Simulation on Effect of Doppler shift in Fading channel and Imperfect Channel Estimation for OFDM in Wireless Communication

Manita Baral Kharel, Sarbagy Ratna Shakya

Tribhuvan University

Corresponding Email: zzinita@yahoo.com, ratnasunsar@hotmail.com

Abstract: In wireless communication system the transmitted signal is distorted by various phenomena that are intrinsic to the structure and contents of the wireless channel. Among these fading and interference are the main dominant sources of distortion that are responsible for the degradation of performance. Fading as is the fluctuation in amplitude phase and multipath delays over very short travels distance or very short time duration. To increase high data rate in wireless communication Multiple-input multiple-output (MIMO) and orthogonal frequency division multiplexing (OFDM) techniques have been considered best as it has high frequency spectrum efficiency. In this study the performance over fading channel on the wireless communication is studied, simulation and compared for maximum Likelihood receivers in different modulation structure in the presence of Gaussian Channel estimation error based on different Doppler shift. The second part is to study the performance degradation due to channel estimation error, fading noise, interference between users for several fading channels in multiple user multiple antenna with different performance measures like Average signal-to-interference ratio, signal to noise Ratio (SNR) and Average Bit Error Probability (BEP).

Keyword: Orthogonal frequency division multiplexing (OFDM), Bit Error Rate (BER), Fading channel, Interference, MIMO, Doppler Shift, Signal to noise ratio, Maximum

1. Introduction

Wireless communication is one of the most active areas of Technology development which has experience massive growth and commercial success in the recent years. Each system in wireless communication should transmit digital signals in the physical channels which can cause fading. Due to random and time variant in nature simulation of wireless channels accurately has become an important field of study for the design and Performance evaluation of wireless Communication systems and components [1]. Radio waves propagate from a transmitting antenna, and travel through free space undergoing absorption, Reflection, refraction, diffraction and scattering. They are greatly affected by different physical structures such buildings, bridges, hills, tress and ground terrain, the atmosphere, and the obstacles in their path, like etc.[2] These multiple physical phenomena are responsible for most of characteristic features of the received signal with random attenuations and delays. This type of fading affects the signals transmitted through wireless channels and causes the short-term signal variations[5]. Small-scale fading, or simply fading, is used to describe the rapid fluctuations of the amplitudes, phases, or multipath delays of a radio signal over a short period of time or travel distance, so that large-scale path loss effects may be ignored. Fading is caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times. These waves, called multipath waves, combine at the receiver antenna to give a resultant signal which can vary widely in amplitude and phase, depending on the distribution of the intensity and relative propagation time of the waves and the bandwidth of the transmitted signal. The effects due to small scale multipath propagation can be Rapid changes in signal strength over a small travel distance or time interval and Random frequency modulation due to varying Doppler shifts on different multipath signals and also time dispersion (echoes) caused by multipath propagation delays. When the transmitter or receiver is moving the frequency of the received signal changes it will be different from the transmitted signal which is due to Doppler shift. The Doppler shift will be positive if the mobile is moving towards the direction of the arrival of the wave whereas it will be negative if the mobile is moving away from the direction of arrival of the wave. Depending on how rapidly the transmitted baseband signal changes as compared to the rate of change of the channel, a channel may be also classified either as a fast fading or slow fading channel. When the channel impulse response changes rapidly within the symbol it is known as fast fading and when it changes at a rate much slower than the transmitted baseband signal then it is slow fading. There are various models to describe statistical behaviour of this phenomenon. Two common models are Rayleigh and Rice fading channels .The Rayleigh distribution models multi-path fading with no line-of-sight (LOS) while Rice distribution models fading channel in the presence of LOC.

