TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

Pulchowk Campus

A MIDTERM REPORT ON

Performance analysis of Orthogonal-frequency-division-multiplexing (OFDM) based on Channel Estimation Technique

By

Indu Bhandari

(068/MSI/607)

Submitted to

Master of Science in Information and Communication Engineering

Department of Electronics and Computer Engineering

September, 2013

Performance analysis of Orthogonal-frequency-division-multiplexing (OFDM) based on Channel Estimation Technique

By

Indu Bhandari

(068/MSI/607)

A midterm report submitted in partial fulfillment of the requirements for the degree of

Master of Science in Information and Communication Engineering

Department of Electronics and Computer Engineering

Institute of Engineering, Pulchowk Campus

Lalitpur, Nepal

September, 2013

ACKNOWLEDGEMENT

I would like to extend my gratitude my sincere thanks to my honorable supervisor Assistant Professor Daya Sagar Baral, Department of Electronics and Computer Engineering, IOE Pulchowk Campus, for his constant motivation, support, guidaince, constant supervision and constructive suggestion for the submission of progress report of thesis work on “Performance Analysis of OFDM based on Channel Estimation Technique”.

I also express my gratitude to Assistant Professor Sharad Ghimire, Department of Electronics and Computer Engineering, IOE Pulchowk Campus, for his valauable guidance and constant support for thesis work.

I also like to show sincere thanks to my family and friends who have indirectly supported me during thesis study.

Indu Bhandari (068 MSICE 607)

ABSTRACT

In order to achieve the potential advantages of OFDM based systems, the channel coefficients should be estimated with minimum error. Orthogonal frequency division multiplexing (OFDM) is a method to transmit multi carrier in wireless environment, and can also be seen as a multi-carrier digital modulation or multi-carrier digital multiplexing technology. Channel estimation plays a vital role in OFDM system. The channel estimation technique that can be pilot based or blind based can be helpful to improve the performance of OFDM system. The channel estimation technique for OFDM systems based on pilot arrangements is investigated. A different algorithm for both estimating channel at pilot frequencies and interpolating the channel is performed. The Performance comparison of all schemes by measuring bit error rate and mean square error using different modulation techniques like QPSK, and 16-QAM is discussed. Simulation results show the performance of different type channel estimation techniques under various channel condition and modulation technique.

Amplitude Modulation (QAM), Quadrature Phase Shift Key (QPSK), Phase Shift Key (QPSK), Binary Phase Shift Key (BPSK), Inter-symbol Interference.

TABLE OF CONTENT

LIST OF FIGURES

S.N. **Page No.**

LIST OF ABBREVIATIONS

ACI	Adjacent Channel Interference
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CCI	Co-Channel Interference
CP	Cyclic Prefix
CSI	Channel State Information
DSL	Digital Subscriber Line
DVB	Digital Video Broadcasting
HYPERLAN	High Performance Radio LAN
IEEE	Institute of Electrical and Electronics Engineers
ISI	Inter Symbol Interference
LMS	Least Mean Square
LMMSE	Linear Minimum Mean Square Error Estimation
LTE	Long Term Evolution
MCM	Multi Carrier Modulation
MIMO	Multiple Input Multiple Output
OFDM	Orthogonal-frequency-division-multiplexing
PDF	Probability Density Function
QAM	Quadrature-Amplitude Modulation
QPSK	Quadrature Phase-Shift Keying
SNR	Signal-to-Noise Ratio
WiFi	Wireless Fidelity
ZF	Zero Forcing

CHAPTER 1

1 INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has recently been applied widely in wireless communication systems due to its high data rate transmission capability with high bandwidth efficiency and it robustness to multi-path delay. It is simply defined as a form of multi-carrier modulation where the carrier spacing is carefully selected so that each sub carrier is orthogonal to the other sub carriers. Two signals are orthogonal if their dot product is zero. That is, two signals are taken and multiplied together. If their integral over an interval is zero, then two signals are orthogonal in that interval. Orthogonality can be achieved by carefully selecting carrier spacing, such as letting the carrier spacing be equal to reciprocal of the useful symbol period. As the sub carriers are orthogonal, the spectrum of each carrier has a null at the center frequency of the other carriers in the system [3].

OFDM has been adopted as the modulation method of choice for practically all the new wireless technologies being used and developed today. It is perhaps the most spectrally efficient method discovered so far, and it mitigates the severe problem of multipath propagation that causes massive data errors and loss of signal. OFDM systems are attractive for the way they handle ISI, which is usually introduced by frequency selective multipath fading in wireless environment. Each sub- carrier is modulated at a very low symbol rate, making the symbols much longer than the channel impulse response. In this way, ISI is diminished. Moreover, if a guard interval between consecutive OFDM symbols is inserted, the effects of ISI can completely vanish. This guard interval must be longer than the multipath delay. Although each-subcarriers operate at a low data rate, a total high data rate can be achieved by using a large number of sub-carriers. ISI has very small or no effect on the OFDM systems hence an equalizer is not needed at the receiver side. Cyclic Prefix (CP) is inserted between two successive symbols as guard interval which not only mitigates Inter Symbol Interference (ISI), but also converts the linear convolution between the transmitted OFDM symbol and channel impulse response to a circular one. At the receiver, the CP corrupted by ISI is generally discarded and the ISI free part of the OFDM symbol is used for channel estimation and data detection.

A dynamic estimation of channel is necessary before the demodulation of OFDM signals since the radio channel is frequency selective and time-varying for wideband mobile communication systems [2]. The channel estimation can be performed by either inserting pilot tones into all of the subcarriers of OFDM symbols with a specific period or inserting pilot tones into each OFDM symbol [4]. In addition, the channel estimation based on block type pilot arrangement is performed by sending pilots at every sub-channel and using this estimation for a specific number of symbols like BPSK, QPSK and 16 QAM has been carried out. The Performance comparison of all schemes by measuring bit error rate using different modulation techniques like 16QAM, QPSK, and BPSK.

1.1 Channel Characteristics

Performance of wireless mobile communication system is mainly constrained by the wireless channel, which consists of base station antennas and propagation paths between the user antennas. Communication between the transmitter and receiver path can be more complex, because of variety of complex topography, such as buildings, mountains, forests, etc.. Compared with the predictable channel like cable, radio channel is very random, which results in distortion of amplitude, phase and frequency of received signal. So, it is necessary to have an overall understanding about wireless communication channel [16].

1.1.1 Channel Estimation

The channel estimation can be performed by either inserting pilot tones into all of the subcarriers of OFDM symbols with a specific period or inserting pilot tones into each OFDM symbol. There are basically two types of classification of Channel estimation in OFDM

i. **Pilot Based Channel Estimation**: Known symbol called pilots are transmitted.
ii. **Blind Channel Estimation**: No pilots required. It uses some underlying mathematical properties of data sent. The performance evaluation of Pilot Based Channel estimation in OFDM will be studied. The Blind channel estimation methods are computationally complex and hard to implement. The Pilot based channel estimation methods are easy to implement but they reduces the bandwidth efficiency.

1.1.2 Block Type Pilot based channel estimation

In this type, OFDM symbols with pilots at all subcarriers (referred to as pilot symbols herein) are transmitted periodically for channel estimation. Using these pilots, a time-domain interpolation is performed to estimate the channel along the time axis. Since pilot tones are inserted into all subcarriers of pilot symbols with a period in time, the block type pilot arrangement is suitable for frequency-selective channels.

Block Type pilot signal estimation

Channel can be estimated at pilot frequencies by two ways:

i. Least Square (LS) Estimation
ii. Minimum Mean Square Error Estimation (LMMSE)

For block type arrangements, channel at pilot tones can be estimated by using LS or LMMSE estimation, and assumes that channel remains the same for the entire block. So in block type estimation, we first estimate the channel, and then use the same estimates within the entire block.

1.1.3 Comb-Type Pilot channel estimation

The comb type pilot arrangement is suitable for fast-fading channels, but not for frequency selective channels.

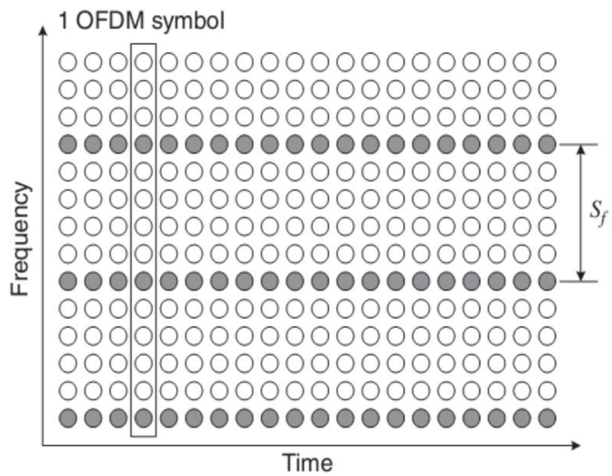


Figure 1.1: Comb-type Pilot Channel Estimation

To achieve high data rates as well as good performances, coherent detection is commonly used in most existing OFDM Systems. Coherent detection relies on knowledge of channel state information. One simple approach to obtain channel state information is to send some pilot symbols at the transmitter. Pilot subcarriers are often interlaced with data subcarriers. Comb-type pilot insertion has been shown to be suitable for channel estimation in fast fading channels. The channel estimation algorithm based on comb-type pilot is divided into pilot signal estimation and channel interpolation [1].

