1 = \underline{R_{y_i}^{-1}} \underline{C_1} h_1 \tag{3.5}$$

Where R_{y_i} represents auto-correlation matrix for y, and can be expressed mathematically as [19]

$$\underline{R_{y_i}} = E[yy^H] = \sum_{k=1}^{K} \underline{C_i^k} h_i h_i^H \underline{(C_i^k)}^T + 2\sigma^2 \underline{I} \tag{3.6}$$

Where in (3.6), $\underline{I}$ and σ^2 represents identity matrix and noise variance respectively, $\underline{R_{yi}}$ can be calculated without and knowledge of other users.

Decision variable can be represent mathematically as [20]

$$z_i^1 = (w_i^1)^H y_i \tag{3.7}$$

To detect i_{th} bit of 1^{st} user, MMSE requires knowledge of all user participating in transmitting their data bits.

3.1.3 Adaptive Least Mean Square Detector

Adaptive detectors use training sequence generated at receiver side to update their weights $\widehat{w_1}(i)$ at each iteration until optimum weights are achieve. This is known as training mode. After training mode, received signal is detected with the aid of optimum weights. This mode is known as decision directed mode (DD). Block diagram of adaptive LMS detector can be seen in Fig. 3.2. To achieve optimum weights $\widehat{w}(i)$, a steepest descent algorithm is used to estimate gradient vector $\widehat{\bigtriangledown}J(i)$. At each iteration n weights $\widehat{w}(i)$ are updated. Gradient vector $\widehat{\bigtriangledown}J(i)$ can be mathematically represent as [19]

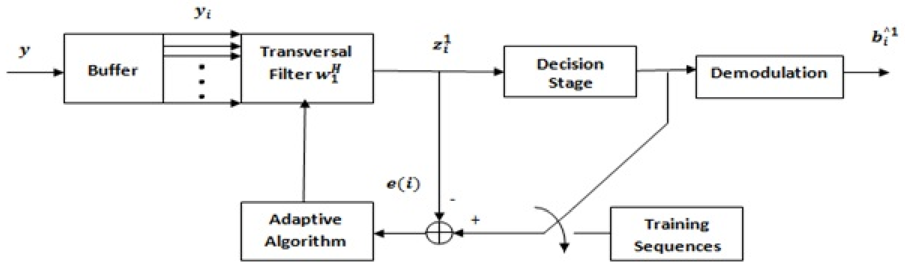

Figure 3.2: Adaptive LMS block diagram [19].

$$\widehat{\bigtriangledown}J(i) = -2y_i b_i^{*1} + 2y_i y_i^H w^1(i) \tag{3.8}$$

In (3.8), y_i, b_i^1 and $\widehat{w}(i)$ is received vector, desire responce and weights vector respectively of 1^{st} user. The steepest descent used to evaluate optimum weights vectors $\widehat{w}(i)$ represented as [19]

$$\widehat{w}(i+1) = \widehat{w}(i) - \frac{1}{2}\mu\|\widehat{\bigtriangledown}J(i)\|^2 \tag{3.9}$$

By substituting (3.8) and (3.9), it yields

$$\widehat{w}(i+1) = \widehat{w}(i) + \mu\|y_i b_i^{*1} - y_i y_i^H w^1(i)\|^2 \tag{3.10}$$

(3.9) can be minimize as [19]

$$\widehat{w}(i+1) = \widehat{w}(i) + \mu y_i [b_i^{*1} - y_i^H w^1(i)]^2 \tag{3.11}$$

$$\widehat{w}(i+1) = \widehat{w}(i) + \mu y_i [b_i^1 - y_i w_1^H(i)]^* \tag{3.12}$$

$$\widehat{w}(i+1) = \widehat{w}(i) + \mu y_i e^*(i) \tag{3.13}$$

Error between $z_i^1 = w_1^H(i) y_i$ and desire response b_i^1 is $e^*(i) = b_i^1 - w_1^H(i) y_i$.

3.2 Complexity Analysis

In this section, complexity of each detector has been analyzed for DS-TH CDMA system. Complexity of these detectors can be analyzed by evaluating numbers of additions and multiplication. Consider a matrix operation [21]

- To Multiply two rectangular matrix having dimension $P \times Q$ and $Q \times R$ it requires

$$\text{Number of Additions} = P \times (Q-1) \times R$$

$$\text{Number of Multiplications} = P \times Q \times R$$

Here $Q > 1$, P is numbers of rows and Q is numbers of columns for 1^{st} matrix and Q is number of rows and R is numbers of columns for 2^{nd} matrix.

