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ADAPTIVE CHANNEL ESTIMATION FOR MIMO-OFDM SYSTEM IN MULTIPATH FADING CHANNEL

by

Surendra Khatri

A THESIS

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The undersigned certify that they have read and recommended to the Department of Electronics and Computer Engineering for acceptance, a thesis entitled **"Adaptive Channel Estimation for MIMO-OFDM system in Multipath Fading Channel"**, submitted by **Surendra Khatri** in partial fulfillment of the requirement for the award of the degree of "**Master of Science in Information and Communication Engineering**".

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DEPARTMENTAL ACCEPTANCE

The thesis entitled **“Adaptive Channel Estimation for MIMO-OFDM system in Multipath Fading Channel”,** submitted by **Surendra Khatri** in partial fulfillment of the requirement for the award of the degree of “**Master of Science in Information and Communication Engineering**” has been accepted as a bonafide record of work independently carried out by him in the department.

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ABSTRACT

Channel Estimation is a critical task in wireless communication. It is one of the vital parts of the wireless communication which is a method used to significantly improve the performance of the system. OFDM can be associated with number of antennas at the sender and receiver sides called MIMO-OFDM system. In this thesis, Adaptive Channel Estimation techniques such as Least Mean Square, Recursive Least Square and Kalman filtering are used for the MIMO-OFDM system in the Rayleigh and Rician fading channels. The various diversity configurations like 2x1, 2x2, 2x3 and 2x4 for the MIMO-OFDM have been used. Performance of the high order diversity is better than the low order diversity system i.e 2x4 has the best result in terms of BER. Simulation results show that RLS has better performance than LMS. The performance of the Kalman filter is better than the LMS and RLS techniques. The effect of the Doppler shifts has been studied for the different MIMO system to analyze the time varying environment of the system. The throughput analysis has been done. Performances are measured in terms of the bit error rate vs SNR and Throughtput vs SNR. While analyzing computational complexity of the LMS, RLS and Kalman filter, LMS algorithm is less complex than RLS and kalman filter algorithm. Simulation has been done to verify the proposed method.

Key words: BER, kalman filter, LMS, MIMO, OFDM, Rayleigh Fading Channel, RLS, SNR, OSTBC

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LIST OF ABBREVIATIONS

3GPP	3rd generation partnership project
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CSI	Channel State Information
ICI	Inter Carrier Interference
ISI	Inter-symbol Interference
LMS	Least Mean Square
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MMSE	Minimum Mean Squared Error
OFDM	Orthogonal Frequency Division Multiplexing
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RLS	Recursive Least Square
SIMO	Single Input Multiple Output
SISO	Single Input Single Output
SNR	Signal to Noise Ratio
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access

CHAPTER ONE: INTRODUCTION

1.1 Background

In modern commercial wireless communications, the demand for high speed and reliable communication within the constraints of limited radio frequency spectrum and power, are the prime technical criteria for communication systems. To obtain a higher data rate at an acceptable bit error rate, larger bandwidth is required. To mitigate severe fading channel conditions, a higher transmitted power level is required. Multiple-input multiple-output (MIMO) communication systems have the potential to provide increased capacity and reliability without increasing the bandwidth or transmitted power. Orthogonal frequency division multiplexing (OFDM) has become a popular technique for transmission of signals over wireless channels. OFDM has been utilized in many applications such as digital television and audio broadcasting, DSL broadband internet access, wireless networks, and 4G mobile communications [1].

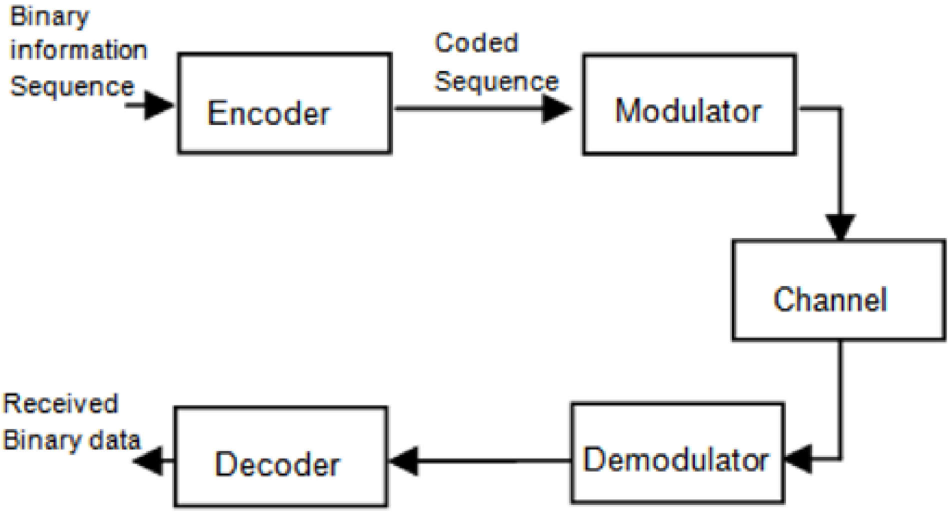


Figure 1:1 Generic Block diagram of Communication System

Multi-antenna systems have been investigated for several decades, and are one promising technique to significantly improve the spectral efficiency and the reliability. Multiple antennas have been adopted by several current wireless communication standards such as Wi-MAX, LTE and LTE-A, and successfully employed in some countries for broadband wireless access. MIMO with spatial multiplexing in different configuration including several conventional detection algorithms and iterative processing can be done. Spatial multiplexing techniques can substantially maximize the data rate by sending multiple independent data streams simultaneously through multiple transmit antennas .The capacity of MIMO channels may be achieved using spatial multiplexing [2].

Further in order to increase spectral efficiency and to effectively overcome effects of ISI and frequency Selective Fading by multipath, MIMO can be combined with OFDM (Orthogonal Frequency Division Multiplexing) system. OFDM is a multicarrier transmission technique that has been recently recognized as an excellent method for high speed bi-directional wireless data communication and its signal offers an advantage in a channel that has a frequency selective fading [3].

1.2 Motivation

The motivation of the thesis comes from the major concern in modern communication for the Quality of service and high data rate requirement. The major problems which occur in the communication are fading channel correlation, inter-symbol interference and frequency selective fading response. To achieve the performance enhancement in presence of fading correlations, the proposed schemes in this thesis employed the channel estimation approach at the receiver, which can enhance performance of the system in the spatial diversity. Since the channel estimation predicts the channel characteristics and channel gain and can be used to improve the SNR which ultimately increases the quality of the receive signal. In fading channel, the channel tracking is very difficult and proper tracking algorithm is needed. The conventional MMSE equalization is used for the MIMO-OFDM system. The adaptive algorithm, LMS, RLS and Kalman filter have used for the channel estimation to improve the SNR. It also improves the SNR by steering the nulls towards co-channel users which is called Interference Suppression. Furthermore, to circumvent the problem induced from inter-symbol interference and frequency selective fading MIMO-OFDM based detector is used [3].

I proposed the thesis titled "**Adaptive Channel Estimation for MIMO-OFDM System in Multipath Fading Channel**" to investigate the BER under the Rayleigh and Rician fading channel with QPSK modulation scheme.

1.3 Problem Definition

Advance communication need high date rate and reliable communication which is depend upon the foundation of high performance and bandwidth efficient wireless transmission technology. The problem of this thesis is to analyze the performance MIMO-OFDM system by the measure of Bit Error Rate with QPSK modulation scheme on Rayleigh and Rician fading channel with channel estimation at the receiver. The adaptive algorithm that effectively estimates the channel parameters and channel gain is to reduce the bit error rate of the received signal.

1.4 Objective

The objectives of my thesis work are outlined as follows.

- To use LMS, RLS algorithm for channel estimation in MIMO-OFDM system.
- To use the kalman filter for the channel estimation to improve performance in MIMO-OFDM system.

1.5 Scope

MIMO technology has attracted wireless communication because it offers significant increase in data throughput and link range without additional bandwidth or increased transmit power. It achieves this goal by spreading the same total transmit power over the antennas to achieve an array gain that improves the spectral efficiency (more bits per second per hertz or bandwidth) or to achieve a diversity gain that improves the link reliability (reduced fading) so, MIMO is important part of WiFi, 4G, 3GPP, LTE, WiMAX, HSPA. This thesis is focused on simulation that includes the analysis of a basic of MIMO-OFDM communication system with space time block code at the transmitter and channel estimation at the receiver on Rayleigh fading channel and Rician with QPSK modulation scheme. Basically, the fading in MIMO systems are reduced due to multiple antennas. ISI and ICI are mitigated by OFDM. The input data is a binary bit which firstly modulates with QPSK, 16- QAM and 64-QAM modulations and then the modulated signals are transmitted with MIMO-OFDM. In the various technologies such as 3G, WiFi, WiMAX, and LTE, channel estimation can be efficiently used.

1.6 Organization of Report

This thesis report is divided into six chapters as follows**.** **Chapter 2** is review of literature on MIMO-OFDM, channel estimation algorithms. **Chapter 3** deals with related theory of my thesis. Theoretical background of MIMO-OFDM, different algorithms for the channel estimation, modulation scheme, coding and decoding techniques are presented. **Chapter 4** deals with the Methodology that have taken for detail design of channel estimation of MIMO-OFDM, which describes the data collection, system model, algorithms and verification of the thesis. The simulation parameters, simulation results and discussion of the results are presented in **chapter 5**. **Chapter 6** shows the conclusion of my thesis work and future works.

CHAPTER TWO: LITERATURE REVIEW

Modern wireless techniques are implemented for high data rates. One of the latest methods is use of multiple inputs multiple output system, which uses multiple antennas at the transmitter and receiving side. MIMO with orthogonal frequency division multiplexing gives better bit error rate of the system [1][2]. Multiple-input multiple-output (MIMO) techniques have attracted tremendous attention. In a MIMO system, a high data rate is achieved by simultaneously transmitting data from several antennas. A typical scheme embedded in the MIMO system is orthogonal space-time block coding (OSTBC).In the paper [4] authors proposed a theory of space–time block coding, a simple method for transmission using multiple transmit antennas in a wireless Rayleigh/Rician environment. These codes have a very simple maximum-likelihood decoding algorithm which is only based on linear processing. Moreover, they exploit the full diversity given by transmit and receive antennas [5].

MIMO techniques of antenna array spatial diversity and channel coding to provide significant capacity gains in a wireless channel. Without loss of generality, it is assumed that the channels are flat fading and time invariant over an OSTBC code word period. However, in a fast-fading channel, the MIMO system requires an efficient equalization technique to eliminate inter-symbol interference (ISI), which is caused by high data rate applications or data transmissions over broadband frequency-selective channels [6][7].

To overcome the frequency selectivity of the wideband channel experienced by single-carrier transmission, multiple carriers can be used for high rate data transmission. Wideband signal is analyzed through multiple narrowband filter into several narrowband signals at the transmitter and is synthesized through multiple narrowband filter at the receiver so that the frequency-selective wideband channel can be approximated by multiple frequency-flat narrowband channels [8][9].The received signal at the receiver is usually distorted by the channel characteristics. In order to recover the transmitted bits, the channel effect must be estimated and compensated in the receiver. The excellent performance of symbol detection at the receiver is based on the perfectly known state of the CSI [10]. However, perfect CSI is usually unknown to the receiver in wireless communication systems. The impact of channel estimation errors on the performance of MIMO OFDM detectors has recently attracted a significant amount of research interest [11].

Channel estimation is done by using data signal as well as training signal or both. Pilot insertion indifferent arrangement as block type, and lattice type has been used. When training symbols are available, least square (LS) and minimum mean square error (MMSE) are widely used [12]. An adaptive algorithm is a process that changes its parameters as it gain more information of its possibly changing environment. Among numerous iterative techniques that exist in the open literature, the popular category of approaches which are from the minimization of the mean square error (MSE) between the output of the filter and desired signal to perform CE .MIMO OFDM systems normalized least mean (NLMS) square and recursive least squares (RLS) adaptive channel estimator are described for MIMO OFDM systems [13].

The channel for the terminals that move fast may vary within an OFDM symbol period, longer OFDM symbol period has a more severe effect on the channel estimation and may destroy the orthogonality among subcarrier at the receiver. In paper [14] effect of ICI in the time varying channels has successfully eliminated. The EM (Expectation-Maximization) algorithm has been widely used in a large number of areas that deal with unknown factors affecting the outcome. The EM-based channel estimation is an iterative technique for finding maximum likelihood (ML) estimates of a channel. It is classified as a semi-blind method since it can be implemented when transmit symbols are not available [15].

Using the statistical properties of received signals, the channel can be estimated without resorting to the preamble or pilot signals. A blind channel estimation technique has an advantage of not incurring an overhead with training signals.. The subspace-based channel estimation technique is another type of the blind channel estimation techniques developed for OFDM systems [16].

A time-varying velocity of the mobile station communicated in the MIMO-OFDM system is considered, in which the fading rate may be high or low for a user at any time instant[17]. The parameters of the AR process are determined by the Doppler frequency (or the mobile velocity). The EKF is suitable for nonlinear channel estimation. However this is only the first-order approximation to the nonlinear channel estimation and needs the computation of Jacobians to linearize the process and measurement equations [18]. In MIMO system, there are two or more antennas in transmitter and receiver side. The very first and well-known STBC is the Alamouti code, which is a complex orthogonal space-time code specialized for the case of two transmit [19].

For channel estimation and tracking scheme for MIMO-OFDM system we can also use pilot tones. For channel estimation LMSE and LS estimator can be used. The Performance of LMSE is better than LS estimator because LMSE estimator works on statistical channel properties [20].In the paper [21] the optimum training sequences are derived base on calculated MSE for LS channel estimation, utilizing these training sequences adaptive methods based on LMS and RLS are applied to estimate the channel for a system which emits independent data streams from transmitter antennas and is capable of computing all sub-channel coefficients between a receiver antenna and all transmitters.