1.2 Problem Statement

During the transmission of source signal from source to destination, the signal gets distorted by different channel impairments (noise). In order to achieve the potential advantages of OFDM based systems, the channel coefficient should be estimated with minimum error. To estimate the channel coefficient and correct received signal, the pilot based approach is inserted in frequency, and channel coefficients that belong to the pilot subcarriers are estimated using the different estimation method. The estimation methods are performed assuming the statistical properties of the channel are perfectly known at the receiver side.

1.3 Objective

i. The objective of the thesis "Performance Analysis of OFDM based on Channel Estimation Technique" is to evaluate the performance depending on different channel estimation technique.
ii. To analyze and suggest the best channel Estimation technique for OFDM to improve the performance under different channel estimation technique.

1.4 Scope

Scope of the thesis entitled "Performance analysis of OFDM based on Channel Estimation Technique" is to evaluate the performance depending on different channel estimation technique. The Performance analysis of all schemes by measuring bit error rate using different modulation techniques like 16QAM, QPSK, and BPSK has been discussed under "Performance analysis of MIMO OFDM under various channels" at Institute of Engineering, Pulchowk Campus T.U., Nepal. The estimated BER on different fading channel condition can further be reduced by appropriate channel estimation technique. So an approach to analyze the performance based on channel estimation technique has been purposed.

1.5 Thesis Outline

The thesis entitled “Performance Analysis of Orthogonal-frequency-division-multiplexing (OFDM) based on Channel Estimation Technique” is divided on seven chapters. Chapters 1 include the basic introduction of the OFDM system describing different technique of the channel estimation. Chapter 2 describes the detail Literature Review including research papers of OFDM system. Chapter 3 includes the methodology, simulation set up and the tools that have been applied to get the simulation results. Similarly, Chapter 4 contains obtained simulations and plots. Finally chapter 5 describers the conclusion of the output of simulation and results obtained. On the last two chapters thesis schedule and references are include.

CHAPTER 2

2 LITERATURE REVIEW

OFDM is a promising technology for achieving high data rate transmission. The application of OFDM for achieving the high data rate in communication system is important topic for the researcher. The first OFDM scheme was proposed by Chang in 1966[4] for dispersive fading channels. OFDM was standardized as the European digital audio broadcast (DAB) as well as digital video broadcast (DVB) scheme. Finally, OFDM was selected as the high performance local area network's (HIPERLAN) transmission technique as well as becoming a part of the IEEE 802.11 Wireless Local Area Network (WLAN) standard. OFDM has been adopted as the downlink transmission scheme for the 3GPP Long-Term Evolution (LTE) and is used for several other radio technologies, e.g. WiMAX [5] and the DVB broadcast technologies [6].

In the year 1985 Cimini proposed a cellular mobile radio system based on OFDM used with pilot based correction system [11]. It has provided large improvements on performance under various fading channel condition. One of the important applications of OFDM used in Digital Satellite services and Satellite Mobile channel and was proposed by Fernado and Rajtaheva in the year 1988 [12].

As wireless communication systems are usually interference limited, new technologies should be able to handle the interference successfully. Interference can be from other users e.g. Co-Channel Interference (CCI) and Adjacent Channel Interference (ACI), or it can be due to users own signal (self-interference) , e.g. Inter symbol Interference (ISI). ISI is one of the major problems for high data rate communications which is treated with equalizers in conventional single-carrier systems [13]. However, for high data rate transmission, complexity of equalizers becomes very high due to the smaller symbol time and large number of taps needed for equalization. The problem is especially for channels with large delay spreads.

Multi-carrier modulation is one of the transmission schemes which are less sensitive to time dispersion (frequency selectivity) of the channel. In multi-carrier systems, the transmission bandwidth is divided into several narrow sub-channels and data is transmitted parallel in these sub-channels [7]. Data in each sub-channel is modulated at a relatively low rate so that the delay spread of the channel does not cause any degradation in quality of services.

Although, the principles were known since early sixties multi-carrier modulation techniques, especially Orthogonal Frequency Division Multiplexing (OFDM), gained more attention in these years due to the increased power of digital signal processors. OFDM technique converts a frequency selective channel into a number of frequencies non-selective channels by dividing the available spectrum into a number of overlapping and orthogonal narrowband sub channels where each of them sends own data using a subcarrier.

An OFDM signal is a sum of subcarriers that are individually modulated by using phase shift keying (PSK) or quadrature amplitude modulation (QAM). The symbol can be written as:

$$s(t) = Re\left\{\sum_{i=-\frac{N_s}{2}}^{\frac{N_s}{2}-1} d_{i+\frac{N_s}{2}} \exp\left(j2\pi(f_c - \frac{i+0.5}{T}\right)(t-t_s)\right\}, t_s \le t \le t_s + T$$

$$s(t) = 0, t < t_s \; and \; t > t_s = T \qquad (2.1)$$

where:

NS is the number of subcarriers

T is the symbol duration

fc is the carrier frequency

The digital source is usually protected by channel coding and interleaved against fading phenomenon, after which the binary signal is modulated and transmitted over multipath fading channel. Additive noise is added and the sum signal is received [8].

2.1 OFDM Principles

The basic principle of OFDM is to split a high-rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. The relative amount of dispersion in time caused by multipath delay spread is decreased because the symbol duration increases for lower rate parallel subcarriers. The other problem to solve is the inter symbol interference, which is eliminated almost completely by introducing a guard time in every OFDM symbol. This means that in the guard time, the OFDM symbol is cyclically extended to avoid inter carrier interference. An OFDM signal is a sum of subcarriers that are individually modulated by using phase shift keying (PSK) or quadrature amplitude modulation (QAM) [19].

2.1.1 M-ary Digital Modulation

In order to achieve efficient information transmission, M-ary digital modulation could be used to transmit data symbols. Compared with the binary digital modulation, an M-ary symbol can carry $log_2 M$ bits of information, whereas a binary symbol can only carry one bit of information. Commonly, M-ary digital modulation methods used in digital communication systems includes constant amplitude modulation and non-constant amplitude modulation. A typical example of two modulation methods are M-ary phase shift keying (MPSK) and quadrature amplitude modulation (QAM) [1].

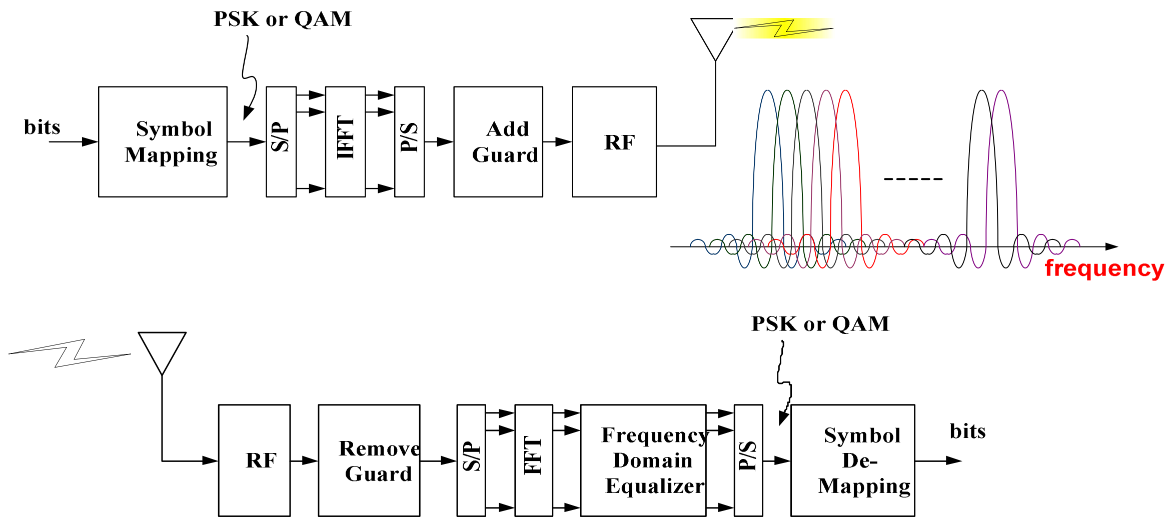


Figure 2.1 OFDM Transmission and Reception with Modulation

In MPSK modulation, carrier phase could be chosen by different M, then $\theta_i = \frac{2\pi i}{M}, i - 0,1,2 \ldots \ldots \ldots . M - 1$. The function of phase after Modulation can be given by,

$$s_i = \sqrt{E_s} \cos\left(2\pi f_c t + \frac{2\pi i}{M}\right)$$
$$= \sqrt{E_s} \cos(2\pi f_c t) \cos\left(\frac{2\pi i}{M}\right) - \sqrt{E_s} \sin(2\pi f_c t) \sin\left(\frac{2\pi i}{M}\right) \quad (2.1)$$

where, $\sqrt{E_s}$ means energy per symbol [16].