- The matrix having dimension $P \times P$, it inverse requires

$$\text{Number of Additions} = P^3/6$$

$$\text{Number of Multiplications} = P^3/6$$

Now complexity of each detector can be measured.

Operations	No. of Addition	No. of Multiplication
$h_1^T \underline{(C_i^1)}^T$	$(L-1)U$	LU
$\underline{z_i^1}$	$U-1$	U
Total Operations	$(UL-1)$	$(L+1)U$

Table 3.1: Numbers of addition and multiplication for correlation detector

Operations	No. of Addition	No. of Multiplication
$\underline{C_i^k} h_i h_i^H \underline{(C_i^k)}^T$	$2U(L-1)$	$2UL$
$\sum_{k=1}^K \underline{C_i^k} h_i h_i^H \underline{(C_i^k)}^T$	$2KU(L-1)$	$2KUL$
$\underline{R_{y_i}^{-1}}$	$U^3/6$	$U^3/6$
$\underline{C_i^1} h_1$	$U(L-1)$	UL
$\underline{w_i^1}$	$U(U-1)$	U^2
z_i^1	$(U-1)$	U
Total Operations	$2KU(L-1)+3UL-3U$ $+U^2+U^3/6-1$	$UL(3+2K)$ $+U^2+U^3/6+U$

Table 3.2: Numbers of addition and multiplication for MMSE detector

3.2.1 Complexity of Correlation Detector

In (3.2), where h_1^H, $\underline{(C_i^1)}^T$ and y_i having matrix dimensions $(1 \times L)$, $(L \times N_c N_\Psi + L - 1)$ and $(N_c N_\Psi + L - 1 \times 1)$ respectively.
Suppose $U = (N_c N_\Psi + L - 1)$, then numbers of addition and multiplication can be seen in Table 3.1.

3.2.2 Complexity of MMSE Detector

Consider (3.5)to (3.7) for MMSE detector, the total number of additions and multiplication operations required can be seen in Table 3.2.

3.2.3 Complexity of Adaptive LMS Detector

In (3.13), numbers of addition and multiplication operations required are as follow

From Table 3.1, 3.2 and 3.3, it can be seen that MMSE has highest number

Operations	No. of Addition	No. of Multiplication
z_i^1	$U-1$	U
$\widehat{w_1}(i+1)$	U	U
Total Operations	$(2U-1)$	$2U$

Table 3.3: Numbers of addition and multiplication for LMS detector

of addition and multiplication than correlation and LMS detector. On other hand, LMS has lowest numbers of addition and multiplication. Hence it is clear that LMS has lowest complexity then correlation and MMSE detector. Also, it can be seen that correlation and LMS detector are independent of factor k (number of user).

3.3 Summary

In this chapter, equalization techniques has been discussed for non-coherent detection. Three different detector have been discussed correlation detector, MMSE detector and LMS detector. Their block diagram and mathematical equation have also been discussed to analyze these detector under DS-TH CDMA system. The complexity of each detector has also been discussed by analyzing their number of additions and multiplication required for detection.

Chapter 4

Simulation Results and Discussions

In this chapter, simulation results will be analyzed and briefly discussed for DS-TH CDMA system. As mention previously, three detectors will be simulated namely correlation detector, linear MMSE detector and adaptive LMS detector.

While performing simulation, some considerations have to be assumed regarding modulation technique, fading channel model and number of multipath in channel.

Non-coherent binary differential phase-shift-keying (DPSK). Result will be simulated and compared for $L = 1$ and $L = 3$ number of multipath.Rayleigh fading channel will be assumed for constant path delays and path gains for multipath, also a slow moving users at Doppler frequency of $F_d = 0.0001Hz$. Each detector will be simulated and compared for $k = 1$ single-user and $k = 8$ multi-user (8 users) environment. Each detector will be simulated and compared for pure DS-CDMA system and hybrid DS-TH CDMA system.