CHAPTER THREE: RELATED THEORY

3.1 Multiple Input Multiple Output

Multiple input multiple output (MIMO) systems were described in the mid-to-late 1990s. The astonishing bandwidth efficiency of such techniques seemed to be in violation of the Shannon limit. But, there is no violation because the diversity and signal processing employed with MIMO transforms a point-to-point single channel into multiple parallel or matrix channels, hence in effect, multiplying the capacity. MIMO offers higher data rates as well as spectral efficiency. The capacity of SISO channel is given by the following equation

$$C = B\log_2(1+SNR) b/s/Hz \ldots\ldots\ldots\ldots(3.1)$$

This relationship says that an increase of power by a factor of 10 times, i.e. a SNR of 20 dB will increase the capacity to 6.65 b/s/Hz, a less than doubling of capacity with SNR of 10dB. A one-hundred-time increase in power will increase the channel capacity, only 9.96 b/s/Hz , approximately a tripling of capacity. The capacities are increasing as a log function of the SNR, which is a slow increase.

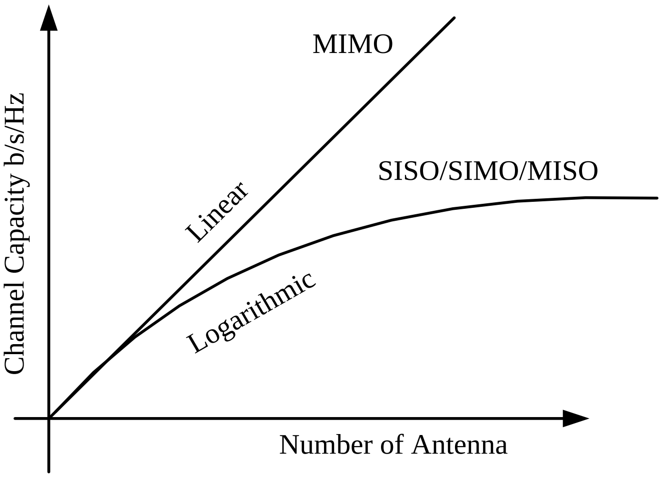


Figure 3:1 Capacity Comparison of MIMO with SISO, SIMO and MISO

Clearly increasing the capacity by any significant factor takes an enormous amount of power in a SISO channel. Wouldn’t it be nice if we can increase the capacity instead, by a linear function of power; 10 times increase in power, 10 times increase in capacity. With MIMO, we move to a different paradigm of channel capacity. To give this, we just made the transmitter and receiver more complex, with no increase in power at all. We got the same performance as increasing the power 100 times.

The information-theoretic capacity increase under a MIMO is quite large and easily justified the increase in complexity. The determination of this increase in capacity and the various parameters affects the capacity. The theoretical capacity of MIMO is given as,

$$C = \max \log_2 \det(I_{nR} + \rho H R_{SS} H^H) \ldots\ldots (3.2)$$

The general schematic diagram of MIMO system is shown below.

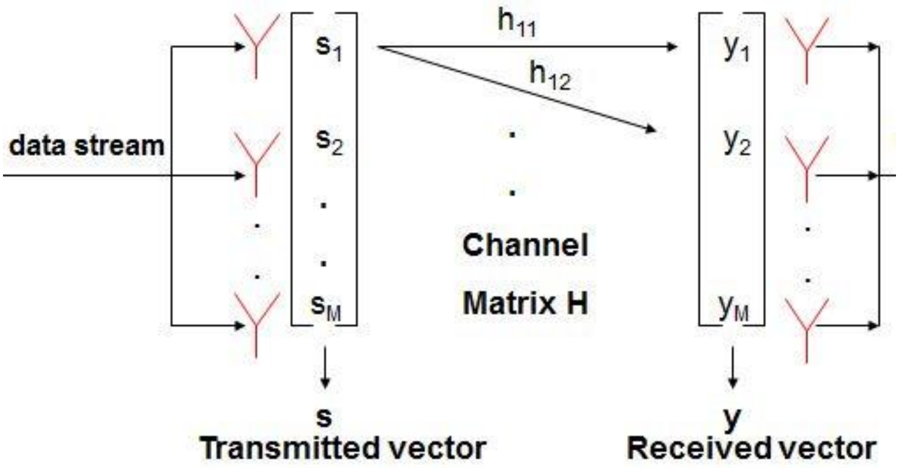


Figure 3:2 MIMO System Model

In a single user MIMO model with N transmit and M receive antennas, the MIMO System equation is given by

$$\begin{bmatrix} r1 \\ r2 \\ \vdots \\ rM \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N} \\ h_{21} & h_{22} & \cdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ h_{M1} & h_{M2} & \cdots & h_{MN} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ \vdots \\ s_N \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_N \end{bmatrix}$$

The MIMO signal model is described as

$$\vec{y} = H\vec{s} + \vec{n} \ldots\ldots (3.3)$$

Where,

$\vec{y}$ is the received vector of size $N_T \times 1$,

H is the channel matrix of size $N_R \times N_T$

$\vec{s}$ is the transmitted vector of size $N_T \times 1$, and

$\vec{n}$ is the noise vector of size $N_R \times 1$

The channel matrix H is the factor by which the signal is amplified and is also known as the channel coefficient. The element h in the channel matrix H represents the complex gain between transmitter antenna j and receiver antenna i [22].

3.2 OFDM

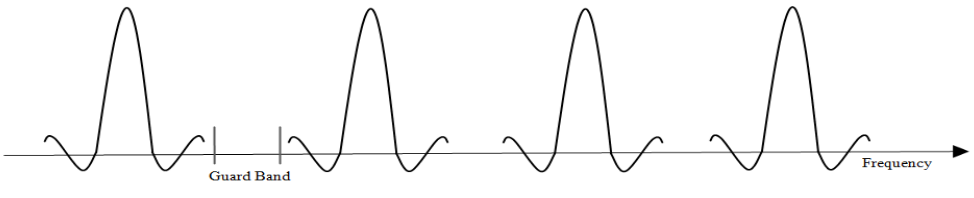
OFDM is a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method. A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels. In OFDM system, the two periodic signals are orthogonal when the integral of their product over a period is equal to zero. This can be represented in continuous time as,

$$\int_0^t \cos(2\pi f_0 nt)\cos(2\pi f_0 mt)dt = 0 \text{..} (3.4)$$

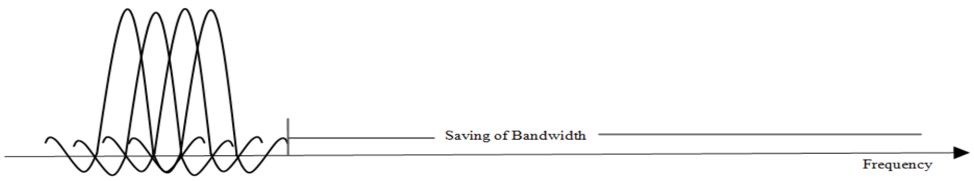
In discrete time, it can be represented as,

$$\sum_{k=0}^{N-1} \cos\left(\frac{2\pi kn}{N}\right)\cos\left(\frac{2\pi km}{N}\right)dt = 0 \text{..} (3.5)$$

Presence of Doppler shifts and frequency and phase offsets in an OFDM system causes loss in orthogonally of the subcarriers. The loss of orthogonally introduces interference between subcarriers. This phenomenon is known as inter carrier interference (ICI). Due to ISI, OFDM systems become very sensitive to frequency offsets and degrade the performance.



(a) Conventional Frequency Division Multiplex (FDM) Multicarrier Modulation Technique



(b) Orthogonal Frequency Division Multiplexing (OFDM) Multicarrier Modulation Technique

Figure 3:3 Comparison of FDM and OFDM in frequency

Frequency offsets correction for OFDM system can be done by using data aided techniques where known bit patterns or pilot tones are inserted in OFDM system [7]. Each subcarrier in an OFDM system is a sinusoid with a frequency that is an integer multiple of fundamental frequency. Each subcarrier can be expressed as a Fourier series component of the composite signal i.e. an OFDM symbol.

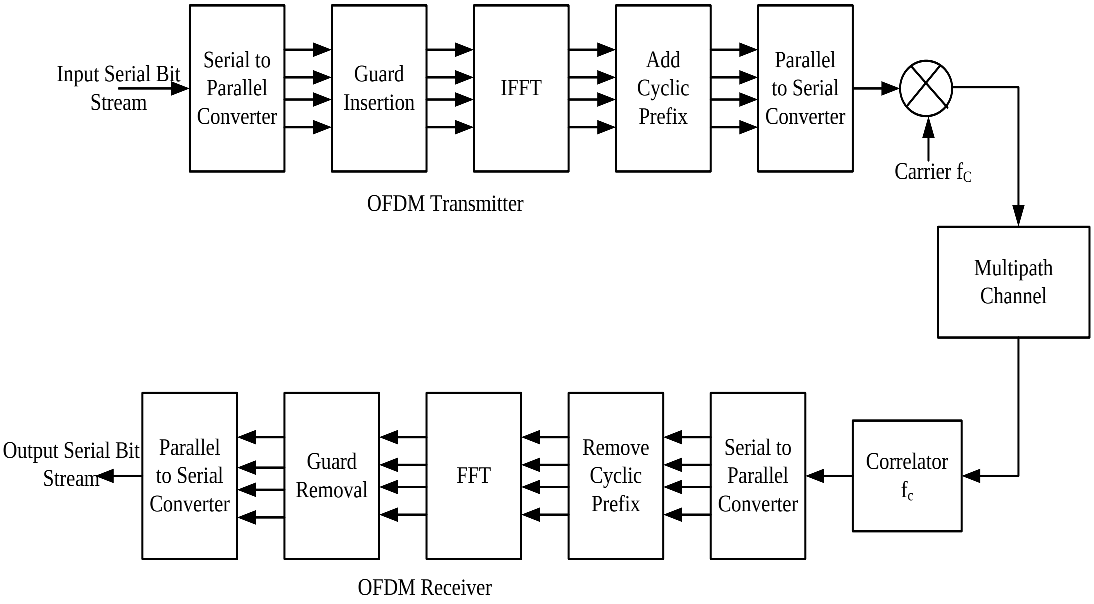


Figure 3:4 OFDM Transmitter and Receiver

The subcarrier waveform can be mathematically expressed as,

$$S(t) = \cos(2\pi f_c t + \theta_k) = a_n \cos(2\pi f_0 t) + b_n \cos(2\pi f_0 t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.6)$$

In many wireless systems, multiple channels create problems when the transmitted signal reflects from several objects. As a result, multiple delayed versions of the input signal arrive in the receiver at different time spans. Due to the multiple versions of the input signal, received OFDM symbol becomes distorted by the previously transmitted OFDM symbols. This problem is called as Inter Symbol Interference.

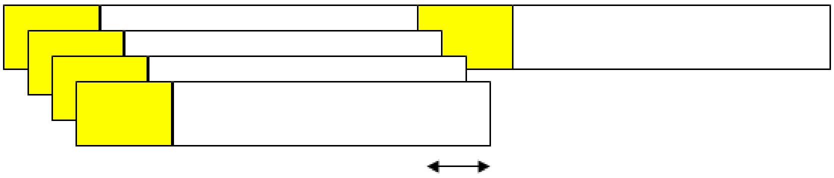


Figure 3:5 Example of inter-symbol interference

First few samples of an OFDM symbol are distorted by inter-symbol interference. This problem can be minimized by adding extra guard interval in front of every OFDM symbol. Due to the multipath fading environment, channel causes consecutive OFDM symbols to overlap and introduce symbol interference. This degrades the performance of the overall system and destroys the orthogonally of subcarriers. To prevent ISI and to preserve the orthogonally, a guard interval is used in every OFDM. This type of guard interval is called cyclic prefix (CP). The only disadvantage of cyclic prefix is that it increases transmitting energy due to the extra data in payload and hence reduces the efficiency of the overall system. CP is used in multi carrier systems for equalization of frequency-selective fading channels.

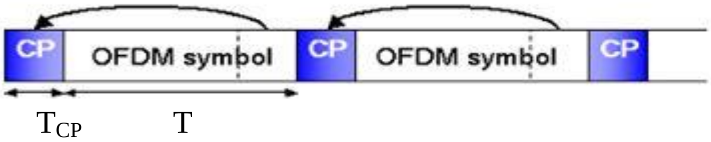


Figure 3:6 cyclic prefix in OFDM

Typically, cyclic prefix duration is determined by the expected duration of the multipath channel in the operating environment. For example, for the indoor wireless multipath channel the typically expected multipath channel is around 0.8 μs duration.

$$T_{total} = T + T_{cp} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. (3.7)$$

Where T is the OFDM symbol length without cyclic prefix, T_g is the length of cyclicprefix and the OFDM symbol T_{total} is the overall length.