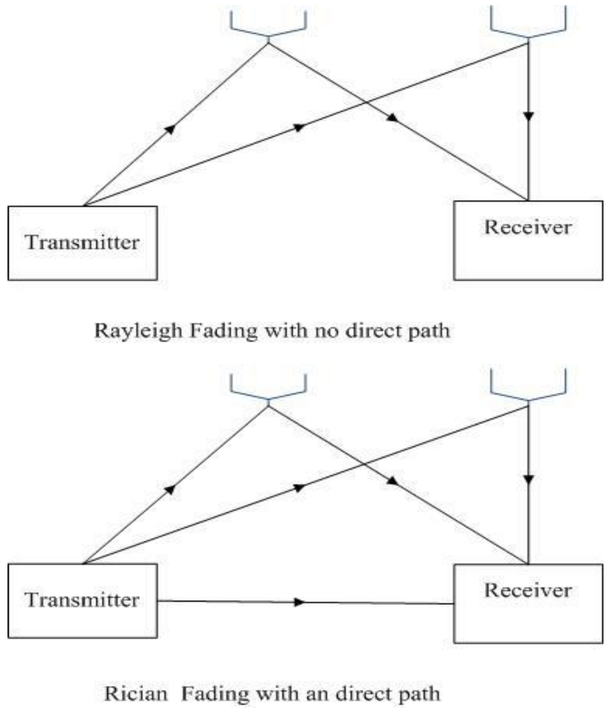

Fig 1: Rayleigh and Racian Channel

In the second section the ML receiver receives the BPSK signal from the Rayleigh channel with the presence of Additive white Gaussian Noise. To extract the signal from the imperfect channel Maximum likelihood sequence estimation (MLSE) algorithm is used. The data are transmitted into the distorted channel and the ML equalization is used to detect error at the receiver side where the receiver compares the time response of the received signal and determines the most likely signal by root mean square as the decision criterion for the lowest error probability.

2. Doppler shift

When a transmitter or receiver is moving, the frequency of the received signal changes, i.e. it is different than the frequency of transmission. This is called Doppler Effect. The change in frequency is called Doppler Shift.

It depends on

1. The relative velocity of the receiver with respect to transmitter
2. The frequency (or wavelength) of transmission
3. The direction of travelling with respect to the direction of the arriving signal.

When a source generating waves moves relative to an observer, or when an observer moves relative to a source, there is an apparent shift in frequency. If the distance between the observer and the source is increasing, the frequency apparently decreases, whereas the frequency apparently increases if the distance between the observer and the source is decreasing. This relationship is called **Doppler Effect** (or **Doppler Shift**) [5]. The Doppler Effect causes the received frequency of a source (how it is perceived when it gets to its destination) to differ from the sent frequency. For a vehicle moving in a straight line at constant velocity v, the Doppler frequency shift, fd is given

$$f_d = \frac{2\pi}{\lambda}\|v\|\cos\big(\theta(t)\big) \qquad (2.1)$$

The difference between the maximum and minimum values of f_d is called Doppler spread. Doppler spread also causes fading in wireless communication. Doppler spread B_D is defined as the maximum Doppler shift

i.e., $fm = v/\lambda$

If the baseband signal bandwidth is much greater than B_D then effect of Doppler spread is negligible at the receiver side.

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. When the user is moving at a constant velocity v along a path, vs is the velocity of the source, f' is the observed frequency and f is the emitted frequency. Then the detected frequency signal is given by

$$f' = \left(\frac{v}{v\mp vs}\right) f \qquad (2.2)$$

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.

Coherence time is the time duration over which the channel impulse responses essentially invariant. In general, coherence time is inversely related to Doppler spread, typically expressed as:

$$T_c = 1/f_s \qquad (2.3)$$

Where T_c is coherence time and f_s is Doppler shift.