In order to explain the MPSK scenario let us take an example of quadrature phase shift keying QPSK. It uses four points on the constellation diagram, equispaced around a circle. With four phases, QPSK can encode two bits per symbol, as shown in Figure 2.2, with Gray coding to minimize the bit error rate (BER) sometimes misperceived as twice the BER of binary phase shift keying (BPSK)

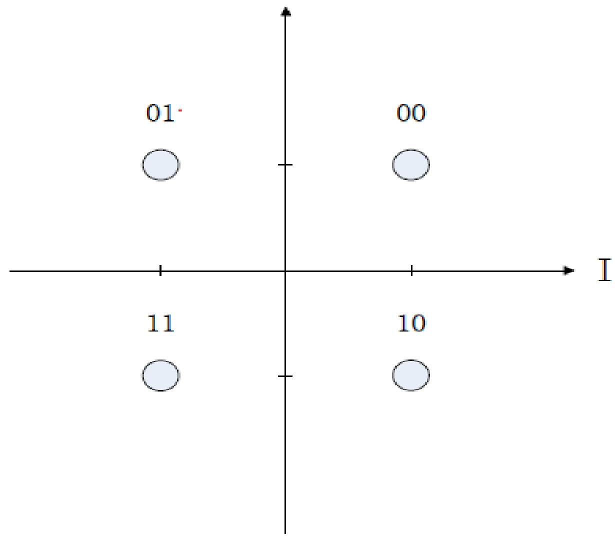


Figure 2.2: Constellation of QPSK

The implementation of QPSK is more general than that of BPSK and also indicates the implementation of higher-order PSK. Writing the symbols in the constellation diagram in terms of the sine and cosine waves used to transmit them.

$$s_i(t) = \sqrt{\frac{2E_s}{T}}\cos\left(2\pi f_c t + \frac{(2n-1)\pi}{4}\right), n = 1,2,3,4 \tag{2.2}$$

This yields the four phase's π/4, 3π/4, 5π/4 and 7π/4 as needed. This results in a two-dimensional signal space with unit basis functions.

$$\varphi(t)_1 = \sqrt{\frac{2}{T_s}}\cos\,(2\pi f_c t) \tag{2.3}$$

$$\varphi(t)_1 = \sqrt{\frac{2}{T_s}}\sin(2\pi f_c t) \tag{2.4}$$

The first basis function is used as the in-phase component of the signal and the second as the quadrature component of the signal. Hence, the signal constellation consists of the signal-space 4 points$(\pm\sqrt{\frac{E_S}{2}}, \pm\sqrt{\frac{E_S}{2}})$. The factors of 1/2 indicate that the total power is split equally between the two carriers.

Amplitude of MPSK modulation is kept constant, so that we can get circular constellation map. If the phase and amplitude of signal modulated can be changed, we can get QAM method with non-constant amplitude. The signal function after QAM modulation could be written as below

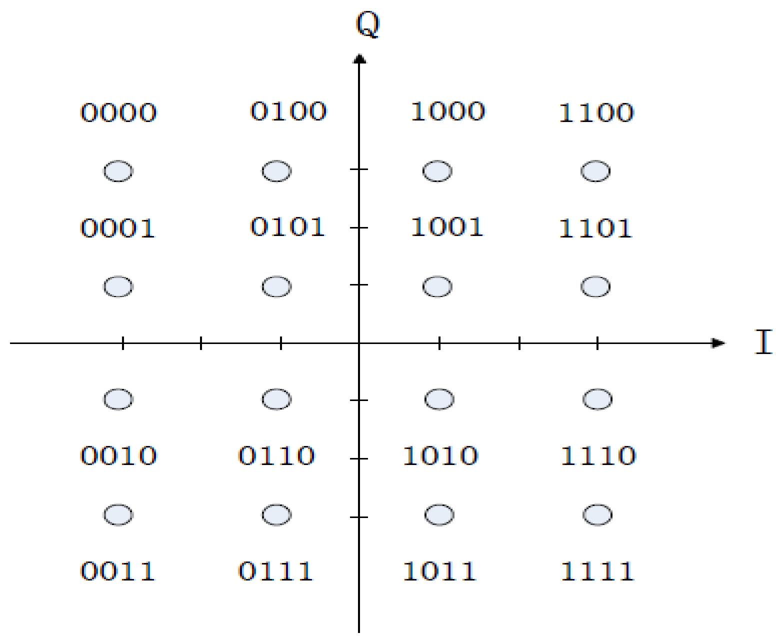


Figure 2.3 Constellation of 16 QAM

2.1.2 Guard Time and Cyclic Prefix

The inter symbolic interference is almost completely eliminated by introducing a guard time for a each OFDM symbol. The guard time is chosen larger than the expected delay spread such that multipath components from one symbol cannot interfere with the next symbol. This guard time could be no signal at all but the problem of inter carrier interference (ICI) would arise. Then, the OFDM symbol is cyclically extended in the guard time. Using this method, the delay replicas of the OFDM symbol always have an integer number of cycles within the FFT interval, as long as the delay is smaller than the guard time. Multipath signals with delays smaller than the guard time cannot cause ICI.

If multipath delay exceeds the guard time by a small fraction of the FFT interval (for example 3%), the subcarriers are not orthogonal anymore, but the interference is still small enough to get a reasonable constellation. Considering that the multipath delay exceeds the guard time by 10% of the FFT interval, the constellation is seriously affected and an unacceptable error rate is obtained [19].

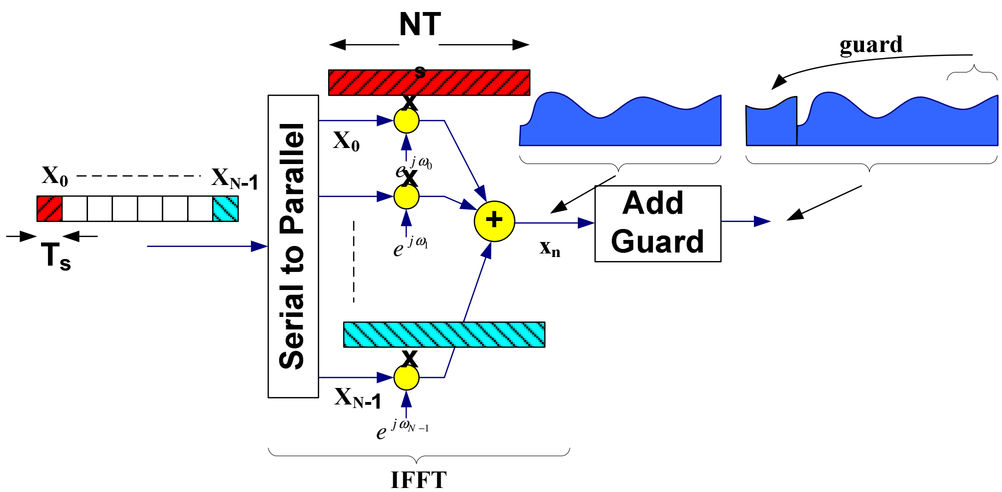


Figure 2.4 OFDM Guard Insertion

Let us consider a simple multipath channel of the form

$$h(t) = \propto_1 \partial(t - t_1) + \propto_2 \partial(t - t_1) \qquad (2.2)$$

Let the transmit symbol be a single sinusoidal

$$x(t) = e^{j2\pi f_1 t}$$

The received signal is given by,

$$y(t) = x(t) * h(t)$$

$$= \propto_1 e^{j2\pi f(t-t_1)} + \propto_2$$

$$= e^{j2\pi f_1 t} \underbrace{\left[\propto_1 e^{-j2\pi f_1 t_1} + \propto_2 e^{-j2\pi f_1 t_2}\right]}$$

After passing through the multipath channel, the received signal is the original sinusoidal *x(t)* albeit with modifications in amplitude and phase. To prevent the effect of ISI in OFDM signals, a guard time which well known as cyclic prefix, must be add to the symbol.

Cyclic prefix acts as a buffer region where delayed information from the previous symbols can get stored. The receiver has to exclude samples from the cyclic prefix which got corrupted by the previous symbol when choosing the samples for an OFDM symbol.

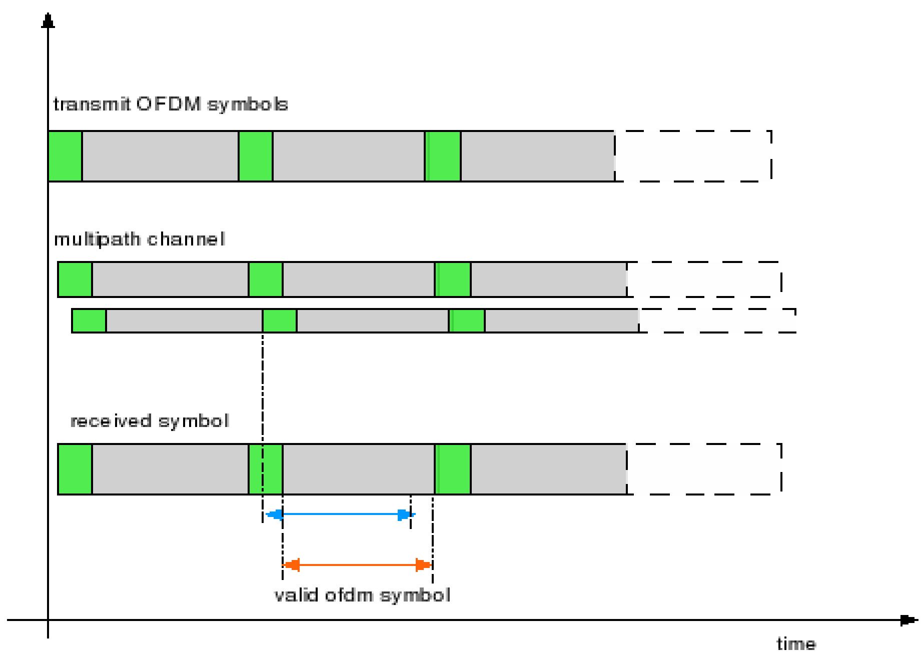


Figure 2.5: OFDM symbol with multipath

Cyclic prefix duration is determined by the expected duration of the multipath channel in the operating environment. Determination of cyclic prefix is done as per the IEEE 802.11a specification.

The adding process is given as [20]:

$$x'(n) = \begin{cases} x(N+n) & n = -N_c, -N_c+1, \ldots\ldots -1 \\ x(n) & n = 0,1,\ldots\ldots, N-1 \end{cases} \quad (2.3)$$

Where 'N_c' denoted the cyclic prefix length.