3.3 Modulation

Modulation is the process of encoding information from a message source in a for suitable for transmission. Modulation is done by varying the amplitude, phase or frequency of a high frequency carrier in accordance with the amplitude phase, or accordance with the amplitude of message signal. Modulation techniques are expected to have three positive properties:

- Good Bit Error Rate Performance
- Power Efficiency
- Spectral Efficiency

3.3.1 Quadrature Phase Shift Keying

QPSK is the most often used scheme since it does not suffer from BER degradation while the bandwidth efficiency is increased. Other M-PSK schemes increase bandwidth efficiency at the expenses of BER performance. Since QPSK is a special case of M-PSK, its signals are defined as

$$S_i(t) = A\cos(2\pi f_c t + \theta) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.8)$$

Where, $0 \le t \le T; i = 1,2,3,4 \quad \theta_i = \frac{(2i-1)\pi}{4}$

The initial signal phases are $\frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4}, \frac{7\pi}{4}$. The carrier frequency is chosen as integer multiple of the symbol rate, therefore in any symbol interval [kT, (k +1) T], the signal initial phase is also one of the four phases. The above expression can be written as $S_i(t) = A\cos\theta_i \cos 2\pi f_c t - A\sin\theta_i \sin 2\pi f_c t$

$$= S_{i1}\phi_1(t) + S_{i2}\phi_2(t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.9)$$

The average Bit error probability of QPSK modulator in the additive white Gaussian noise (AWGN) channel is given in equation (3.14).

$$P_e = erfc(E/N_0) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.10)$$

Table 3.1: QPSK Signal Coordinates

Dibit	Phase θθ_i	$s_{i1} = \sqrt{E}\ \cos\theta_i$	$s_{i2} = \sqrt{E}\ \sin\theta_1$
11	$\pi/4$	$+\sqrt{E/2}$	$+\sqrt{E/2}$
01	$3\pi/4$	$-\sqrt{E/2}$	$+\sqrt{E/2}$
00	$-3\pi/4$	$-\sqrt{E/2}$	$-\sqrt{E/2}$
10	$-\pi/4$	$+\sqrt{E/2}$	$-\sqrt{E/2}$

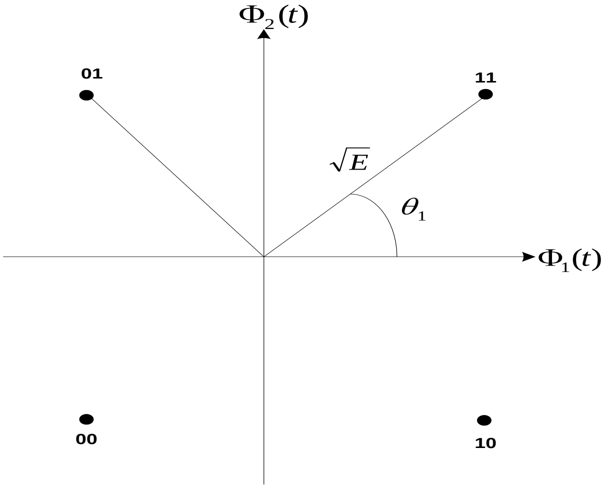


Figure 3:7 Signal Constellation diagram of QPSK Modulation

3.4 Fading

Fading is due to multipath propagation in wireless communication that results in radio signals reaching the receiving antenna by two or more paths. Fading causes the atmospheric ducting, ionosphere reflections and refraction and reflection from terrestrial objects such as mountains and buildings. The effects of multipath include constructive and destructive interference and phase shifting of the signal. The phenomenon of Doppler shift, reflection, diffraction and scattering all give rise to additional radio propagation paths beyond the direct optical LOS path between the radio transmitter and receiver. In wireless communications**,** fading is deviation of the attenuation affecting a signal over certain propagation media.

3.4.1 Rayleigh Fading Model

The Rayleigh model is used to model the statistical time varying nature of the received envelope of a flat fading envelope. The Rayleigh fading is primarily caused by multipath reception. Rayleigh fading is a statistical model for the effect of a propagation environment on a radio signal. It is a reasonable model for tropospheric and ionosphere signal propagation as well as the effect of heavily built-up urban environment when there is no line of sight between the transmitter and receiver. Rayleigh fading model can be describe by the Rayleigh distribution having a probability density function (PDF) given by,

$$p(r) = \begin{cases} \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2} \right); (0 \le r \le \propto) \\ 0; r < 0 \end{cases} \qquad (3.11)$$

Where σ is the r.m.s value of received voltage signal before envelope detection and σ^2 is the time average power of the received signal before signal envelope detection.

3.4.2 Rician Fading Model

The Rician fading model is similar to the Rayleigh fading model, except that in Rician fading a strong dominant component is present. This dominant component is a stationary (non-fading) signal and is commonly known as the LOS. Rician fading model can be describe by the Rician distribution having probability density function (pdf) given by,

$$p(r) = \begin{cases} \frac{r}{\sigma^2} e^{-\left(\frac{r^2+A^2}{2\sigma^2}\right)} I_0\left(\frac{Ar}{\sigma^2}\right); A \ge 0, r \ge 0 \\ 0; r < 0 \end{cases} \qquad (3.12)$$

Where the parameter A denotes the peak amplitude of the dominant signal and $I_0(\bullet)$ is the modified Bessel function of the first kind and Zero-order. The Rician distribution is often described in terms of a parameter K which is defined as the ratio between the deterministic signal power and the variance of the multipath. It is given by $K = A^2 / 2\sigma^2$ or in terms of dB.

$$K(dB) = 10 \log \frac{A^2}{2\sigma^2} dB \qquad (3.13)$$

3.5 Bit Error Rate

In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that has been altered due to noise, interference, distortion or bit synchronization errors. It can be expressed as ratio of Bits in Error to the total bits received. Noise affects the BER performance. Quantization errors also reduce BER performance, through incorrect or ambiguous reconstruction of the digital waveform. BER can also be defined in terms of the probability of error (POE) and represented as,

$$POE = \frac{1}{2}(1 - erf)\sqrt{\frac{E_b}{N_o}} \quad (3.14)$$

Where, erf is the error function, E_b is the energy in one bit and N_0 is the noise power spectral density. The POE is a proportional to E_b/N_0, which is a form of signal to noise ratio or normalized signal to noise ratio i.e. Energy per bit to Noise power spectral density ratio.

3.6 MIMO-OFDM

Most of the MIMO techniques have been developed with the assumption of flat fading channel. For broadband frequency selective wireless channel, the combination of MIMO and OFDM (MIMO-OFDM) was proposed to mitigate the effect of ISI and ICI. In MIMO techniques, CSI is usually required at transmitter and/or receive side, thus OFDM is also used in MIMO systems to estimate CSI. MIMO-OFDM is a promising solution for energy efficient high data rate wireless networks.

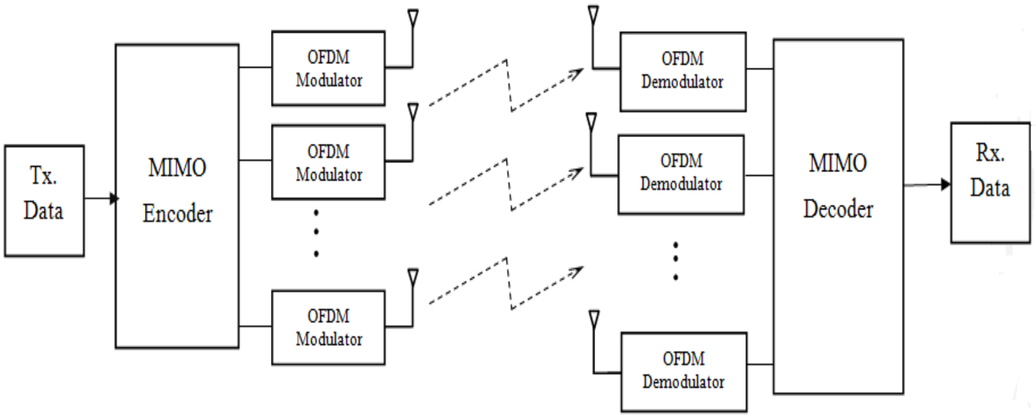


Figure 3:8 MIMO-OFDM system with Nt transmitting and Nr receiving Antennas

The OFDM modulation transforms a broadband, frequency-selective channel into a multiplicity of parallel narrow-band single channels. A guard interval (called Cyclic Prefix CP) is inserted between the individual symbols. This guard interval must be temporally long enough to compensate for jitter in the transmission channel. Transmitted OFDM symbols experience different delays through the transmission channel. The variation of these delays at the receiving location is called jitter. The occurrence of inter-symbol interference (ISI) can thus be prevented. It has been shown that OFDM can be favorably combined with multiple antennas on the sending side as well as the receiving side to increase diversity gain and/or transmission capacity in time-varying and frequency-selective channels.

3.7 Space Time Coding and Decoding

The different replicas sent for exploiting diversity are generated by a space-time encoder which encodes a single stream through space using all the transmit antennas and through time by sending each symbol at different times. This form of coding is called Space-Time Coding (STC). Due to their decoding simplicity, the most dominant form of STC is space-time block codes (STBC) and Space Time Trellis Code (STTC).

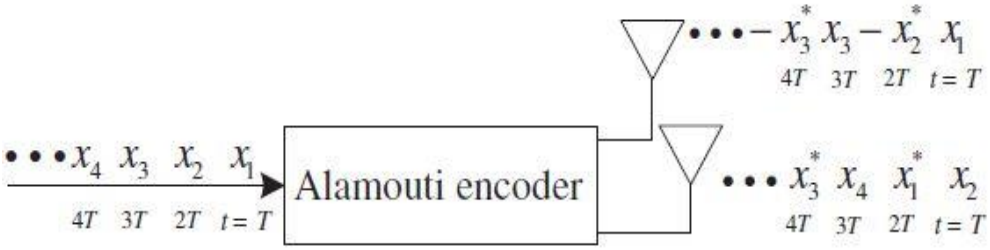


Figure 3:9 Alamouti encoder

Space Time Block Code is a technique used in wireless communications to transmit a copy of a data stream in a number of antennas and utilizes a variety of data received to improve the reliability of data transfer. STBC was first introduced by Alamouti showing the same performance of simple scheme MRC diversity.

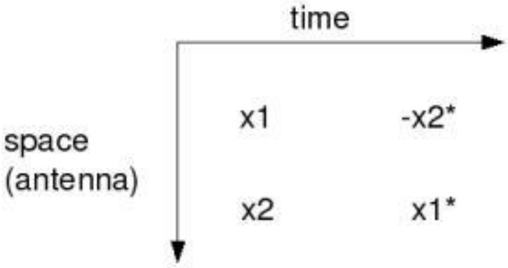


Figure 3:10 2-Transmit, 1-Receive Alamouti STBC coding

STBC techniques apply spatial diversity (multiple antenna transmitters and receivers) and time diversity techniques (sending replica conjugate signals) in the time series. Alamouti made the basic foundation of OSTBC developed to be used for more than two transmitting antennas [4] [5].

Alamouti encoded signal is transmitted from the two transmit antennas over two symbols period. During the first symbol period, two symbols x1 and x2 are simultaneously transmitted from the two transmit antennas. During the second symbol period, these symbols are transmitted again, where $-x_2^*$ is transmitted from the first transmit antenna and x_1^* transmitted from the second transmit antenna.

In the Alamouti encoder, two consecutive symbols x1 and x2 are encoded with the following space-time code word matrix.

$$\boldsymbol{X} = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.15)}$$

Alamouti code word **X** in Equation (3.15) is a complex-orthogonal matrix. STBC can be expressed in the following for

$$\boldsymbol{X}\boldsymbol{X}^H = \sum_{n=1}^{N} |X_n|^2\, I \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.16)}$$

Where transmitting X is orthogonal to each other, H is the Hermitian transpose, whereas I is the identity matrix n x n. This means that in each block, the signal sequence of every two transmit antennas are orthogonal .Due to a total transmit power constraint (i.e., total transmit power split into each antenna by one half in the Alamouti coding).

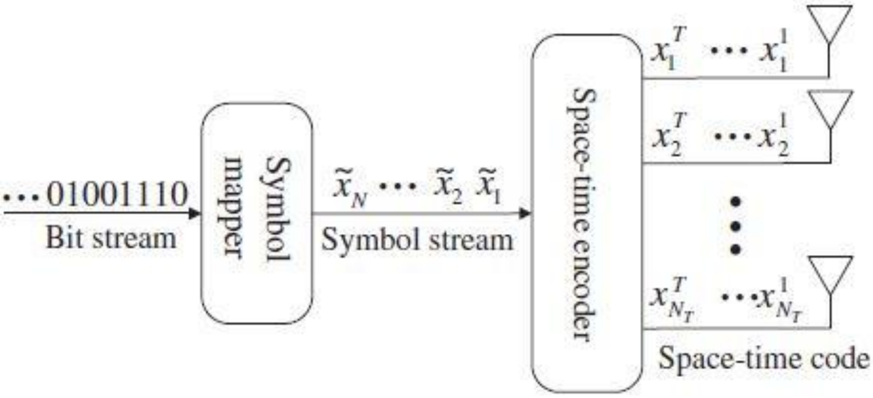


Figure 3:11 Space-time block encoder

STBC technique allows us to achieve diversity and send it at the same time. This also allows the receiver to separate the signals transmitted from different antennas and a simple ML decoding to be used .The main advantage of space-time block codes is that a maximum diversity gain can be achieved with a relatively simple linear-processing receiver. The reception and decoding of the signal depends on the number of receive antennas available. Alamouti STBC does not require CSI at the transmitter. Also, the Alamouti STBC can be used with 2 transmit antennas and 1 receive antenna while accomplishing the full diversity of 2.This is an important characteristic of Alamouti STBC as it reduces the effect of fading at mobile stations while only requiring extra antenna elements at the base station, where it is more economical than having multiple antennas at the receivers. However, if having more antennas at the receivers is not a problem, this scheme can be used with 2 transmit antennas and N_R receiver antennas while accomplishing a $2N_R$ full diversity.

3.8 Convolutional Coding

Convolution codes are different from the block codes by the existence of memory in the encoding scheme. In block codes, each block of K input bits is mapped into a block of length n of output bits by a rule defined by the code and regardless of the previous inputs to the encoder.

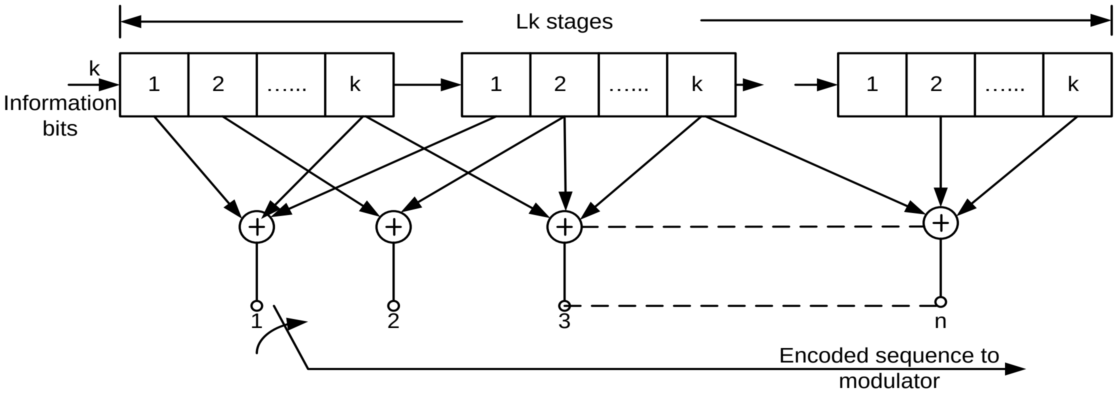


Figure 3:12 Block diagram of a convolutional encoder

In convolutional codes, each block of k bits is again mapped into a block of n bits to be transmitted over the channel, but these n bits are not only determined by the present k-information bits but also by the previous information bits. The rate of such code is given by

$$R_C = \frac{k}{n} \qquad (3.17)$$

The main three parameters of convolutional code are Rate, Constraint Length and Generator Polynomial. The convolutional encoder with rate R = ½ k=3 and m=2 is shown in figure 3.13.