4.1 Correlation Detector

In this section, the correlation detector BER performance will be tested for both DS and hybrid DS-TH CDMA system. In Fig. 4.1., When a single-user is tested for pure DS-CDMA system when channel has no multipath and TH spreading factor $N_{\Psi} = 1$ and DS spreading factor $N_c = 8$, it can be observed that correlation BER performance is ideal. However, as multi path increases at $L = 3$ it is clear that BER performance degrade but not worst, since correlation does have ability mitigate multipath effect up to some extent. Above simulation has been test under pure DS-CDMA system, now TH-DS system will be employed for same scenario and BER performance will be analyzed. It is observed that, at $N_{\Psi} = 4$ the BER performance is optimum for $N_c = 8$. If value of N_{Ψ} is increase or decrease than 4, then it is observed SNR degrades.

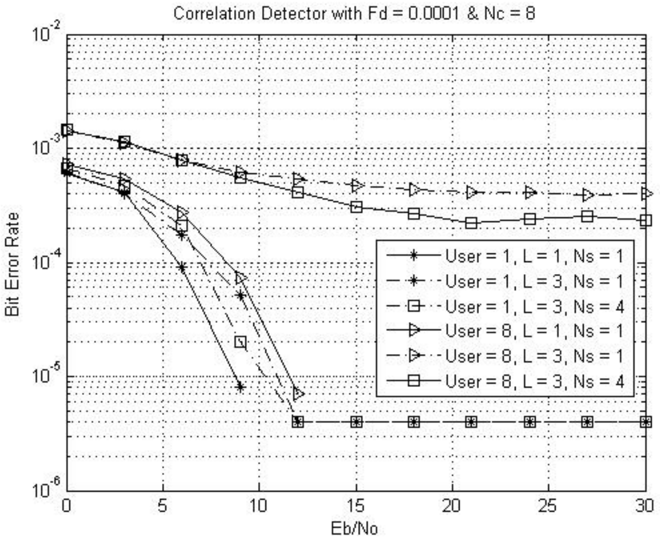

Figure 4.1: Correlation detector BER versus SNR performance curve for pure DS and hybrid DS-TH CDMA

Now consider multi-user $k = 8$ for correlation detector. In Fig. 4.1., When pure DS-CDMA system is employed with no multipath and DS spreading factor $N_c = 8$, BER performance degrade because correlation detector does not have ability to mitigate MUI as well as ISI. If multipath introduced under such scenario, it can be observed the BER performance get even worst.

Now TH-DS CDMA is employed for correlation detector for multi-user. It is observed that for DS spreading factor $N_c = 8$, there exit an optimum BER performance when TH factor $N_{\Psi} = 4$. Increasing or decreasing N_{Ψ} then 4,

BER degrade.
From above simulation for correlation detector under DS-TH CDMA system. It is observed, DS-TH CDMA system improves BER performance after selecting optimum N_Ψ for any particular N_c. However, complexity of correlation detector is relatively low but does not have ability to mitigate MUI and ISI.

4.2 MMSE Detector

In this section, MMSE detector simulation result will be analyzed for BER performance. In Fig. 4.2., the MMSE detector is employed for pure DS-CDMA system for single-user under no multipath when DS spreading factor is $N_c = 8$. It is observed that, BER performance for single-user for MMSE is ideal. However, after introducing multipath the BER performance degrade since MMSE does not have ability to mitigate multipath effects.

After introducing DS-TH CDMA by taking $N_\Psi = 4$, BER performance

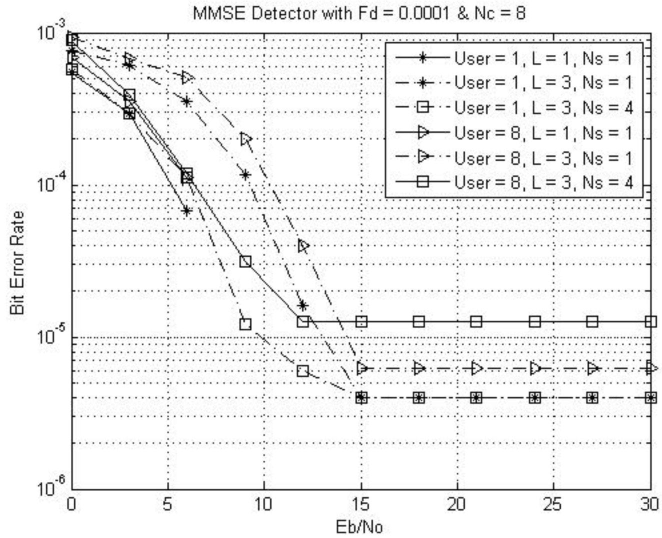

Figure 4.2: MMSE detector BER versus SNR performance curve for pure DS and hybrid DS-TH CDMA

improved. Now considering multi-user with no multipath at DS spreading factor $N_c = 8$, BER performance degrade a little but still better than correlation detector under same scenario, since MMSE detector has ability to mitigate MUI and ISI. However, after introducing multipath MMSE performance get worst. Now DS-TH CDMA system is employed, it is observed that for DS spreading factor $N_c = 8$ the TH factor produced optimum BER performance at $N_\Psi = 4$.