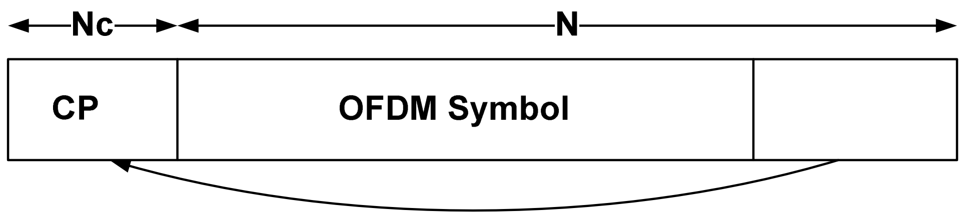


Figure 2.6 Cyclic Prefix adding process in OFDM symbol

2.1.3 Channel Estimation

In any communication systems, channel estimation is a most important and challenging problem, especially in wireless communication systems. Usually, the transmitted signal can be degraded by many detrimental effects such as mobility of transmitter or receiver, scattering due to environmental objects, multipath and so on. These effects cause the signal to be spread in any transformed domains as time, frequency and space. To reducing these effects anyone must estimate the channel impulse response (CIR). Channel estimation has a long history in single carrier communication systems. In these systems, CIR is modeled as an unknown FIR filter whose coefficients are time varying and need to be estimated [21]. There are many channel estimation methods that can be used in multicarrier communication systems but the especial properties of multicarrier transmission systems give an additional perspective which forces to developing new techniques to channel estimation in wireless communication systems. In general, channel estimation methods based on OFDM systems can be categorized into two groups as blind and non-blind techniques. In the former, all of the techniques use the statistical behavior of the received signals and therefore, to obtain the accurate CIR a large amount data is required [22]. Finally, the complexity of computations is very high. In the later, to obtain a good estimation of channel, the transmitter sends a collection of data aided as pilots whose are previously known by the receiver [21].

2.1.4 Radio Channel

In the wireless communication systems, electromagnetic wave propagation can be divided into direct wave, ground reflected wave and scattering, reflection and diffraction of the radiation energy in the dissemination of path caused by a variety of obstacles in the path. And because of the movement of the receiver itself, it makes the channel between transmitter and receiver changeful and difficult to control. So, signals are attenuated through the wireless channel called fading. The fading may vary with time, geographical position or radio frequency, and is often modeled as a random process. Fading may occur due to multipath propagation referred to as multipath induced fading, or due to shadowing from obstacles affecting signal propagation [23]. Because of the movement of the receiver and the other objects in wireless channel environment, the instantaneous change of space is converted to the instantaneous change of signal, when the mobile station moves through the multipath area. It presents the time-varying of wireless channel, such as Doppler shift [16].

Doppler spread and coherence time are parameters which describe the time varying nature of the channel in a small-scale region. Coherence Time is a measure of the minimum time required for the magnitude change of the channel to become uncorrelated from its previous value. It actually measures the time duration over which the channel impulse response is essentially invariant, and quantifies the similarity of the channel response at different times. In other words, coherence time is the time duration over which two received signals have a strong potential for amplitude correlation. If the reciprocal bandwidth of the baseband signal is greater than the coherence time of the channel, then the channel will change during the transmission of the baseband message, thus causing distortion at the receiver [23].

Slow fading arises when the coherence time of the channel is large relative to the delay constraint of the channel. In this regime, the amplitude and phase change imposed by the channel can be considered roughly constant over the period of use. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver.

Fast fading occurs when the coherence time of the channel is small relative to the delay constraint of the channel. In this regime, the amplitude and phase change imposed by the channel varies considerably over the period of use. Although a deep fade may temporarily erase some of the information transmitted, use of an error- correcting code with successfully transmitted bits during other time instances can allow for the erased bits to be recovered. In a slow-fading channel, it is not possible to use time diversity because the transmitter sees only a single realization of the channel within its delay constraint. A deep fade therefore lasts the entire duration of transmission and cannot be mitigated using coding [23].

The coherence time of the channel is related to with as described Doppler spread of the channel. When a user (or reflectors in its environment) is moving, the user's velocity causes a shift in the frequency of the signal transmitted along each signal path. Signals traveling along different paths can have different Doppler shifts, corresponding to different rates of change in phase. The difference in Doppler shifts between different signal components contributing to a single fading channel tap is known as the Doppler spread. Channels with a large Doppler spread have signal components that are each changing independently in phase over time. Since fading depends on whether signal components add constructively or destructively, such channels have a very short coherence time.

In general, coherence time is inversely related to Doppler spread, typically expressed as:

$$T_c = 1/D_s$$

where T_c is the coherence time, D_s is the Doppler spread

Let the n-th reflected wave with amplitude c_n and phase $\emptyset$ arrive from an angle α_n relative to the direction of the motion of the antenna then the Doppler shift of this wave is

$$\Delta f_n = \frac{v}{\lambda} cos\alpha_n$$

where v is the speed of the antenna.

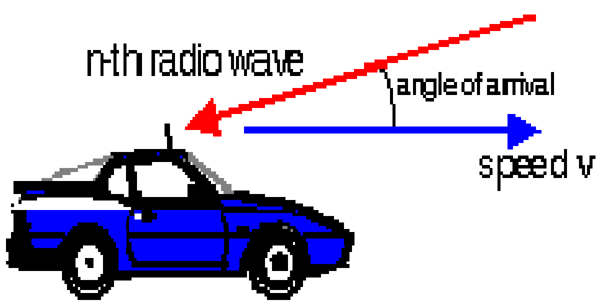


Figure 2.7 Doppler Shift of Incoming Signal

Such motion of the antenna leads to phase shifts of individual reflected waves, affecting the amplitude of the resulting signal [24].

CHAPTER 3

3 METHODOLOGY

The performance of the OFDM link will be evaluated in terms of BER and SNR plot comparing the different channel estimation technique. The technique which will give less BER vs SNR plot will be the best method for better performance. The analysis can be carried out on MATLAB 7.0 to simulate and model different problems. MATLAB is a strong mathematical tool which provides help to engineers to solve, model, simulate the problems and find their solutions. We will use estimation and interpolation technique to analyze the performance.

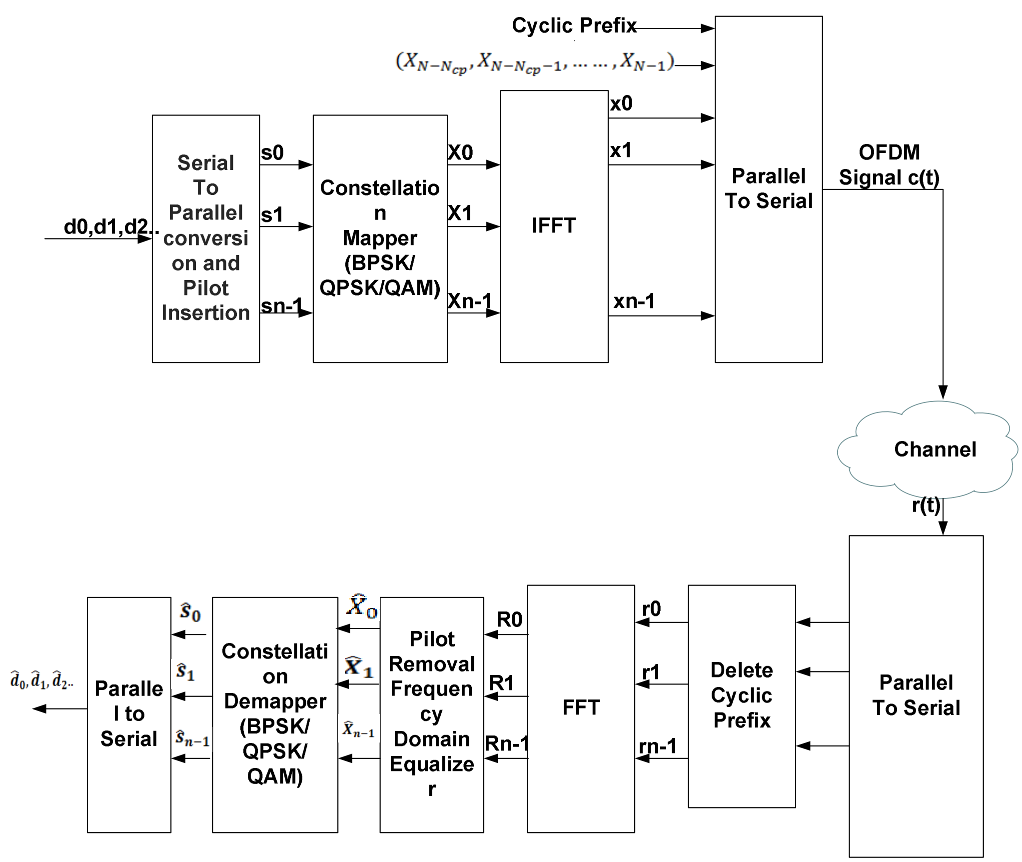


Figure 3.1 Basic block diagram of OFDM system.

Figure shown above is the block diagram of an OFDM system. The whole section of the OFDM block can be divided into 7 fundamental sections. They are

1. Input data stream
2. Serial to parallel conversion
3. Constellation mapping
4. Pilot insertion and Padding
5. IDFT
6. Cyclic Prefix Insertion and
7. Parallel to serial conversion

The main focus of the thesis will be Pilot insertion and Channel Estimation Technique.