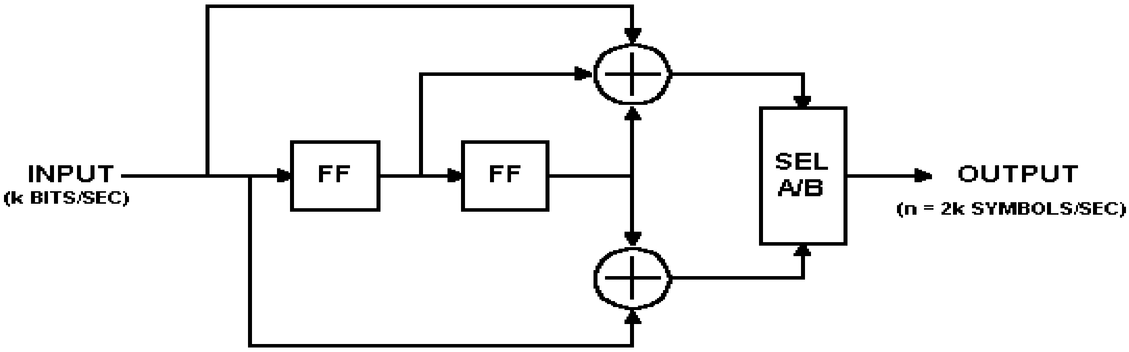


Figure 3:13 Convolutional encoder with rate = ½ k = 3 and m = 2

3.9 Viterbi Decoder

The Viterbi algorithm operates on the principle of maximum likelihood decoding and archives optimum performance. The maximum likelihood decoder has to examine the entire received sequence Y and find a valid path which has the smallest Hamming distance from Y. But there are 2N possible paths for a message sequence of N bits. These are a large number of paths. The Viterbi algorithm applies the maximum likelihood principle to limit the comparison of so many surviving paths, so make the maximum likelihood possible. Viterbi algorithm consists of following three major parts are Branch Metric Calculation, Path Metric Calculation and Trace Back.

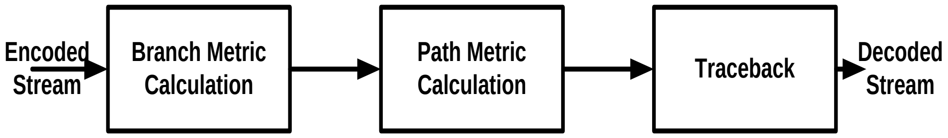


Figure 3:14 Viterbi decoder data flow

3.10 Channel Estimation

Channel estimation is the process of characterizing the effect of the physical medium on the input sequence. Aim of any channel estimation procedure is minimize some sort of criteria, e.g. MSE. and utilize as little computational resources as possible allowing easier implementation. A channel estimate is only a mathematical estimation of what is truly happening in nature. Need of channel estimation are

- Allows the receiver to approximate the effect of the channel on the signal.

- The channel estimate is essential for removing inter symbol interference, noise rejection techniques etc
- Also used in diversity combining, ML detection, angle of arrival estimation etc.

Channel estimation is an important technique especially in mobile wireless network system where the wireless channel changes over time, usually caused by transmitter and/or receiver being in motion at vehicular speed [24].

3.10.1 Minimum Mean Square Error

It is a channel estimation method which minimizes the mean square error (MSE) of the fitted values of a dependent variable, which is a common measure of estimator quality. The MMSE estimator is given by the posterior mean of the parameter to be estimated.

Let x be any random vector variable. y is the known random vector. The estimation $\hat{x}(y)$ is the function based on the y.The estimation error vector is given by the estimation error vector is given by $e = x - \hat{x}$ and its mean squared error (MSE) is given by the trace of error covariance matrix.

$$MSE = tr\{E\{(x-\hat{x})(x-\hat{x})^T\}\} \text{ .... (3.18)}$$

E is the expectation simplifies to $E\{(\hat{x}-x)^2\}$. In the other way it can be defined as the $E(e^Te) = \sum_{i=1}^{n} e_i^2$

$\hat{x}_{MMSE}(y) = \arg min\, MSE$

Two basic numerical approaches to obtain the MMSE estimate depends on either finding the conditional expectation or finding the minima of MSE:

- Direct numerical evaluation of the conditional expectation is computationally expensive, since they often require multidimensional integration usually done via Monte Carlo methods**.**
- Another computational approach is to directly seek the minima of the MSE using techniques such as the gradient descent methods**;** but this method still requires the evaluation of expectation.

3.10.2 Least Mean Square

The Least Mean Square (LMS) algorithm is an adaptive algorithm, which uses a gradient-based method. It uses the estimates of the gradient vector from the available data. It incorporates an iterative procedure that makes successive corrections to the weight vector in the direction of the negative of the gradient vector which eventually leads to the minimum mean square error compared to other algorithms. LMS algorithm is relatively simple it does not require correlation function calculation nor does it require matrix inversions.

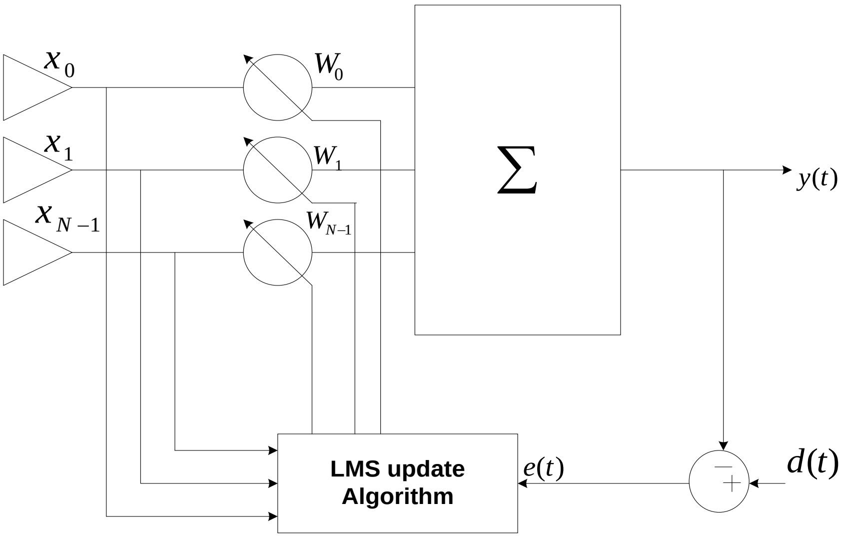


Figure 3:15 Adaptive LMS System

The recursive equations for the error and the filter coefficients of the least mean square algorithm are given by

$$\widehat{W}(n+1) = \widehat{W}(n) + \mu x(n)e(n) \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.19)$$

Where $\widehat{W}(n)$ initial weight vectors, $\widehat{W}(n+1)$ final weight vector, $x(n)$ input vector, $e(n)$ error signal

$$e(n) = d(n) - y(n) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.20)$$

Here, $d(n)$ desired signal and the filter output or the estimated value is

$$y(n) = \widehat{W}^H(n)x(n) \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.21)$$

Where, μ is the step size (or convergence factor) that determines the stability and the convergence rate of the algorithm.

The convergence factor of the LMS algorithm must be chosen in the range

$$0 < \mu < 2/\lambda_{max}$$

3.10.3 Recursive Least Square

The capacity of the RLS can improve due its faster convergence. This advantage is based on the factor that the error at any point of time is independent of the statistical properties of the signal. The algorithm updates the autocorrelation matrix for the next instant with the aid of the autocorrelation matrix calculated for the present instant. The main drawback of the RLS algorithm is that it suffers from computational complexity. It is an algorithm is derived from the minimization of the sum of weighted least-square errors as

$$J_{LS}(n) = \sum_{i=1}^{n} \lambda^{n-i} e^2(i) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.22)$$

Where, λ is the forgetting factor and has a value less than and close to 1. The forgetting factor weights the current error heavier than the past error values to support filter operation in non-stationary environments [25].

Therefore, in the least-square method, the weight vector **w** *(n)* is optimized based on the observation starting from the first iteration (i = 1) to the current time (i = n).

The autocorrelation matrix and cross-correlation vector are expressed as

$$R \approx R(n) = \sum_{i=1}^{n} \lambda^{n-i} u(i) u^T(i)$$

$$P \approx P(n) = \sum_{i=1}^{n} \lambda^{n-i} u(n-i) u^T(i)$$

The RLS algorithm can be written as

$$W(n+1) = W(n) + g(n)e(n) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.23)$$

Where, the updating gain vector is defined as

$$g(n) = {r(n)}\Big/{1 + U^T(n) r(n)}$$

and

$$r(n) = \lambda^{-1} P(n-1) U(n)$$

The inverse correlation matrix of input data, $P(n) \equiv R^{-1}(n)$, can be computed recursively as [26].

$$P(n) = \lambda^{-1} P(n-1) - g(n)r^{T}(n) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.24)$$

3.10.4 Kalman filter

The KF method is a real time recursive algorithm of dealing with the random signal, which is the optimal estimation method based on the minimum mean square error. It adopts the state space model of signal and noise and the estimates of state variables are updated by the estimation of the previous value and the current measurement value. This means that only the estimated state from the previous time step and the current measurement are needed to compute the estimate for the current state

Therefore, the KF method can be divided into two parts:

- Prediction step: The time status update equation and regarded as the prediction equation, produces estimates of the current state variables, along with their uncertainties, The predict phase uses the state estimate from the previous time step to produce an estimate of the state at the current time step. This predicted state estimate is also known as the a priori state estimate because, although it is an estimate of the state at the current time step, it does not include observation information from the current time step.

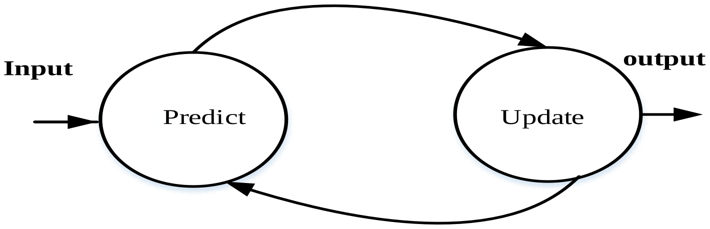


Figure 3:16: kalman filter operation step

- Update: regarded as the correction equation which carries out recursion in the order of prediction-actual measurement-correction. Then, the measured value is used to eliminate the random interference and update the system state. Once the outcome of the next measurement (necessarily corrupted with some amount of error, including random noise) is observed, this estimation is updated using a weighted average, with more weight being given to estimates with higher certainty.

The extended Kalman filter and the unscented Kalman filter which work on nonlinear systems.

The Kalman filter model assumes the true state at time k is evolved from the state at (k − 1) according to

$$X_K = F_K X_{k-1} + B_K U_K + W_K \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.25)}$$

Where,

- F_k is the state transition model which is applied to the previous state x_{k-1};
- B_k is the control-input model which is applied to the control vector u_k;
- w_k is the process noise which is assumed to be drawn from a zero mean multivariate normal distribution with covariance Q_k.

3.10.5 Doppler shift

Doppler shift is the change in frequency of a wave or other periodic event for an observer moving relative to its source. Doppler shift affects wireless communications by creating fading in the signal. Doppler shift occurs when the transmitter or receiver is moving in communication. The relative movement shifts the frequency of the signal, making it different at the receiver than at the transmitter. The movement the channel is model by the Doppler frequency.

$$f_D = {}^{2\pi}/_{\lambda}\, \mathrm{v}\cos(\theta) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.26)}$$

Where, f_D= Doppler shift, λ=wavelength, v=velocity of receiver

- Typical Doppler shifts :5Hz to 300 Hz
- For example, at for a carrier frequency of 2GHz and a mobile speed of 68 mph, max f_D = 200Hz

CHAPTER FOUR: METHODOLOGY

This section describes the method that has followed throughout the thesis work. A systematic approach that is necessary for the system development, algorithm development, flow chart and data collection all has included here.

4.1 Data Collection

Data have been taken from the different previous related works and books, website for the purpose of simulation. Some data are taken from the standards which are already using in the communication systems.

4.2 Development of Model

The functionality diagram of the MIMO-OFDM scheme is proposed for thesis, whose functionality is justified as incorporated with channel estimation. The proposed transmitter and receiver section are show as figure 4.1 and figure 4.2.

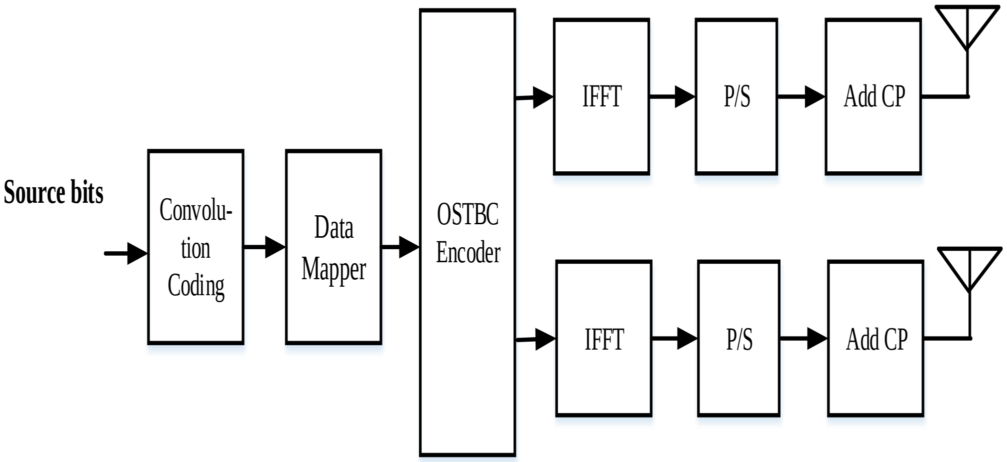


Figure 4:1 Structure of Proposed MIMO-OFDM Transmitter

A MIMO-OFDM system with *Nt* transmit antennas, *Nr* receive antennas, and *Nc* subcarriers is considered. As shown in Figure 4.1, the information bits in digital form, containing sequence of 0’s and 1’s are taken as input. Convolution coding is done as the source coding the feed the data mapped in which the modulation is carried out using QPSK. The Space time block code is to make system as two parallel paths and pilot carrier is inserted. Now, the serial data is converted to the parallel for the orthogonal modulation. These parallel data are modulated orthogonally using IFFT, the length of the IFFT used is 64 point, which convert wideband channel into the narrow band subcarriers and changed to the time domain. In this section guard interval is added to the each symbol to cancel out the inter symbol interference. Pilot carrier is inserted to the OFDM symbols. Again, the parallel to serial conversion is done which is up converted and sent through the fading channel with additive white noise by using the two transmitting antennas. The data stream to be transmitted is encoded in blocks, which are distributed among the spaced antennas and across time.