From Fig. 4.2., it can be observed that MMSE performance is better than correlation detector for single and multi-user detector. However,the MMSE detector requires channel knowledge which makes it complex and impractical to implement.

4.3 LMS Detector

In this section, LMS detector will be analyzed in sense of BER performance for DS-TH CDMA system. In Fig. 4.3., LMS detector is employed under single-user environment without multipath at DS spreading factor $N_c = 8$ for pure DS-CDMA system. It observed LMS produced good BER performance faster than correlation detector. However, after introducing multipath BER performance degrades, but after employing DS-TH CDMA system by where TH factor is $N_\Psi = 4$, BER performance improved.

Now for multi-user environment LMS detector will be employed with no multipath. Total $k = 8$ number of users for pure DS-CDMA system, It can be seen for Fig. 4.3. that it degrades it BER performance. After introducing multipath its BER performance get worst. However, after employing DS-TH CDMA system it can be seen that it improves its BER performance. Here it is also observed that, there exit an optimum value of N_Ψ for $N_c = 8$ where LMS achieve optimum BER performance.

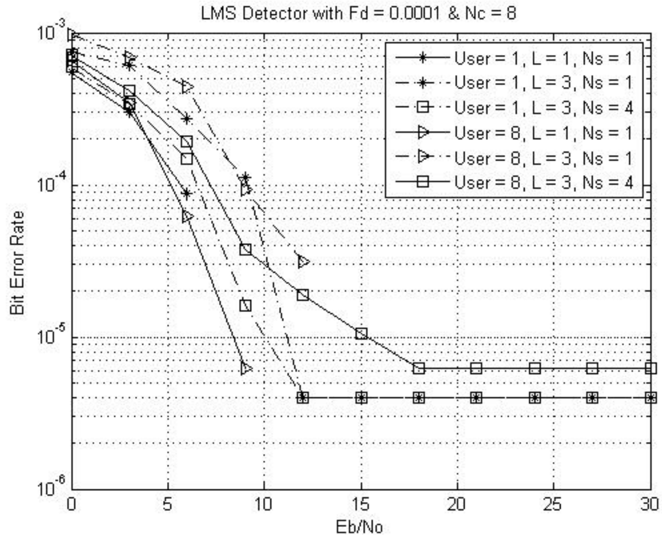

Figure 4.3: LMS detector BER versus SNR performance curve for pure DS and hybrid DS-TH CDMA

	Tap 1	Tap 2	Tap 3	Unit
Delay	0	0.4	0.9	μs
Power Gain	0	-15	-20	dB
Factor K	4	0	0	
Doppler	0.4	0.3	0.5	Hz

Table 4.1: SUI-1 Channel Model

4.4 LMS Detector For Stanford University Interim

SUI contain six channel models represented in variety of Doppler frequency, path gain and tap delay. LMS detector is tested for SUI channel model under Rician distribution channel for different K factor which represent ratio of line-of-sight (LOS) and non-line-of-sight (NLOS) component.

In Fig. 4.4., LMS detector is simulated for SUI-1 channel model for low Doppler frequency, low spread and high LOS as seen in Table 4.1. Under SUI-1, LMS detector able to mitigate ISI and MUI under hybrid DS-TH CDMA system.