3.1 OFDM Transmission Principle

Orthogonal Frequency Division Multiplexing (OFDM) is a multiplexing technique that divides a channel with a higher relative data rate into several orthogonal sub-channels with a lower data rate. For high data rate transmissions, the symbol duration Ts is short. Therefore ISI due to multipath propagation distorts the received signal, if the symbol duration Ts is smaller as the maximum delay of the channel. To mitigate this effect a narrowband channel is needed, but for high data rates a broadband channel is needed. To overcome this problem the total bandwidth can be split into several parallel narrowband subcarriers. Thus a block of N serial data symbols with duration Ts is converted into a block of N parallel data symbols, each with duration $T = N \times Ts$. The aim is that the new symbol duration of each subcarrier is larger than the maximum delay of the channel, $T > Tmax$. With many low data rate subcarriers at the same time, a higher data rate is achieved [17].

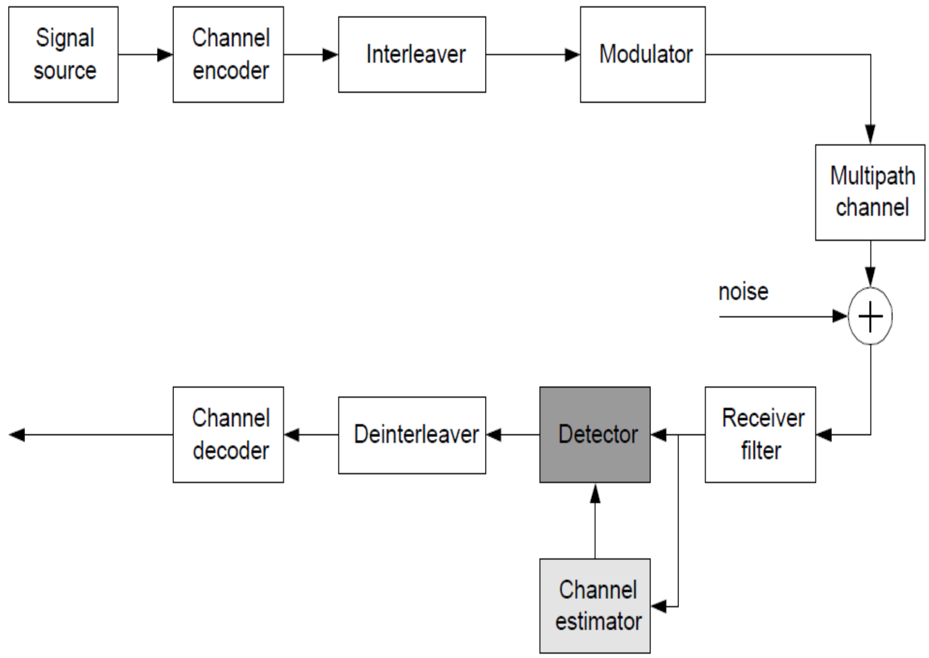


Figure3.2 Block diagram of system utilizing channel estimator and detection

3.2 Symbol Generation, Pilot Insertion and Transmission

In order to create the OFDM symbol a serial to parallel block is used to convert N serial data symbols into N parallel data symbols. Then each parallel data symbol is modulated with different orthogonal frequency subcarriers, and added to an OFDM symbol, [18]. After conversion of symbol from serial to parallel symbols are inserted with different technique between the data symbol. Pilot bits are randomly generated and inserted between data bits.

Two type of pilot insertion technique is used in simulation process i.e. Block Type and Comb Type. In Block type pilot arrangement, OFDM symbols with pilots at all subcarriers are transmitted periodically for channel estimation. Using these pilots, a time-domain interpolation is performed to estimate the channel along the time axis [14].

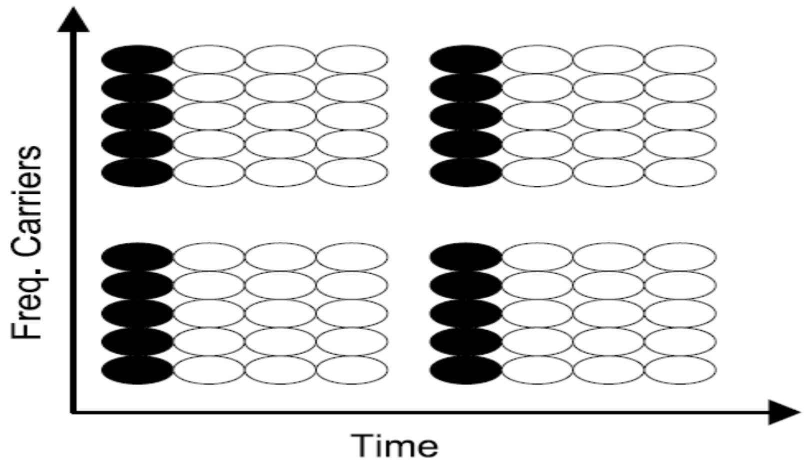


Figure 3.3 Block Type Pilot Arrangement

The channel estimation algorithm based on comb-type pilot is divided into pilot signal estimation and channel interpolation. Pilot signal estimation is based on LS or LMMSE criteria and different interpolation algorithms.

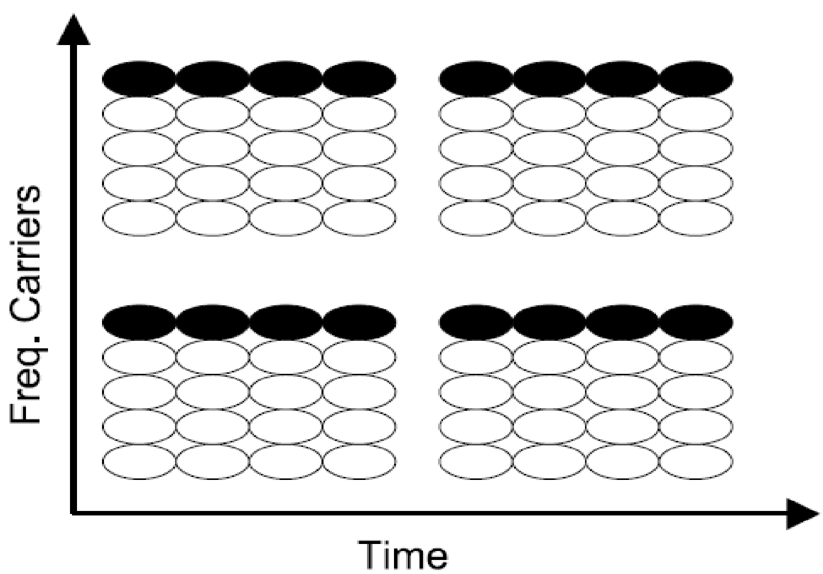


Figure3.4 Comb Type Pilot Arrangement

3.2.1 Using Inverse Fast Fourier Transform FFT to Create the OFDM Symbol

All modulated subcarriers are added together to create the OFDM symbol. This is done by an Inverse Fast Fourier Transformation (IFFT). The advantage of using IFFT is that the system does not need N oscillators to transmit N subcarriers [17].

3.2.2 Cyclic Prefix Insertion

The cyclic prefix is used in OFDM signals as a guard interval and can be defined as a copy of the end symbol that is inserted at the beginning of each OFDM symbol. Guard interval is applied to mitigate the effect of ISI due to the multipath propagation. Figure 1.2 shows the symbol and its delay. These delays make noise and distort the beginning of the next symbol as shown. To overcome this problem, one possibility is to shift the second symbol furthers away from the first symbol. But existence of a blank space for a continuous communication system is not desired. In order to solve this problem a copy of the last part of the symbol is inserted at the beginning of each symbol. This procedure is called adding a cyclic prefix. The Cyclic prefix is added after the IFFT at the transmitter, and at the receiver the cyclic prefix is removed in order to get the original signal.

3.3 Channel Estimation Scheme

Channel state varies continuously so channel state information needs to be estimated on short term basis. An approach of inserting training sequence (or pilot sequence), where a known signal is transmitted and the channel matrix H is estimated using the combined knowledge of the transmitted and received signal.
Let the training sequence be denoted by $P_1, \dots\dots\dots\dots . P_N$ where the vector P_i is transmitted over the channel as:

$$y_i = Hp_i + n_i$$

By combining the received training signals $y_i \, for \, i = 1, \ldots \ldots \ldots \ldots, N$ total training signaling becomes:

$$Y = [y_1 \ldots \ldots .. y_N] = HP + N$$

with the training matrix $P = [p_1, \ldots \ldots . p_N]$ and the noise matrix

$$N = [n_1, \ldots \ldots . n_N]$$

With this notation, channel estimation means that H should be recovered from the knowledge of Y and P.

In order to estimate the channel at receiver side using the transmitted symbol of pilot two types of estimation techniques is used. The block-type refers to that the pilots are inserted into all the subcarriers of one OFDM symbol with a certain period. The block-type can be adopted in slow fading channel, that is, the channel is stationary within a certain period of OFDM symbols. The comb-type refers to that the pilots are inserted at some specific subcarriers in each OFDM symbol.

The channel estimation based on comb-type pilot arrangement is often performed by two steps. Firstly, it estimates the channel frequency response on all pilot subcarriers, by lease square (LS) method, LMMSE method, and so on. Secondly, it obtains the channel estimates on all subcarriers by interpolation, including data subcarriers and pilot subcarriers in one OFDM symbol. There are several interpolation methods including linear interpolation method, second-order polynomial interpolation method, and phase-compensated interpolation

Assuming that inter symbol interference is dropped by guard interval, we write output Y(k) as:

$$Y = Xh + nY$$

Where Y is the received vector, X is a matrix containing the transmitted signaling points on its diagonal, h is a channel attenuation vector, and n is a vector of i.i.d. complex, zero mean, Gaussian noise with variance ${\sigma^2}_n$. In the following the

Linear Minimum Mean Square Error LMMSE and Least Square LS estimate in detail with channel attenuations h from the received vector **y** and the transmitted data X is described. It's assumed that the received OFDM symbol contains data known to the estimator - either training data or receiver decisions.