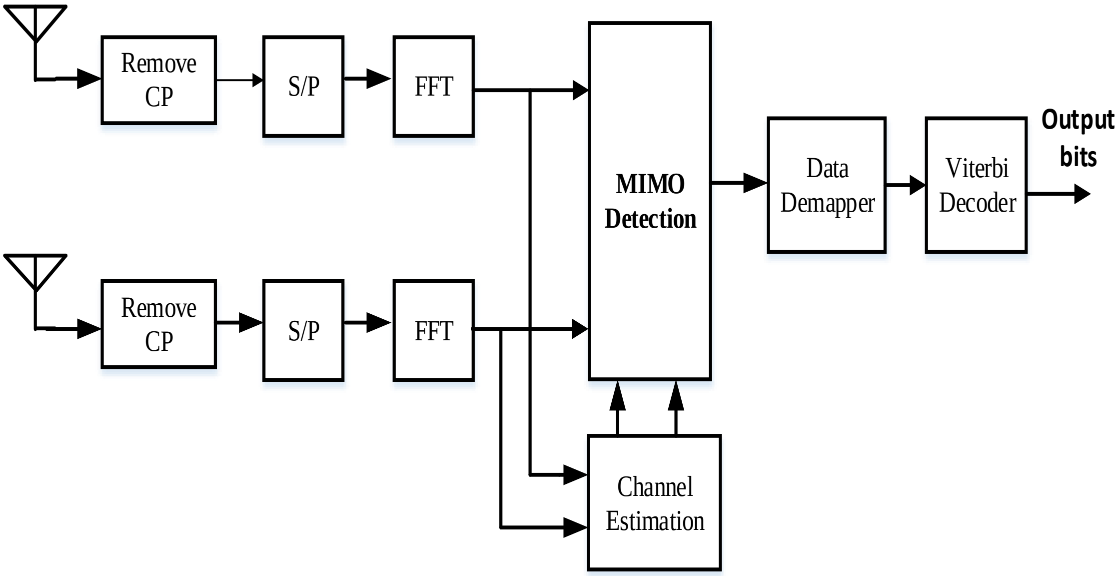


Figure 4:2 Structure of Proposed MIMO-OFDM receiver

The detection process is shown in the fig. 4.2. After removing the cyclic prefix and passing FFT modulation the receive signal is passed through the detection block which uses simple STBC decoding and mmse equalizer in case of the channel estimation the data is passed through the demmaper. Then date is fed into the veterbi decoding. At the last stage the bit rate error versus SNR value. The receiver uses the adaptive channel estimation algorithms LMS, RLS and Kalman filter for the proper detection of the transmitted signal.

The performance of the MIMO-OFDM system is analyzed in terms of the capacity of the system. The plot of the graphs between the throughput vs SNR is plotted in the receiving part in Rayleigh and Rician fading channel. In the receiving part, the effect of the Doppler shifts is also included to analyze the varying nature of the receiver.

4.3 Development of Algorithm

To solve the problem, a systematic steps are needed which is better to explain in the algorithms forms.

1. Specify the number of the TX and RX antenna for the MIMO-OFDM system.
2. Specify SNR value in dB.
3. Generate a random binary bit streams or symbols.
4. Encode a binary bit by convolutional encoder.
5. Map the convolutional encoded signal by the QPSK modulation scheme.
6. Use the Space Time Block code to convert the data into two parallel paths.
7. Insert Pilot carrier and OFDM are done which is carried out by taking an IFFT and adding cyclic prefix.
8. Generate the channel matrix for Rayleigh and Rician Fading channel with addition of AWGN.
9. Remove a cyclic prefix and Perform FFT.
10. Estimate a channel with RLS, LMS algorithm and Kalman fliter, extract the pilot carrier.
11. Use a channel knowledge to detection signal
12. Covert a parallel data into a serial data stream.
13. Demodulate the signal.
14. Decode the demodulated signal by Viterbi decoding algorithm.
15. Compare the estimated signal with generated signal. Plot graphs required to evaluate the performance of the system. Plot the graphs BER vs SNR for the different configuration of MIMO, Doppler shift and plot graph throughput vs SNR. Also calculate the computational complexity of the each algorithms

These algorithms are used to develop the system and to verify the result.

The algorithm describes the general flow of the MIMO-OFDM system for the performance and throughput analysis. The fading channel model for MIMO system is modeled by using the Rayleigh and the Rician channel.

4.4 Flow Chart

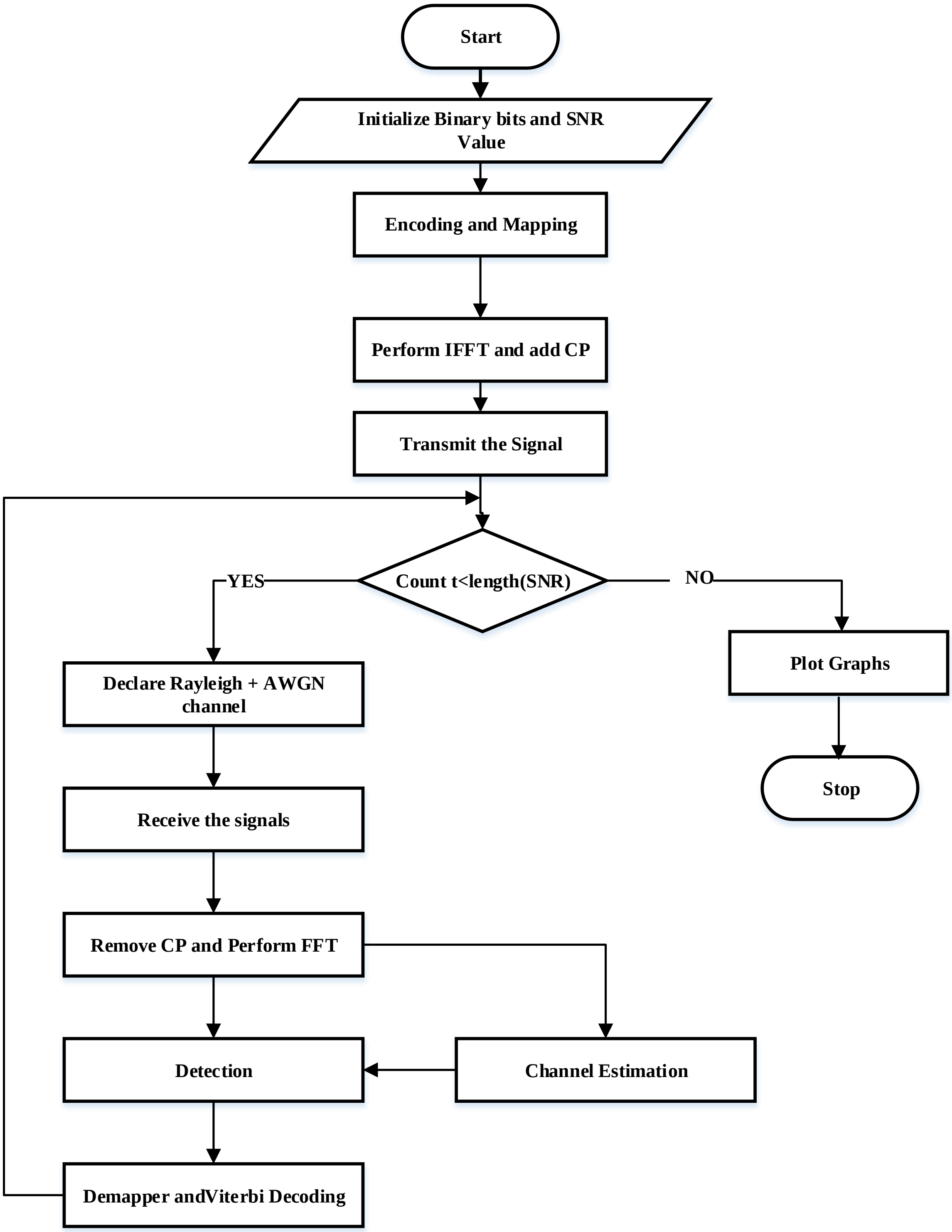


Figure 4:3 Flow Chart of Proposed System

4.5 Verification

Verification and simulation of different detections scheme on different modulation techniques with an algorithms are programmed on the MATLAB software simulation for the proposed system are performed. Plots of different graphs have been shown in the results sections. To verify the simulated of my system, it is compared with the previous results and analysis. The results of the thesis are analyzed with the previous related work of channel estimation in MIMO-OFDM system. Also, the standards that are already in used in the communication systems have analyzed and compared.

CHAPTER FIVE: SIMULATION RESULTS AND ANALYSIS

5.1 Simulation Parameters

In this thesis I consider the different parameters for the simulation purpose. The proposed system uses a QPSK modulation scheme in Rayleigh fading channel and Rician with AWGN noise. For the OFDM of the signal I consider the FFT size is 64 and guard interval is ¼ with Block type pilot insertion. For the encoding in transmitter convolutional encoder is used and for decoding at the receiver Viterbi decoding is used. For the MIMO encoding STBC is used at the transmitter.

Simulation parameters are as given in the table 5.1.

Table 5.1: Simulation Parameters

Parameters	**Specification**
Number of Input Bits	300000
FFT Size	64
Guard Interval	¼
Number of Carrier	64
Signal Constellation	QPSK
Channel Model	Rayleigh and Rician with AWGN
Pilot Type	Block
MIMO encoder	STBC
Encoding	Convolutional code
Decoding	Viterbi
Channel Estimation Algorithm	LMS, RLS and Kalman filter

The simulation parameter shown in the table 5.1 is used throughout the thesis. To verify the proposed method, MATLAB simulation is done. Parameters which are necessary for the simulation are taken from the standards in the MIMO-OFDM communication system.

5.2 Results and Discussion

The simulation results are obtained, after the MATLAB simulation by using the parameters given in section 5.1.

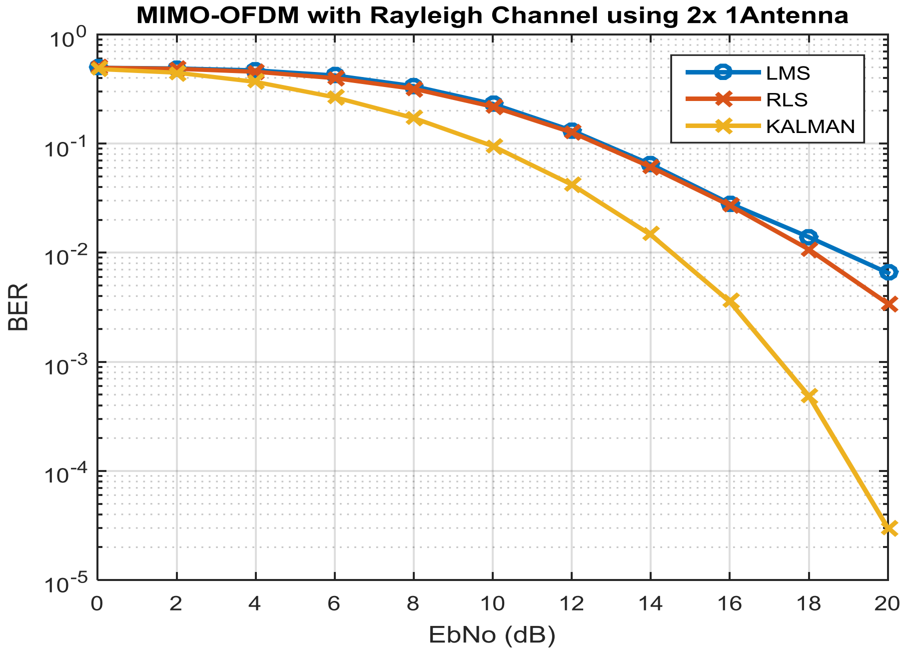


Figure 5:1 BER vs SNR for MIMO-OFDM with channel estimation in Rayleigh channel

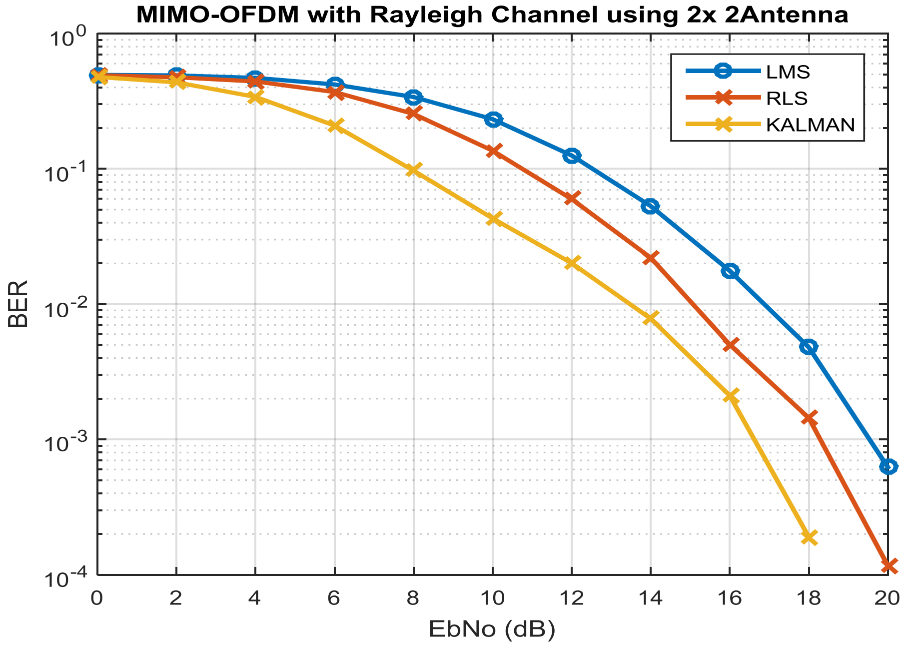


Figure 5:2 BER vs SNR for 2x2 MIMO-OFDM with channel estimation in Rayleigh channel

The simulation result in figure 5.1 shows the channel estimation technique for the MIMO-OFDM system. The antenna configuration for the system is two in the transmitter and one in the receiver which forms the 2x1 MIMO systems. For the channel estimation, the bit error vs. SNR in dB is plotted. For the bit error 0.01, using the LMS algorithm the required SNR value is the 19dB.By using the RLS algorithm the require SNR value is 18dB SNR. For kalman filter system, the SNR value for the bit error rate 0.01 is 15dB.In this case the transmitter diversity is used as two transmitters is used and only one receiver antenna is used.