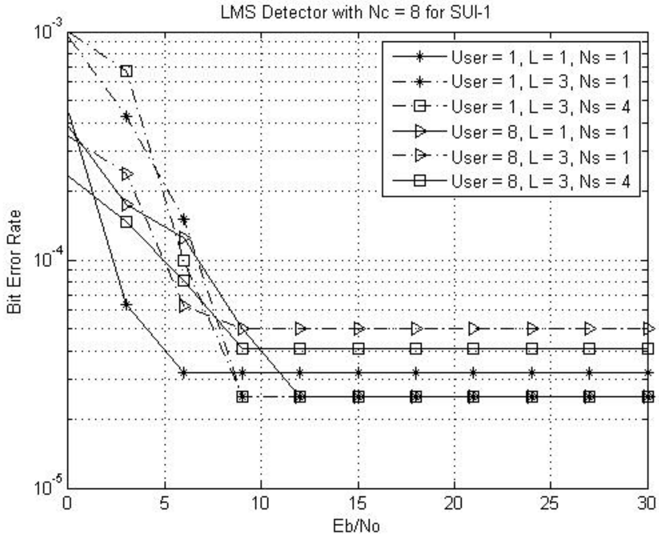

Figure 4.4: LMS detector BER versus SNR performance curve for pure DS and hybrid DS-TH CDMA under SUI-1 channel model

	Tap 1	Tap 2	Tap 3	Unit
Delay	0	0.4	0.9	μs
Power Gain	0	-12	-15	dB
Factor K	2	0	0	
Doppler	0.2	0.15	0.25	Hz

Table 4.2: SUI-2 Channel Model

In Fig. 4.5., LMS detector is simulated for SUI-2 channel model for low Doppler frequency, low spread and high LOS as seen in Table 4.2. Under SUI-2, LMS detector able to mitigate ISI and MUI under hybrid DS-TH CDMA system.

In Fig. 4.6., LMS detector is simulated for SUI-3 channel model for low Doppler frequency, low spread and low LOS as seen in Table 4.3. Under SUI-3, LMS detector able to mitigate ISI and MUI under hybrid DS-TH CDMA system.

In Fig. 4.7., LMS detector is simulated for SUI-4 channel model for high Doppler frequency, moderate spread and low LOS as seen in Table 4.4. Under SUI-4, LMS detector able to mitigate ISI and MUI under hybrid DS-TH

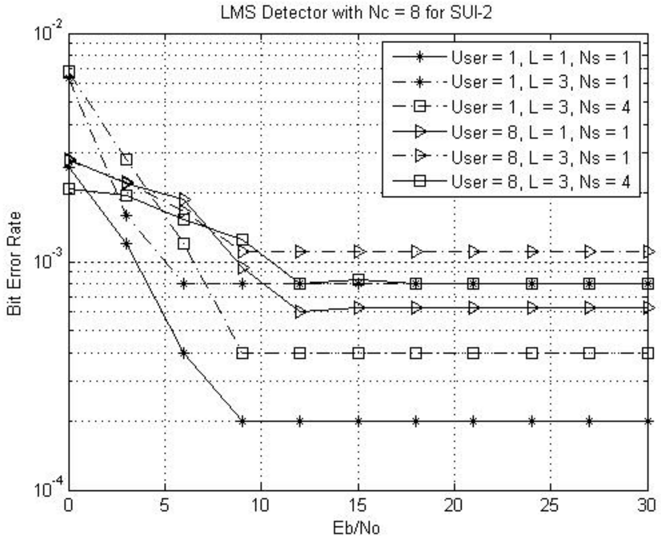

Figure 4.5: LMS detector BER versus SNR performance curve for pure DS and hybrid DS-TH CDMA under SUI-2 channel model

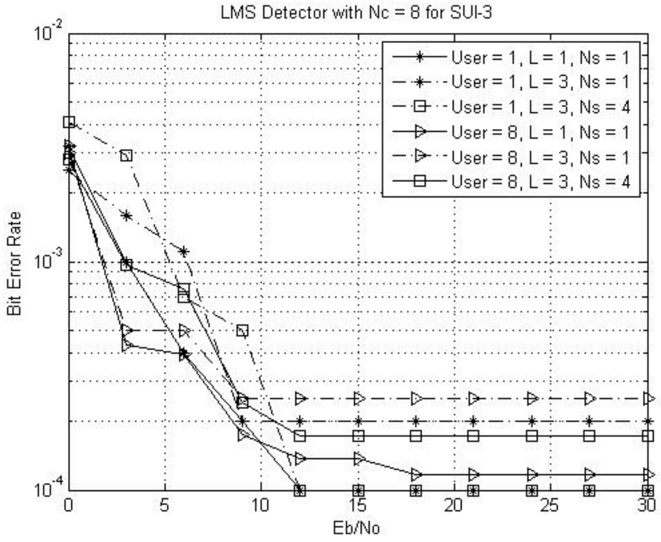

Figure 4.6: LMS detector BER versus SNR performance curve for pure DS and hybrid DS-TH CDMA under SUI-3 channel model

	Tap 1	Tap 2	Tap 3	Unit
Delay	0	0.4	0.9	μs
Power Gain	0	-5	-10	dB
Factor K	4	0	0	
Doppler	0.4	0.3	0.5	Hz

Table 4.3: SUI-3 Channel Model

CDMA system.