3.3.1 Least Square Estimation

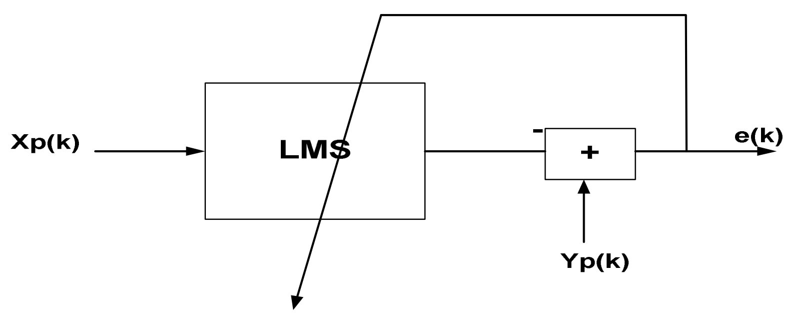


Figure 3.5 Least Square Estimation

The LMS estimator uses a one-tap LMS adaptive filter at each pilot frequency. The first value is found directly through LS and the following values are calculated based on the previous estimation and the current channel output. The error signal e(k) is formed and plotted by taking the difference between the received pilot symbol Y(k) and transmitted pilot symbol X(k).

Let us Suppose pilot signals as *Mpi* with symbols as *Xpi(n), n=0,1,…..,Mpi-1* which are uniformly inserted into *X(k)* data signals. The OFDM signal modulated on the k^{th} subcarrier can be expressed as

$$(k\ ) = X\big((nLs + i)\big)$$

$$= \begin{cases} X_{pi}(n), i = 0 \\ Source\ data, i = 1,2, \ldots \ldots, L_s - 1 \end{cases} \quad (3.1)$$

when the total M subcarriers are divided into Mpi groups, each with $L_s = M/M_{pi}$ adjacent subcarriers. The estimate of pilot signals based on least squares (LS) criterion is given by [15],

$$\hat{H}_{pi} = X_{pi}^{-1} Y_{Pi} \tag{3.2}$$

$$H_{pi} = \left[H_{pi}(0) H_{pi}(1) \dots \dots .. H_{pi}(M_{pi} - 1)\right]^T \tag{3.3}$$

the channel frequency response at pilot sub-carriers,

$$Y_{pi} = \left[Y_{pi}(0) Y_{pi}(1) \dots \dots .. Y_{pi}(M_{pi} - 1)\right]^T \tag{3.4}$$

received pilot signals vector which can also be expressed as

$$Y_{pi} = X_{pi}.H_{pi} + I_{pi} + W_{pi} \tag{3.5}$$

where $X_{pi} = \begin{pmatrix} X_{pi}(0) & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & X_{pi}(M_{pi} - 1) \end{pmatrix}, I_p \; and \; W_{pi} are \; the \; intercarrrier$ interference (ICI) vector and the Gaussian noise vector in pilot subcarriers, respectively.

3.3.2 Linear Minimum Mean Square Error Estimation

The linear minimum mean square error (LMMSE) estimate has been shown to be better than the LS estimate for channel estimation in OFDM systems based on block type pilot arrangement. The LMMSE estimate has about significant gain in SNR over LS estimate for the same MSE values in low SNR regions. The major drawback of the LMMSE estimate is its high complexity, which grows exponentially with observation samples. In a low rank approximation is applied to a linear minimum mean squared error estimator (LMMSE estimator) that uses the frequency correlations of the channel [14].

Let us denote the error of channel estimation as

$$e = H - \hat{H} \tag{3.6}$$

Where H is actual channel estimation and is raw channel estimation, respectively. And the MSE of channel estimation is [16]

$$E\{[|e^2|\} = e\{\left|H - \widehat{H}\right|^2\})$$
$$= e\left\{\left(\left|H - \widehat{H}\right|\right)\left(\left|H - \widehat{H}\right|^H\right)\right\} \quad (3.7)$$

Where E{ } is the expectation. Since the channel and AWGN are not correlated, we can rewrite Equation 3.7 as:

$$\widehat{H}_{MMSE} = R_{HY}\, {R_{YY}}^{-1} Y \quad (3.8)$$

Let us denote the auto-covariance matrixes of H, Y by $R_{HH,} R_{YY,}$ respectively, and cross covariance matrix between H and Y byR_{HY}. Let ${\sigma^2}_N$ is the noise-variance, since the channel and AWGN are not correlated, we could get:

$$R_{HY} = E\{HY^H\}$$
$$= E\{H(HX + W)^H\}$$
$$= E\{HH^H X^H + HW^H\}$$
$$= R_{HH} X^H \quad (3.9)$$

$$R_{YY} = E\{YY^H\}$$
$$= E\{(HX + W)(HX + W)^H\}$$
$$= E\{HXH^H X^H + HXW + WX^H H^H + WW^H\}$$
$$= XR_{HH}X^H + {\sigma_N}^2 I_N \quad (3.10)$$

If R_{HH} and ${\sigma_N}^2$ are known to the receiver, so channel impulse response could be calculated by LMMSE estimator as below:

$$\widehat{H}_{MMSE} = R_{HY} {R_{YY}}^{-1} Y \quad (3.11)$$
$$= R_{HH}(R_{HH} + {\sigma_N}^2 (X^H X)^{-1})^{-1}\ \widehat{H}_{LS}$$

CHAPTER 4

4 SIMULATION AND PLOTS

The simulated output would is the comparison of BER performance over different channel estimation technique. Firstly the comparison of estimation algorithm is made over different modulation technique and the estimation which will produce least error is used to estimate the channel. Also performance analysis with channel estimation and with no channel estimation is carried out. The simulation result from MATLAB is shown below which shows clear view of simulation result.

For channel estimation technique, basically two types of channel estimation technique: least square and linear minimum mean square error is studied. Performance of both algorithms is analyzed based on mean square error under different modulation schemes. The estimation technique which shows less error is used for channel estimation. No pilot is considered for the estimation performance analysis.

4.1 Comparison of different channel estimation technique in different modulation schemes and channel condition

Parameter consideration is as follows:

PARAMETER	SPECIFICATION
FFT Size	128
Channel	AWGN
Signal constellation	BPSK, QPSK,16-QAM
SNR	5:40 DB

i) Simulation showing comparison of Estimation Techniques based on BPSK

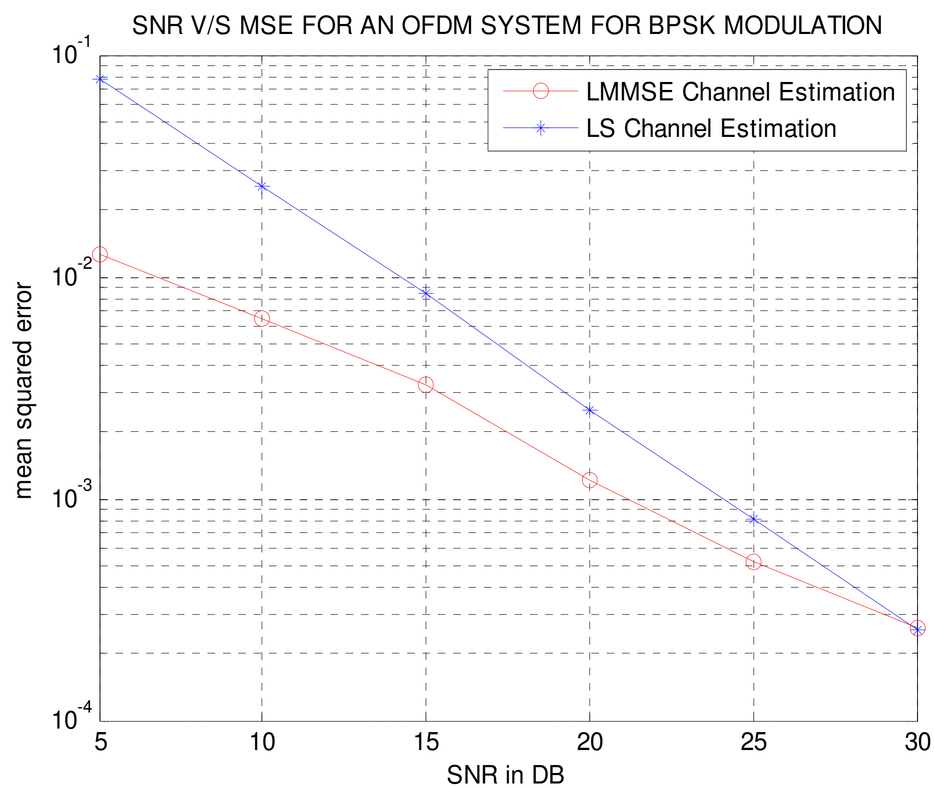


Figure 4.1: Comparison of Estimation technique in BPSK modulation

Figure 4.1 shows the comparison of two channel estimation technique least aquare and linear minimum mean square error. For lower values of SNR LMMSE estimation technique performes best, but when SNR goes high both estimation has similar result. Since least square estimation doesn't require prior knowlegde of noise parameter, so it can be good for channel estiamtion at higher values.