Performance of the MIMO-OFDM system using the channel estimation algorithm is shown in the figure 5.2.The transmitter and receiver have the antenna diversity and two numbers of antennas are used in the both side. From the figure 5.2, the SNR value for the bit error rate of 0.01, LMS requires 17 dB SNR value, RLS requires 15dB and the kalman filter requires the 13dB SNR value. The performance of the adaptive algorithm has efficient analyzed.

The performance RLS is better than that of the LMS by the 2dB for bit error rate of the 0.01 and kalman filter is better than that of RLS by the 2dB value. Hence the performance of the kalman filter has the better performance than LMS by 4dB.The RLS algorithm estimates the error recursively by minimizing the least square error compared to the once the least mean square calculation by the LMS algorithm.In the two number of the transmitter and receiver, the diversity gain is four. Rayleigh channel model has the different multipath components in which none of the component has the dominant effect on the receive signal at the receiver.

The simulation result in figure 5.3 shows the channel estimation technique for the MIMO-OFDM system. The antenna configuration for the system is two in the transmitter and one in the receiver which forms the 2x3 MIMO systems. For the different adaptive channel estimation the bit error vs SNR is plotted. For the bit error 0.01, using the LMS algorithm the required SNR value is the 16dB.By using the RLS algorithm the require SNR value is 13.5dB SNR. For kalman filter system, the SNR value for the bit error rate 0.01 is 10dB. The performance of 2x3 configurations has better result than lower diversity configuration.

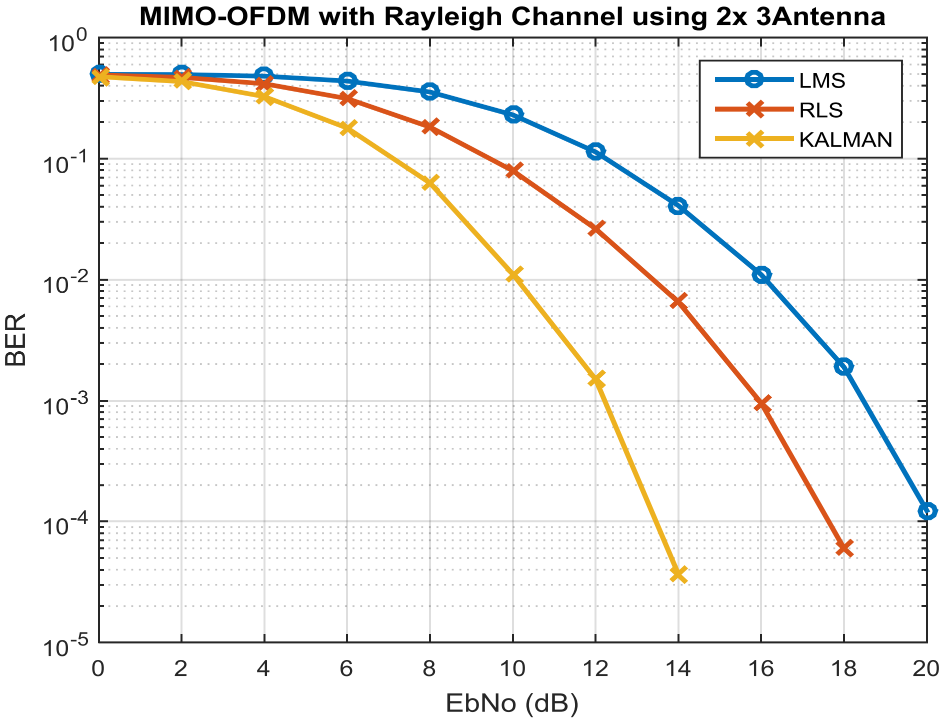


Figure 5:3 BER vs SNR for 2x3 MIMO- OFDM channel estimation in Rayleigh channel

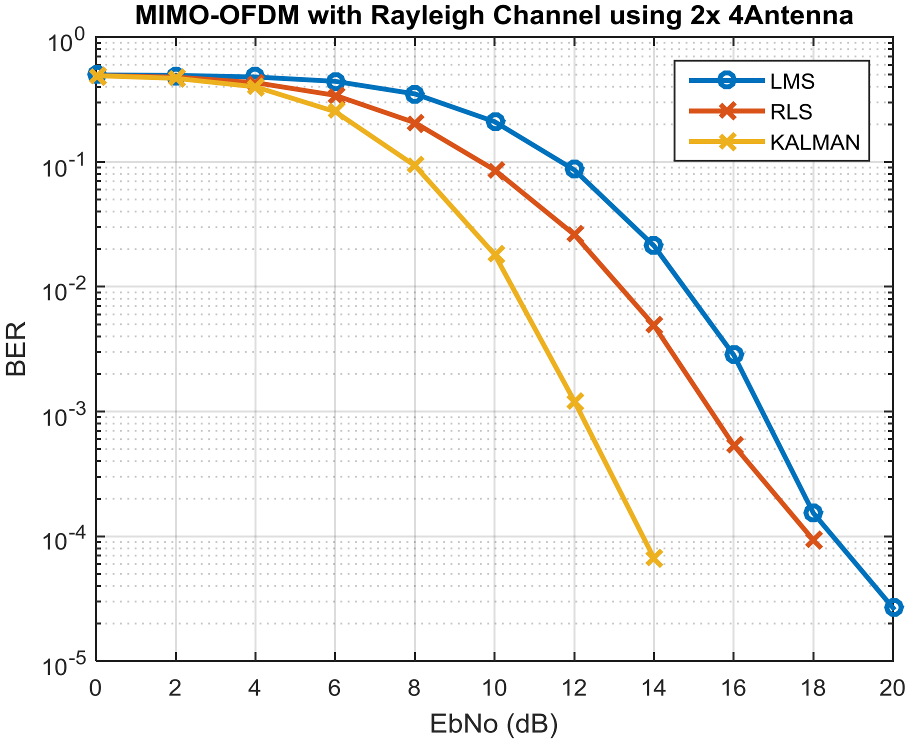


Figure 5:4 BER vs SNR for 2x4 MIMO-OFDM with channel estimation in Rayleigh Channel.

In the figure 5.4, the simulation result shows the channel estimation technique for the 2x4 MIMO-OFDM systems. For the different adaptive channel estimation the bit error vs SNR is plotted. For the bit error 0.01, using the LMS algorithm the required SNR value is the 15dB.By using the RLS algorithm the require SNR value is 13.5dB SNR. For kalman filter system, the SNR value for the bit error rate 0.01 is 10dB. The performance of 2x3 configurations has better result than lower diversity configuration.

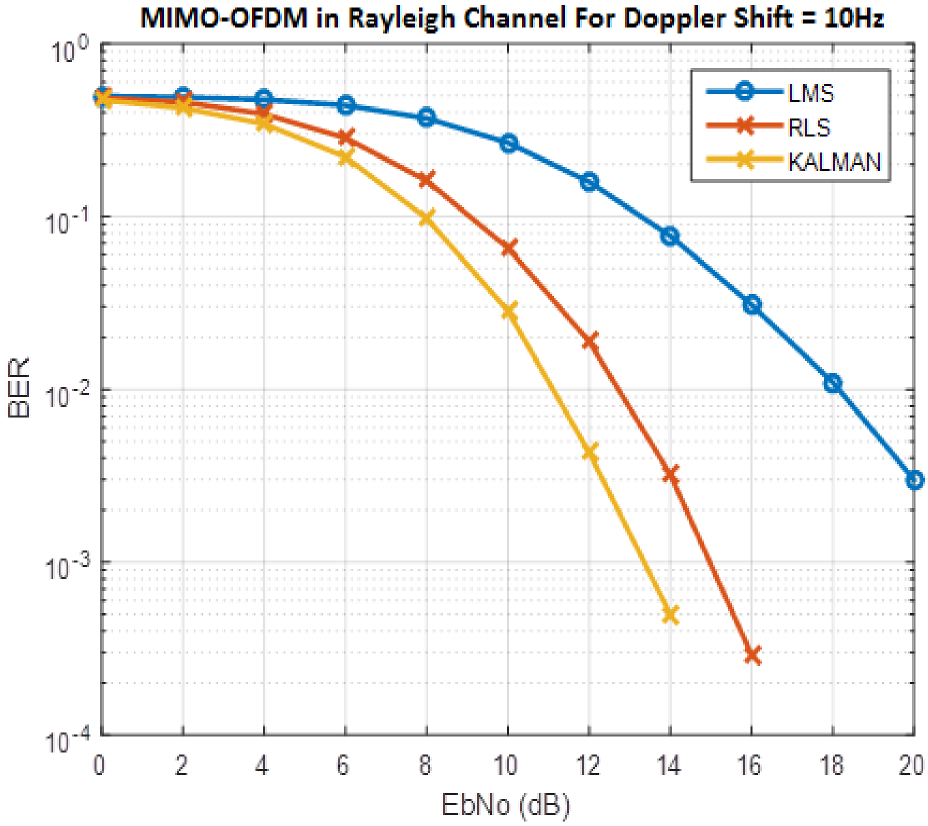


Figure 5:5 BER vs SNR for 2x2 MIMO-OFDM system for Doppler frequency 10Hz

The effect of the doppler frequency on the MIMO-OFDM system is shown in the figure 5.5. Doppler shifts is counted in the case of the time varying channel modeling while the receiver is moving towards or away from the transmitter.In case of the 10Hz dopppler frequency,LMS,RLS and Kalman filter algorithm have 18dB,13dB and 11dB SNR value respectively for the bit error rate of 0.01.In the figure 5.6 and figure 5.7 the SNR vs BER plot is shown for the doppler shift of 100Hz and 200Hz.