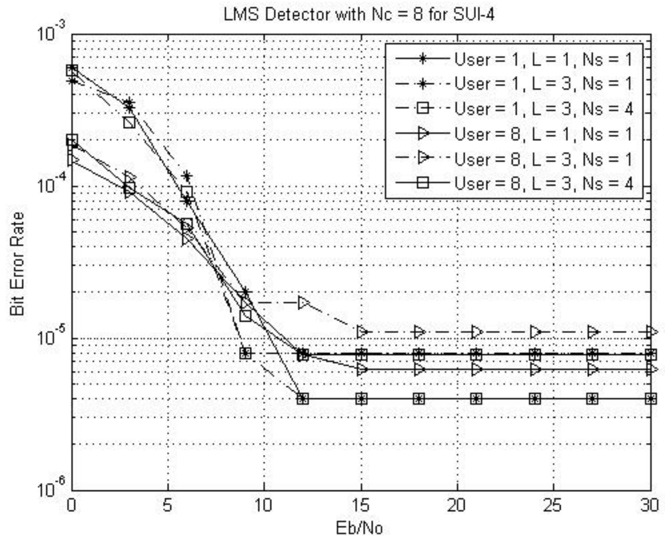

Figure 4.7: LMS detector BER versus SNR performance curve for pure DS and hybrid DS-TH CDMA under SUI-4 channel model

In Fig. 4.8., LMS detector is simulated for SUI-5 channel model for low Doppler frequency, high spread and low LOS as seen in Table 4.5. Under SUI-5, LMS detector able to mitigate ISI and MUI under hybrid DS-TH CDMA system.

In Fig. 4.9., LMS detector is simulated for SUI-6 channel model for high Doppler frequency, high spread and low LOS as seen in Table 4.6. Under SUI-6, LMS detector able to mitigate ISI and MUI under hybrid DS-TH CDMA system.

	Tap 1	Tap 2	Tap 3	Unit
Delay	0	1.5	4	μs
Power Gain	0	-4	-8	dB
Factor K	5	0	0	
Doppler	0.2	0.15	0.25	Hz

Table 4.4: SUI-4 Channel Model

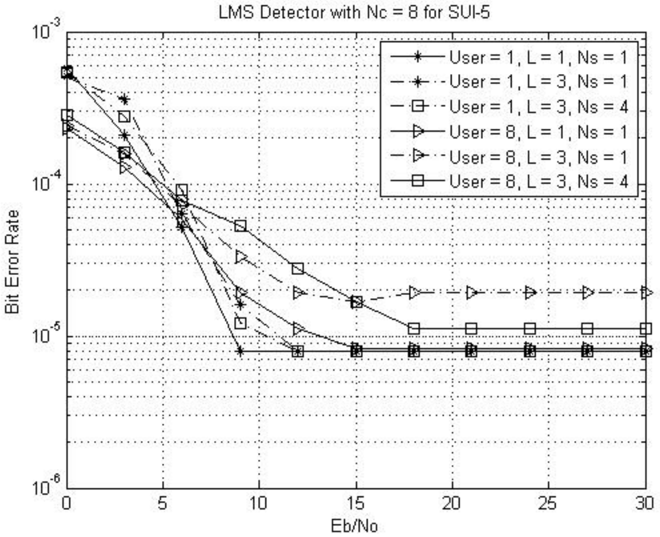

Figure 4.8: LMS detector BER versus SNR performance curve for pure DS and hybrid DS-TH CDMA under SUI-5 channel model

	Tap 1	Tap 2	Tap 3	Unit
Delay	0	4	10	μs
Power Gain	0	-5	-10	dB
Factor K	7	0	0	
Doppler	2	1.5	2.5	Hz