The comparison of estimation algorithm for higher lever moulation is carried out as in figure 4.2. which can be used to compare the result of channel estimation algorithm based on different modulation scheme.

ii) Simulation showing comparison of Estimation Techniques based on 16 QAM

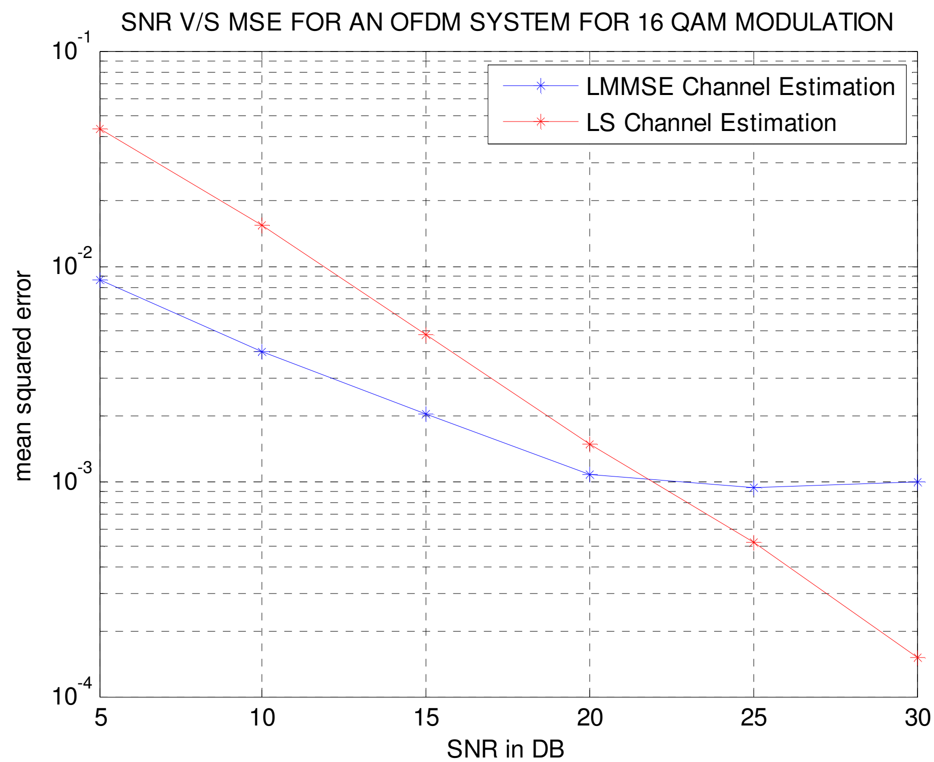


Figure 4.2: Comparison of Estimation technique in 16 QAM modulation

From simulation result of figure 4.1 and figure 4.2 with different modualtion scheme it can been seen that the performance of LMMSE estimation technique has better performance in BPSK to QPSK technique when SNR goes high. However as we go to higher modulation scheme bandwidth efficiecy is increadsed though mean square error increases. So most of the estimation of channel is carried out at higer order modulation.

iii) Simulation showing comparison of Estimation Techniques based on 16-QAM for block type pilot under AWGN Channel

PARAMETER	SPECIFICATION
FFT Size	128
Block Pilot position	4
Cyclic Prefix length	16
Signal constellation	16-QAM
Doppler Shift	132Hz
Channel	AWGN

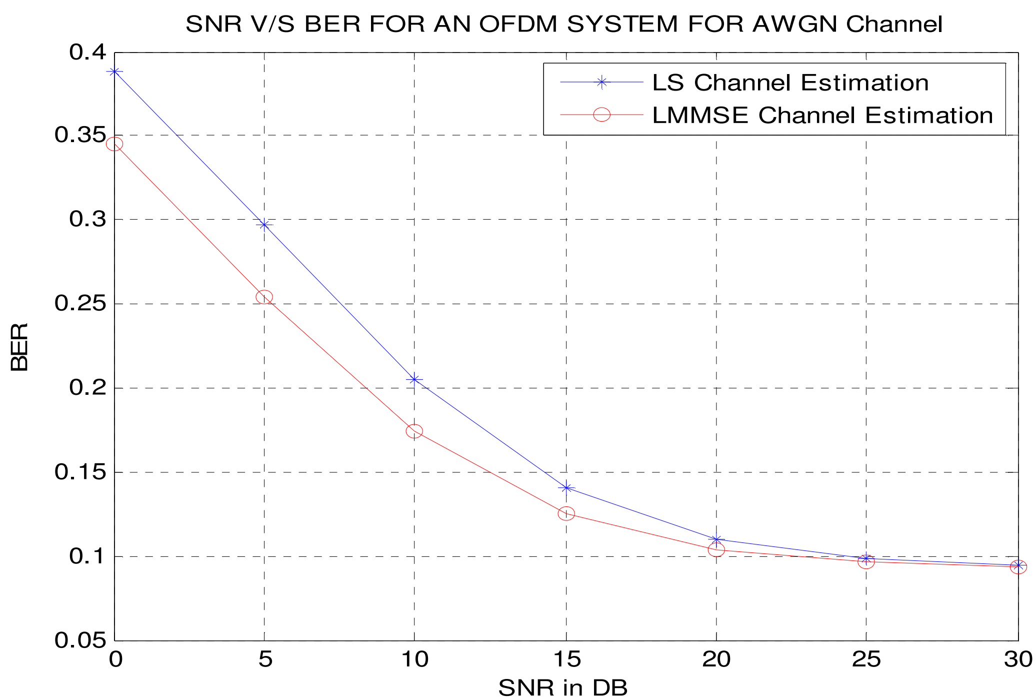


Figure 4.3: Comparison of Estimation technique on AWGN Channel

After comparison of estimation algorithm it has been found that least square estamtion and linear minimum mean square error performes almost same when SNR increases. We have used both the algorithm to analyse the performance for different channel condition. However in lower values of SNR LMMSE performs better. But the complexity of LMMSE technique is high as compared to LSE.

iv)Simulation showing comparison of performance based on Estimation Techniques no estimation technique

PARAMETER	SPECIFICATION
FFT Size	128
Block Pilot position	8
Guard Interval	8
Doppler Shift	100Hz
Channel	AWGN

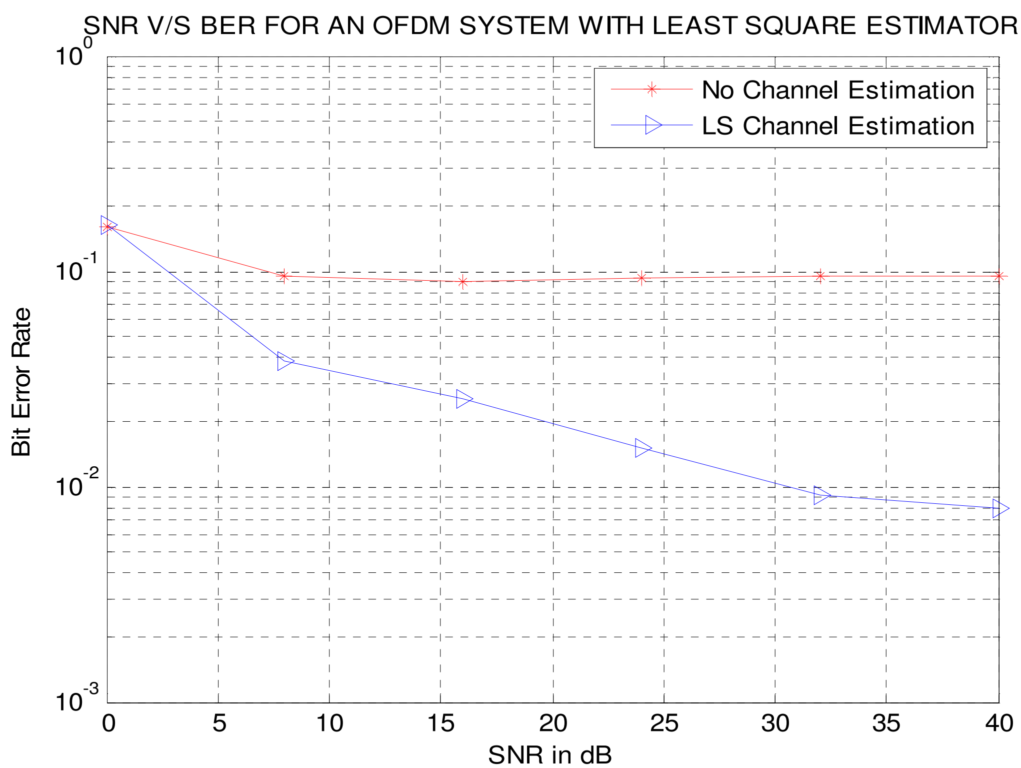


Figure 4.4: Comparison of Estimation technique and no Estimation technique

From the simulation we can see that use of channel estiamation helps to minimize the bit error rate. For low values of SNR there is slight improvement in BER rate with the use of channel estimation. As we go from lower to higter SNR the BER rate decreases drastically with as compared with no channel estimation.