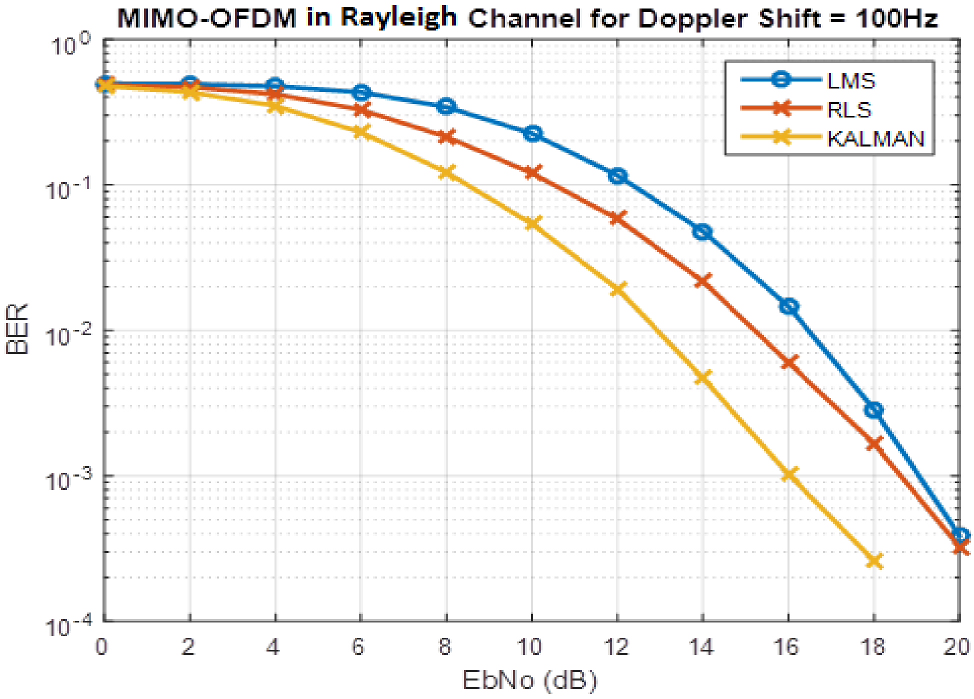


Figure 5:6 BER vs SNR for MIMO-OFDM system for Doppler frequency 100Hz

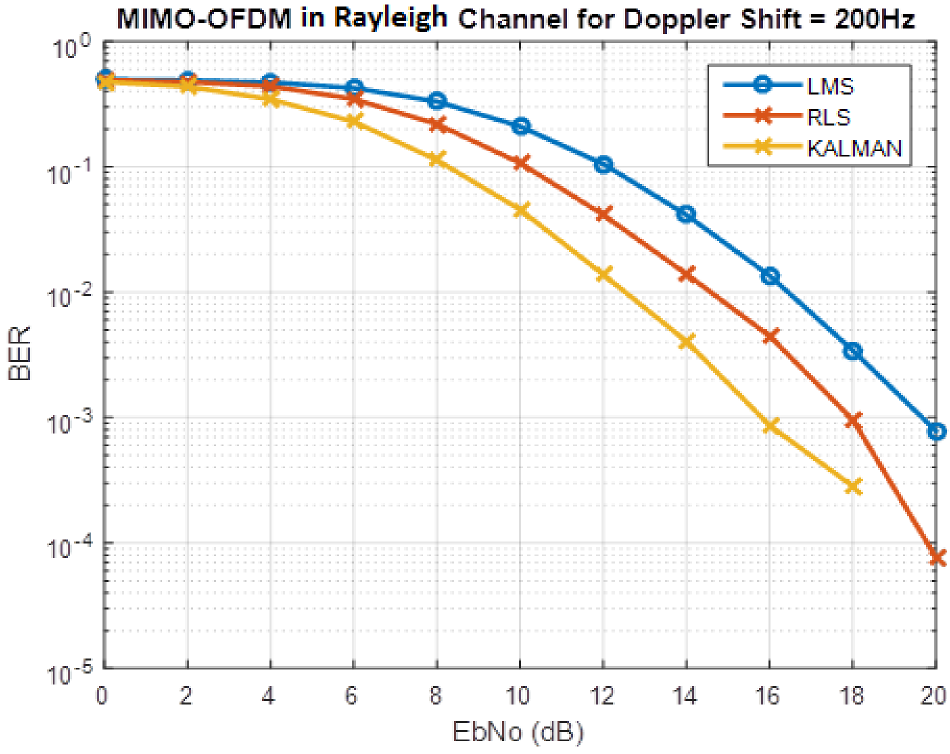


Figure 5:7 BER vs SNR for MIMO-OFDM system for Doppler frequency 200Hz

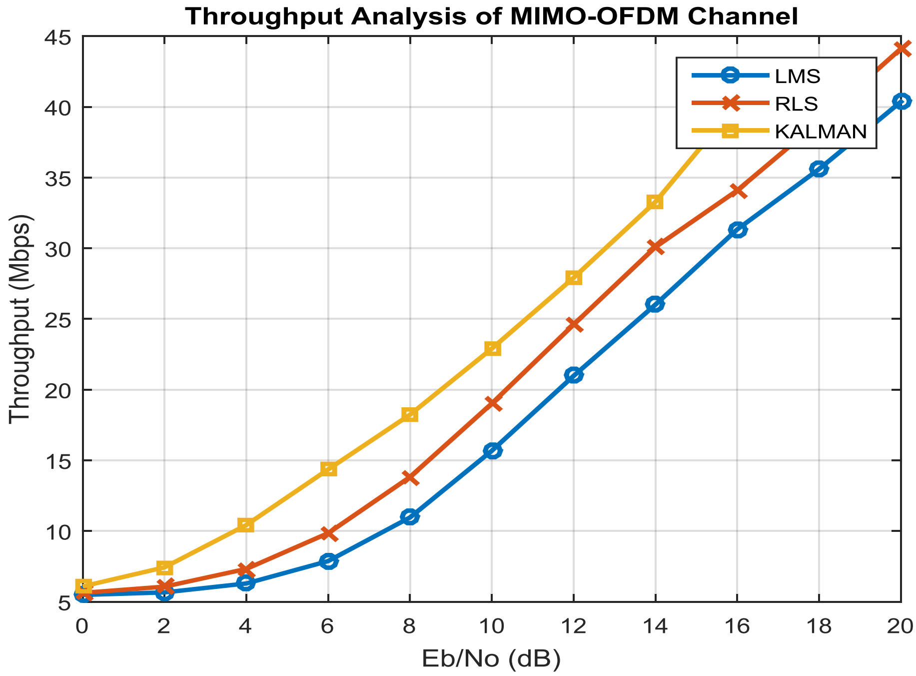


Figure 5:8 SNR vs. Throughput for 2x2 MIMO-OFDM system in Rayleigh channel

In the figure 5.8, the throughput analysis of MIMO-OFDM in Rayleigh channel is shown.The relation between the SNR and the throuhtput, with the kalman filter has the better value than remaining two LMS and RLS algorithms.For the rate of the 25 Mbps kalman filter requares the 11dB SNR,RLS requres the 12 dB SNR value and LMS requares 14dB value.

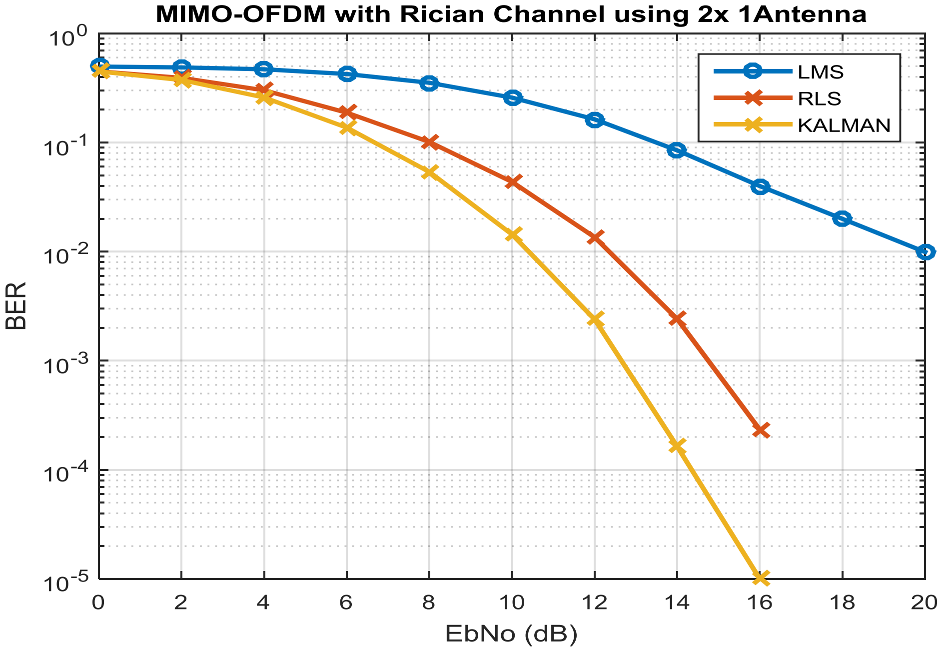


Figure 5:9 SNR vs. BER for MIMO-OFDM with channel estimation in Rician channel

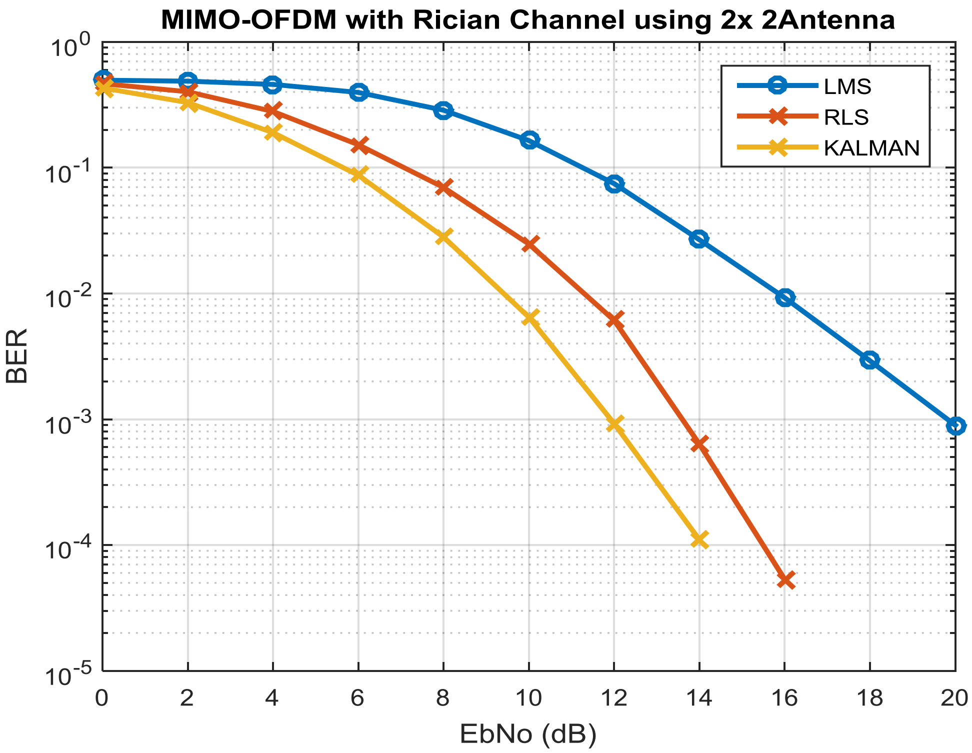


Figure 5:10 SNR vs. BER for 2x2 MIMO-OFDM with channel estimation

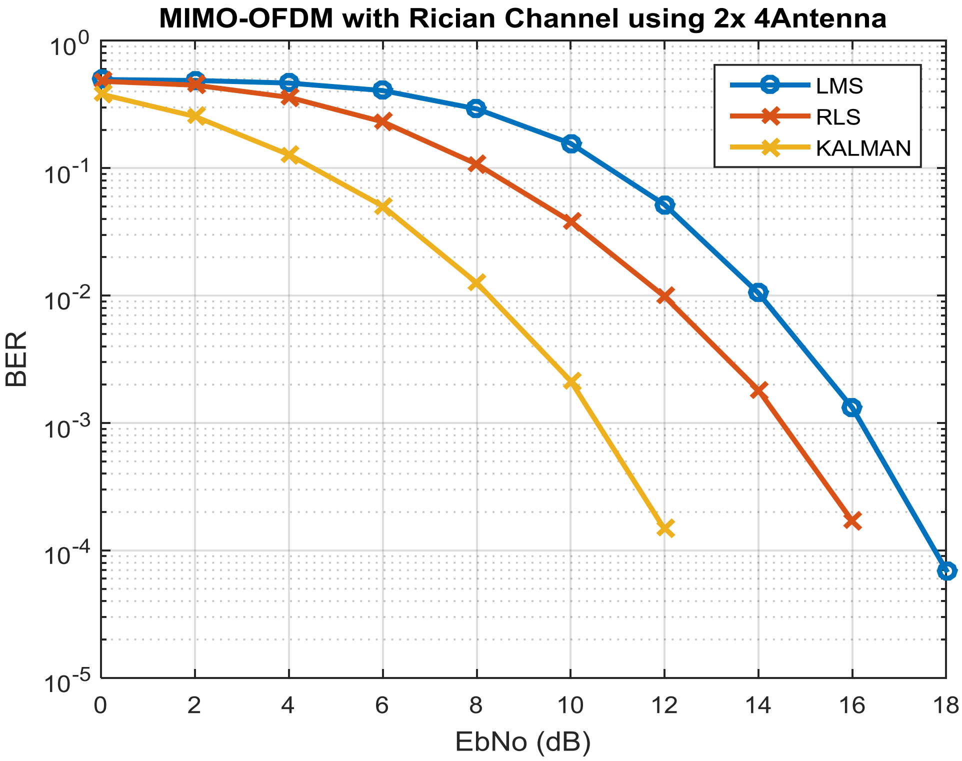


Figure 5:11 SNR vs. BER for 2x4 MIMO-OFDM with channel estimation

The simulation result in figure 5.9 shows the channel estimation technique for the MIMO-OFDM system in the Rician channel. The antenna configuration for the system is two in the transmitter and one in the receiver which forms the 2x1 MIMO systems. For the channel estimation, the bit error vs. SNR in dB is plotted. For the bit error 0.01, using the LMS algorithm the required SNR value is the 20dB. By using the RLS algorithm the require SNR value is 12dB SNR. For kalman filter system, the SNR value for the bit error rate 0.01 is 10.5dB.The transmitter diversity is used as two transmitters is used and only one receiver antenna is used. The channel model is Rician i.e. presence of lone of sight component in the multipath fading channel.

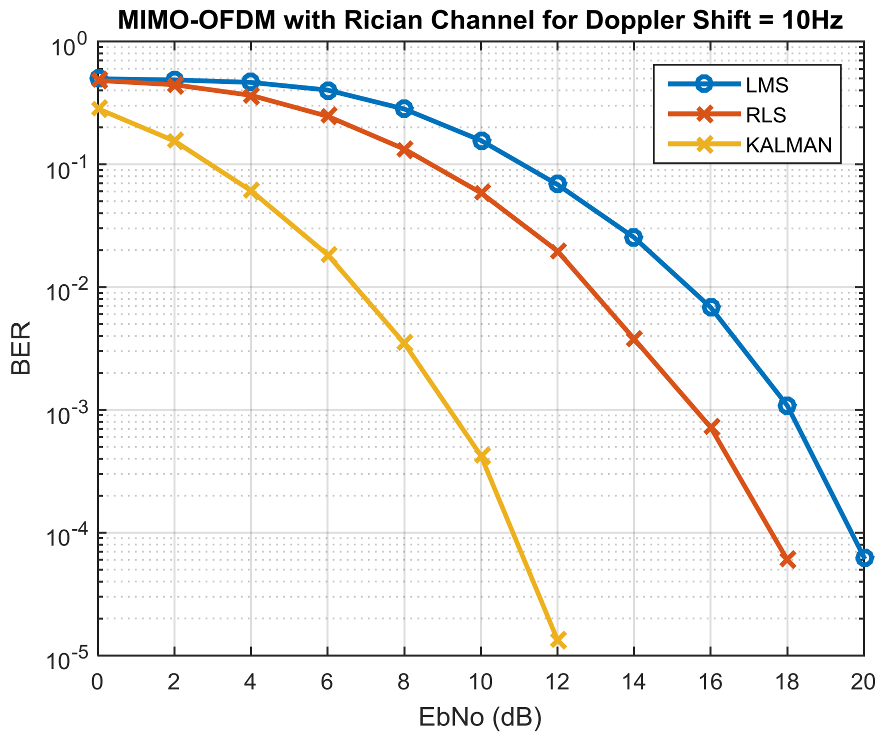


Figure 5:12 SNR Vs BER for 2x2 MIMO-OFDM for f_D=100Hz in Rician channel

The simulation result in figure 5.10 shows the channel estimation technique for the MIMO-OFDM system in Rician. The antenna configuration for the system is two in the transmitter and one in the receiver which forms the 2x2 MIMO systems. For the channel estimation, the bit error vs. SNR in dB is plotted. For the bit error 0.01, using the LMS algorithm the required SNR value is the 16dB.By using the RLS algorithm the require SNR value is 11dB SNR. For kalman filter system, the SNR value for the bit error rate 0.01 is 9dB.In 2x2 MIMO, the performance of the kalman filter has better than LMS and the RLS algorithms.