Table 4.5: SUI-5 Channel Model

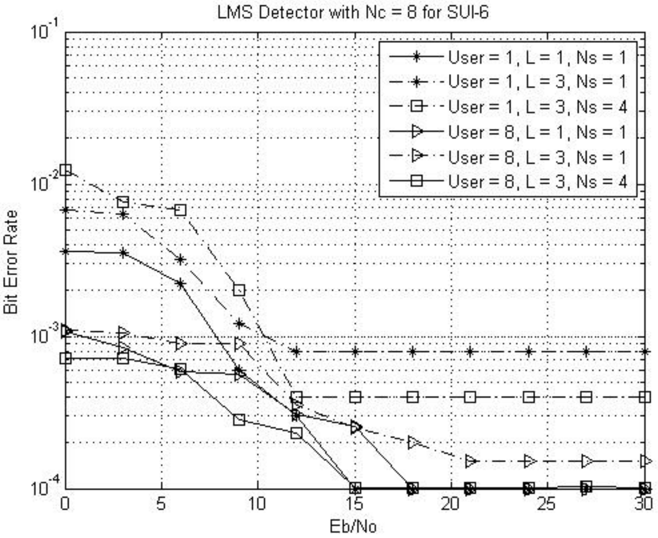

Figure 4.9: LMS detector BER versus SNR performance curve for pure DS and hybrid DS-TH CDMA under SUI-6 channel model

	Tap 1	Tap 2	Tap 3	Unit
Delay	0	1	4	μs
Power Gain	0	-10	-14	dB
Factor K	4	0	0	
Doppler	0.4	0.3	0.5	Hz

Table 4.6: SUI-6 Channel Model

4.5 Summary

In this chapter, performance analysis of DS-TH-CDMA was evaluated by simulating non-coherent detectors. The performance of the hybrid DS-TH-CDMA system was analyzed and compared with DS-CDMA in terms of BER curves. Three basic types of detectors were simulated, that included a single user correlation detector, MMSE detector and a LMS detector. It was observed that single user correlation detector was unable to recover the information bits in multi-user and multipath environment while minimum mean square error detector is capable to recover information in multi-user and multipath environment, but it is slightly more complex and requires extra information of channel and spreading code while performing detection. Furthermore, it was found that when LMS detector was employed in non-coherent detection, algorithm is misadjusted due to MUI, change in Doppler shift and increase in time hop factor.

Chapter 5

Conclusions

In this thesis, the hybrid DS-TH CDMA system is proposed for non-coherent detection. While evaluating and simulating this hybrid system, it is observed that this system is capable of mitigating MUI as well as ISI even in multipath environment.

An overview of CDMA system was discussed in term of their structure and mathematical form in Chapter 2. An overview of DS-SS and TH-SS was provided about their performance and importance, also effect of fading on channel. In Chapter 3 and Chapter 4, hybrid DS-TH CDMA system was discussed, also the transmitter, receiver structure and channel model was presented. The performance of correlation, MMSE and LMS detectors was studied under single and multi-user under multipath fading environment. On the basis of their simulated result, following observation was drawn.

Correlation is a single-user detector without the capability of mitigating MUI and ISI. However, the complexity of correlation detector is relatively low. Under single-user environment, correlation detector was able to mitigate multipath fading effect under DS-TH CDMA system. Also, it was observe that there exit a particular value for TH pattern N_Ψ for particular N_c where BER performance is optimum. Under multi-user environment, correlation detector BER performance degrades.

MMSE is a linear multi-user detector with capability of mitigating MUI and ISI. MMSE required channel information for detection which makes it complex and impractical to implement. Under single and multi-user environment when MMSE detector was employed under multipath fading effect, BER was able to achieve reasonable BER. After DS-TH CDMA system was employed it performance was optimum for both single and multi-user even under dense environment.

Adaptive LMS detector has low-complexity than correlation detector and BER performance near to MMSE detector since it does not required channel knowledge. LMS detector when employed for DS-TH system under multipath fading environment, its BER performance was optimum under particular TH pattern N_Ψ for particular DS spreading factor N_s.

5.1 Future Work

In this thesis, hybrid DS-TH CDMA system had proposed to improve wireless communication system. However, some suggestion cam be made for giving more room to improving the system.

Forward error correction (FEC) techniques can be implement to improve BER performance. Multi-input multi-output (MIMO) based system can be employed to investigate system performance. More adoptive detectors like recursive LMS (RLMS) and normalized RLMS (NRLMS)can be employed for DS-TH CDMA system to investigate their performance.

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