CHAPTER 5

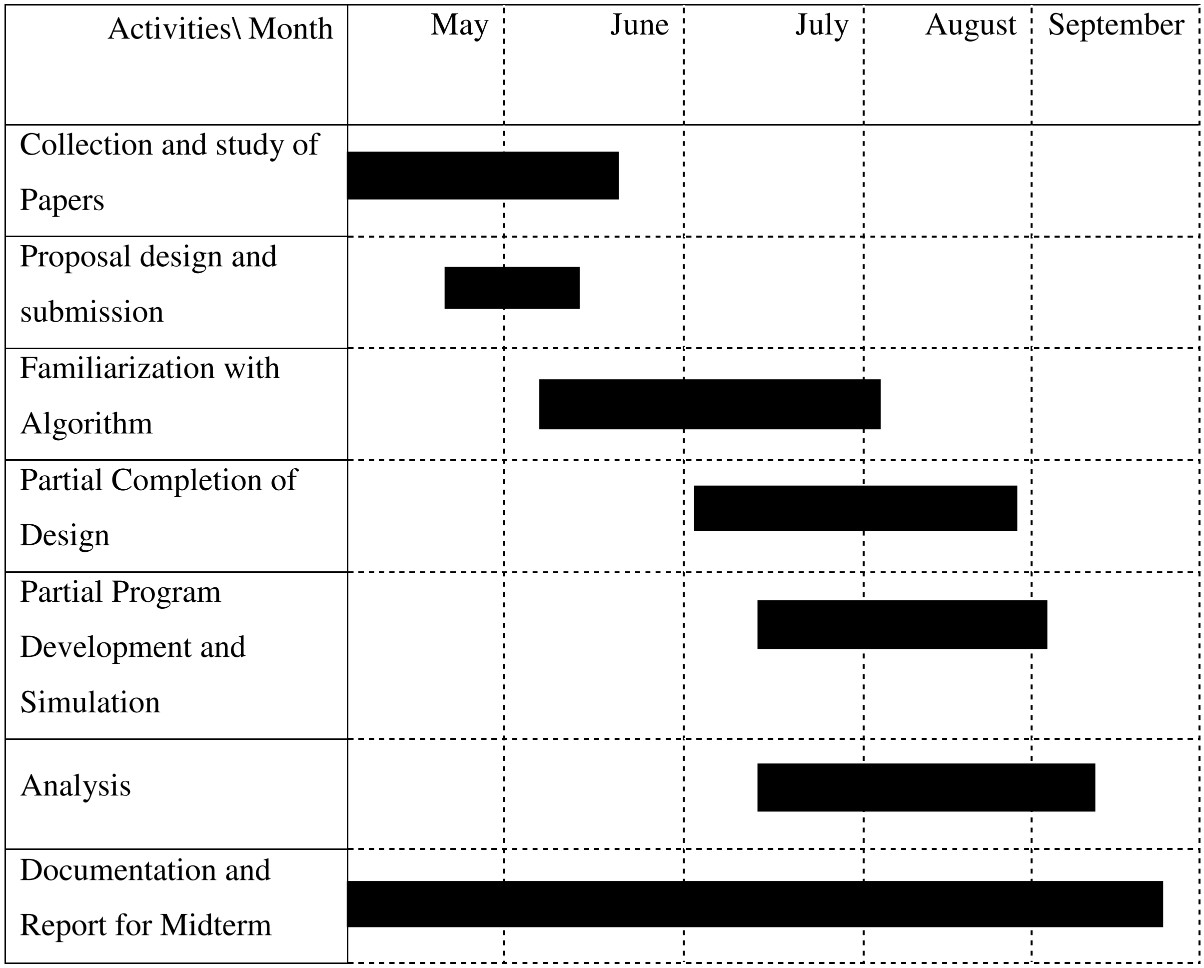
5.1 TASK COMPLETED

In order to analyze the performance of OFDM based on different channel estimation technique, Least square and LMMSE techniques were analysed using different modulation technique like BPSK, 16-QAM etc.., and found that both the method least square estimation and linear minimum mean square error performs almost similar in higher SNR values. Both LMMSE and LS estimation is used to estimate channel with 16-QAM modulation technique in block tyoe pilot insertion technique at Rayleigh and AWGN channel. Performance of block type pilot insertion is analysed. Also the performance of OFDM performance is anlysed based on channel estimation and no estimation. The simualtion has been carried out for comb type least square technique. After the simulation it has been confirmed that channel estimation gives better performance than no channel estimation.

5.2 TASK REMAINING

From the simulation results observed the comparison of algorithm has been made. These algorithms have been simulated and performance has been analyzed in terms of Minimum Mean Square Error MSE and Bit Error Rate BER under different modulation scheme. Also the simulation for Block type channel estimation has been already done. Now the remaining task is to simulate and observe the performance of comb type channel estimation and compare the performance based on channel fading condition. After the simulation of estimation technique in different channel fading condition using different estimation technique appropriate technique to insert pilot i.e block type or comb type according to channel fading condition will be mentioned.

6 THESIS SCHEDULE



7 REFERENCES

[1] Pilot Channel Estimation: A Performance Analysis of OFDM by Keshav Kumar, Amit Grover, *International Journal of Scientific & Engineering Research* Volume 4, Issue 1, January-2013.

[2] R. S. Bahai and B. R. Saltzberg, *Multi-Carrier Digital Communications Theory and Applications of OFDM*: Kluwer Academic/Plenum, 1999.

[3] BER Analysis of MIMO OFDM System for AWGN and Rayleigh Fading Channel by Mitalee Agrawal and Yudhishthir Raut, *International Journal of Computer Applications* (0975-8887) Volume 34-No.9, Novenber 2011.

[4] Sinem Coleri, Mustafa Ergen, Anuj Puri, and Ahmad Bahai, *Channel Estimation Techniques Based on Pilot Arrangement in OFDM Systems,* IEEE transactions on broadcasting, vol. 48, no. 3, September 2002.

[5] S.Imre and A. Mraz, "Fair radio resource allocation in multiuser OFDMA network", *IEEE wireless communication Magazine, 2008.*

[6] "IEEE 802.16e Mobile Wireless MAN Standard: Physical and medium access control layers for combined fixed and mobile operation in licensed bands", *IEEE 2005.*

[7] "Digital video broadcasting (DVB): Guidelines on implementation and use of service information", *European Telecommunication Standard Institute (ETSI), Tech.Rep. (TR) 101211V1.6.1,* May 2004.

[8] Chen, J., C. Chiang and L. Lo, 2007. Iterative Channel Estimation for MIMO OFDM Systems. Proceeding of the International Symposium on Intelligent Signal Processing and Communication Systems, Nov. 28-Dec. 1, *IEEE Xplore Press, Xiamen, pp: 774-777. DOI: 10.1109/ISPACS.2007.4446002.*

[9] Qiao, Y., S. Yu, P. Su and L. Zhang, 2005. Research on an iterative algorithm of LS channel estimation in MIMO OFDM systems. *IEEE Trans. Broadcast.,51: 149-153. DOI: 10.1109/TBC.2004.842524*

[10] Pradip Paudyal, *QOS Aware Adaptive Radio Resource Management for MIMO OFDMA Systems,* 2010 Institute of Engineering (IOE), Pulchowk.

[11] Cimini, J. and Sollenberger, N.R. (1998), "*OFDM with diversity and coding for advanced cellular internet services*", IEEE conference proceedings VTC.

[12] W.A.C. Fernando, P. Rajatheva and K. M. Ahmed, "*Performance of Coded OFDM with Higher Modulation Schemes*", Proceedings of the International Conference on Communications Technology (ICCT'98), Beijing, China, October 1998, Vol. II, S38-03-1:5.

[13] Tev_k Yucek, "*Self-interference Handling in OFDM Based Wireless Communication Systems"*, November 14, 2003, Master of Science in Electrical Engineering Department of Electrical Engineering College of Engineering University of South Florida.

[14] Comparison of Block Type Pilot Channel Estimation Techniques for Evaluating the performance of OFDM by Keshav Kumar, Amit Grover, *International Journal of Scientific & Engineering Research* Volume 3, Issue 11, November-2012.

[15] C. Chuah, D.N.C. Tse and J.M. Kahn, et al., "*Capacity scaling in MIMO wireless system under correlated fading*," IEEE Trans. on Information Theory, Vol. 48. No. 3, pp. 637-650, 2002.

[16] Fei Wang, "*Pilot-Based Channel Estimation in OFDM System*," The University of Toledo May 2011, May, 2011.

[17] Samaneh Shooshtary, "*Development of a MATLAB Simulation Environment for Vehicle –to-Vehicle and Infrastructure Communication Based on IEEE 802.11p*," The University of Toledo GAVLE Vienna, December 2008.

[18] A. F. Molisch, Wireless Communication. IEEE -Press - Wiley and Sons, 2005.

[19] Aníbal Luis Intini, "*Orthogonal Frequency Division Multiplexing for Wireless Networks*", University of California, Santa Barbara, December, 2000.

[20] Ali Asadi and Behzad Mozaffari Tazehkand, "*A New Method to Channel Estimation in OFDM Systems Based on Wavelet Transform",* International Journal of Digital Information and Wireless Communications (IJDIWC) 3(1):

1-9. The Society of Digital Information and Wireless Communications, 2013 (ISSN: 2225-658X).

[21] H. Bolcskei, R. W. Heath Jr. and A. Paulraj, B*lind channel identification and equalization in OFDM based multiantenna systems*," IEEE Trans. Signal Processing,vol 59, No.1, pp.96-109, Jan. 2002.

[22] H. Arslan and G. E. Bottomley, "Channel Estimation in Narrowband Wireless Communication Systems," *Wireless Commun. and Mobile Comp.*,vol.11, no. 2, pp. 201–19, Apr. 2001

[23] en.wikipedia.org/wiki/Fading, sited on 15th September, 2013.

[24] people.seas.harvard.edu/~jones/es151/prop_models/propagation.html#doppler , sited on 15th September, 2013.

[25] Aida Zaier and Ridha Bouallegue, "*Channel Estimation Study for Block Pilot Insertion in OFDM System under Slow Time Varying Condition*", International Journal of Computer Networks & Communications (IJCNC) Vol.3, No.6, November 2011.