Figure 5.11 shows the performance of the 2x4 MIMO-OFDM system in Rician channel. For the channel estimation, the bit error vs. SNR in dB is plotted. For the bit error 0.01, using the LMS algorithm the required SNR value is the 14dB.By using the RLS algorithm the require SNR value is 12dB SNR. For kalman filter system, the SNR value for the bit error rate 0.01 is 8dB.When the diversity order is increased in the receiver or the transmitter side the performance has been increased significantly due to the increase in the diversity gain between the transmitter and the receiver.

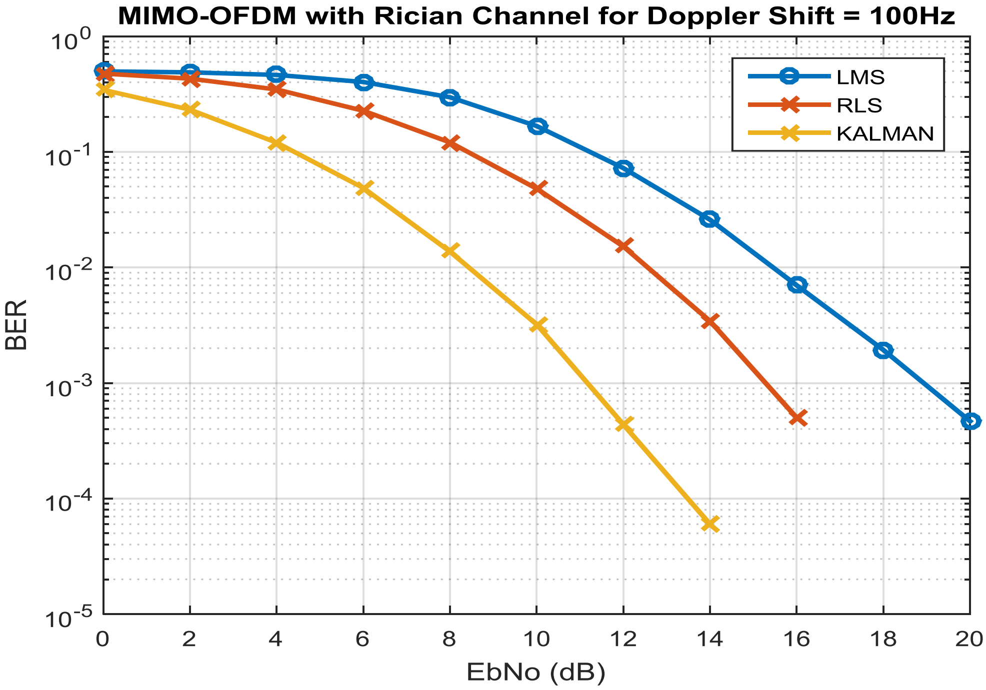


Figure 5:13 SNR vs BER for 2x2 MIMO-OFDM for f_D=100Hz in Rician channel

In the figure 5.12, the effect of the doppler frequency on the MIMO-OFDM system is shown in the Rician channel. Doppler shifts is counted in the case of the time varying channel modeling while the receiver is moving towards or away from the transmitter.In case of the 10Hz dopppler frequency,LMS,RLS and Kalman filter algorithm have 15.5dB,13dB and 7dB SNR value respectively for the bit error rate of 0.01.The variation in the doppler shift shows the velocity varition of the receiver in the time varying envirnment.

The performance in case of the 10Hz dopppler frequency for the MIMO system is shown in the figure 5.13.The three algorithm LMS, RLS and Kalman filter algorithm have 19dB,15dB and 11dB SNR value respectively for the bit error rate of 0.001.The variation in the doppler shift shows the velocity varition of the receiver for the MIMO system in the time varying envirnment.

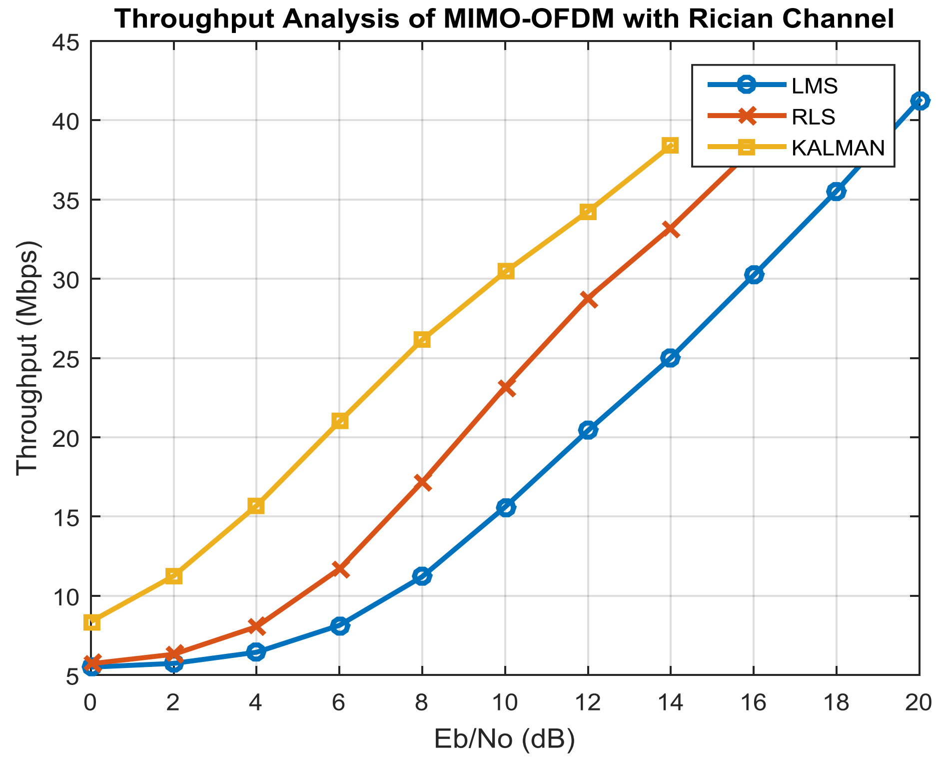


Figure 5:14 SNR vs. Throughput for 2x2 MIMO-OFDM system in Rician channel

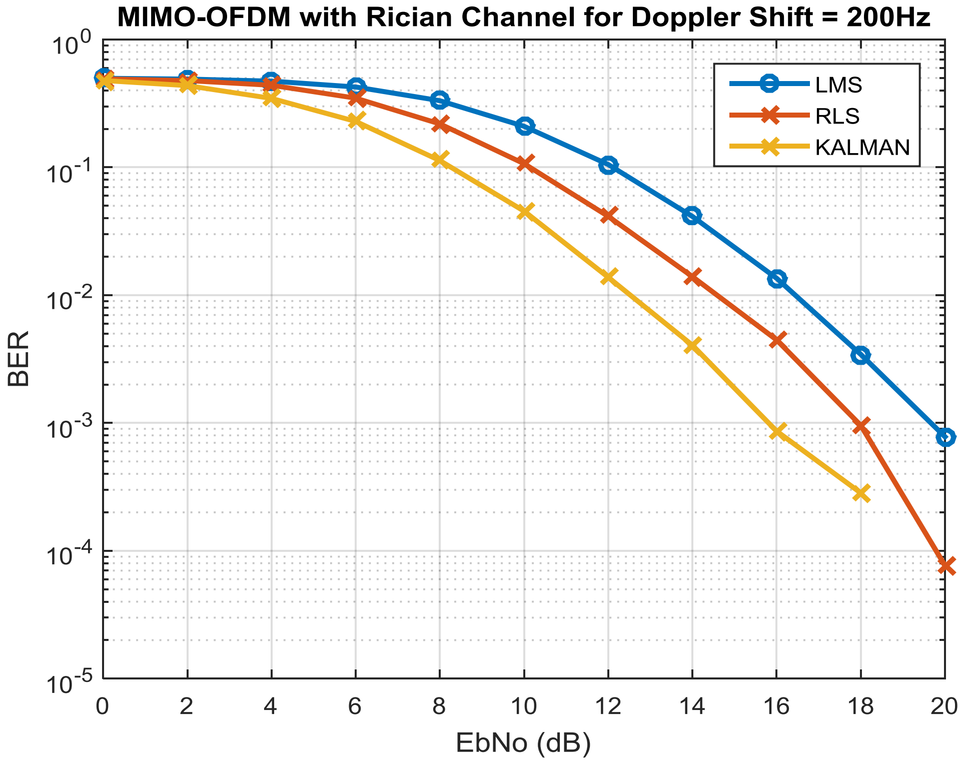


Figure 5:15 SNR vs BER for MIMO-OFDM with f_D=100Hz in Rician channel

The throughput analysis of MIMO-OFDM in Rician channel is shown in the figure 5.14. As the signal to noise value increases, the capacity of the MIMO system in correspondingly.The relation between the SNR and the throuhtput is logarithm with the kalman filter has the better value than remaining two LMS and RLS algorithms. For the rate of the 25Mbps kalman filter requares the 8dB SNR,RLS requres the 11 dB SNR value and LMS requares 14dB value.

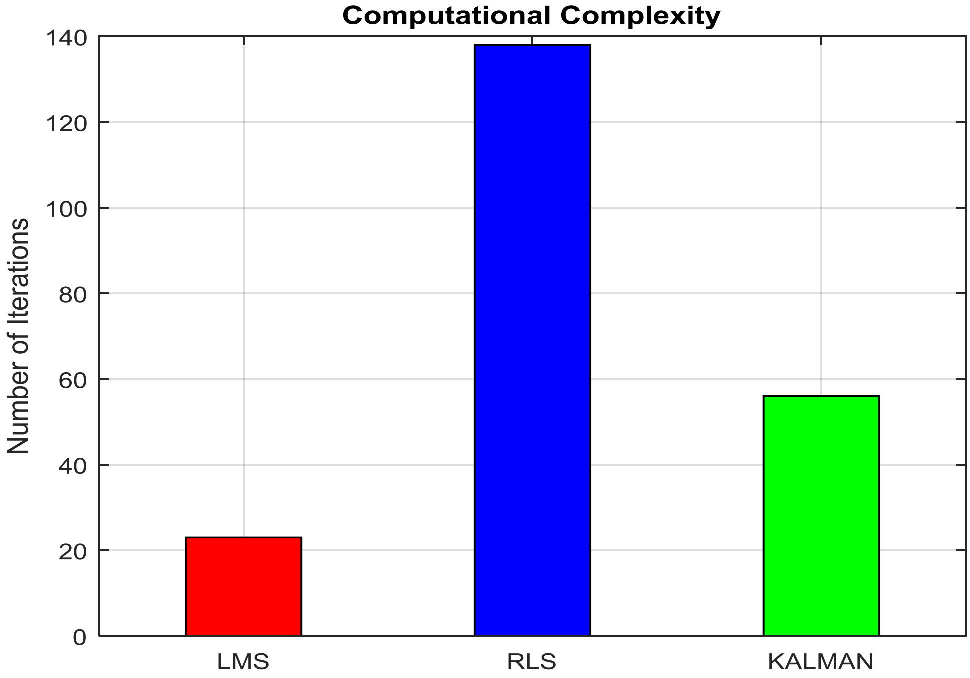


Figure 5:16 Computational complexity of the adaptive algorithm for MIMO-OFDM

The computational complexity of the algorithms is shown in the figure 5.16.Three adaptive algorithms namely LMS, RLS and Kalman filter in the MIMO-OFDM system for channel estimation have been used. The LMS algorithm has the least computation complexity than other algorithms. For the MIMO-OFDM system, LMS requires the 22 iteration whereas the RLS algorithm requires the 138 iteration and the Kalman filter requires the 58 iterations. The reason behind this is, LMS algorithm simply calculates the least error of the incoming signal and the reference input. But the RLS algorithm recursively calculates the error of the incoming signal and the reference input to minimize the error so the signal can be detected properly. And, Kalman filter has the complexity inbetween the LMS and RLS algorithm.

CHAPTER SIX: EPILOGUE

6.1 Conclusion

The performance of the MIMO-OFDM system by using the adaptive channel estimation algorithm LMS, RLS and Kalman filter has been analyzed. For the MIMO-OFDM system the modulation techniques QPSK has been used. The performance of the MIMO-OFDM system in case of the Rayleigh channel and Rician cahnnel has analyzed. The RLS algorithm has the better performance than the LMS algorithm. The proposed kalman filter method has the better performance than LMS and RLS algorithms in terms of the bit error rate and throughtput. In 2x2 MIMO-OFDM, SNR value for LMS is 17dB, for RLS is 15dB and for the Kalman filter is 13dB.For various configuration of the MIMO-OFDM 2x1, 2x2, 2x3 and 2x4 the performance is analyzed in both Rayleigh and Rician channel. The simulation result of bit error rate vs SNR graph showed that higher diversity has the best performance than lower ones i.e. 2x4 has the 5 dB better than 2x1 in kalman filter channel estimation in Rayleigh channel. The Rician channel has the good SNR value than the Rayleigh in all channel estimations and in varying configuration of the MIMO-OFDM system. The small doppler shift has the better performance than the large dopler shift i.e 10Hz Doppler shift has 11dB whereas 200Hz has the 16dB SNR for kalman filter in Rayleigh case for BER 0.01.The throughtput has better in the increasing order of LMS, RLS and Kalman filter. Computational complexity of the RLS has the most complex algorithm and LMS algorithm least complexity. Kalman filter has the less complexity than RLS and more than LMS with improve in the performance in terms of bit error rate.

6.2 Future Work

As a future there is some task that can be based on my thesis. The different modulation schemes can be used to analyze the performance of the MIMO-OFDM system. To model the time varying nature of the receiver, the velocity of receiver can properly tracked by using autoregressive model for channel model and fuzzy logic to categories the velocity of the receiver. I have used only the kalman filter to improve the performance of the MIMO-OFDM system , extended kalman fiter can be used combined with fuzzy to improve the performance of the MIMO system

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