Coherence time can also be defined as

$$Tc \approx \sqrt{\frac{9}{16\pi f m^2}} = \frac{0.423}{fm} \quad (2.4)$$

If the symbol period of the baseband signal (reciprocal of the baseband signal (bandwidth) is greater than the coherence time, then the signal will distort, since channel will change during the transmission of the signal. Coherence time definition implies that two signals arriving with a time separation greater than T_C are affected differently by the channel. There has been great interest in the structure of optimum receivers for detection digital signals transmitted over fading in the presence of additive white Gaussian noise (AWGN) for last decades. To detect transmitted symbols two types of receiver, coherent and non- coherent are conventionally considered [1].

3. Fading

Fading is one consequence of transmitting a signal through a time – varying multi-path channel is to confornt at the receiver with a signal fading (amplitude variation in the received signal). Hence not only the propagation delays but also the random impulse responses of the channel will provoke some attenuation and time spread of the signal transmitted.

Types of Fading

Fading can be divided into different types.

3.1 Due to effect of multipath

3.1.1 Large Scale Fading

In large scale fading, the loss of signal power or strength due to the signal attenuation and the distance between transmitter and receiver causes fading.

3.1.2. Small scale fading

Small scale fading describes rapid fluctuations of the amplitude, phase of multipath delays of a radio signal over short period of time or travel distance. It is caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times. These waves are called multipath waves and combine at the receiver antenna to give a resultant signal which can vary widely in amplitude and phase.

Small scale fading moves in order of its wavelength. Small scale fading can be subdivided into two other types. One is based on the multipath delay spread and the other on the Doppler shift. Depending on the relative length of the multipath delay spread (σ_δ) with respect to the OFDM symbol length we can have either Flat Fading or Frequency Selective Fading. Similarly, the relative magnitude of the channel coherence time (as a result of the Doppler shift) with respect to the OFDM symbol duration determines whether the signal undergoes Fast Fading or Slow Fading [3].

3.2 Due to effect of Doppler spread

3.2.1 Slow fading

If the channel coherence time is larger than the symbol period or delay constraint of the channel slow fading occurs and hence the channel remains approximately static over a symbol or multiple symbols. Slow fading is usually expected with low Doppler spread values; i.e., with slower moving obstacles and receiver/ transmitter. Multipath delay spread based and Doppler spread based fades are completely independent of each other and hence is quite possible to have a flat, fast fading channel or a flat, slow fading channel; and so on. When the signal is obscures by the large obstruction slow fading occurs

3.2.2 Fast Fading

If the channel coherence time is small than the symbol period or delay constraint of the channel fast fading occurs and hence the channel changes over the one period. In other words, the channel coherence time, Tc, is smaller than the symbol period. T_c is related to the Doppler spread, fm, as Tc = 0.423/fm. From this relation it is clear that a high Doppler spread results in a smaller channel coherence time. The coherence time of 0.423ms corresponding to a fm of 1kHz is clear. Hence, a flat fading, fast fading channel is a channel in which the amplitude of the delta function varies faster than the rate of change of the transmitted baseband signal. In the case of a frequency selective, fast fading channel, the amplitudes, phases, and time delays of any one of the multipath components vary faster than the rate of change of the transmitted signal. In practice, fast fading only occurs for very low data rates. The velocity of the mobile (or velocity of objects in the channel) and the baseband signalling determines whether a signal undergoes fast fading or slow fading.

Types of Small scale fading models

There are many models to describe the phenomenon of small scale fading. Some of these models are Rayleigh Fading, Rician Fading and Nakagami fading models which are the most popular [6].

a) Rayleigh fading model:

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 troposphere and ionospheres “signal propagation as well as the effect of heavily built-up urban environments on radio signals. Rayleigh fading is mostapplicable when there is no line of sight between the transmitter and receiver.

b) 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 (nonfading) signal and is commonly known as the LOS (Line of Sight Component).

c) Additive White Gaussian Noise Model:

The simplest radio environment in which a wireless communications system or a local positioning system or proximity detector based on Time of-Flight will have to operate is the Additive-White Gaussian Noise (AWGN) environment. Additive white Gaussian noise (AWGN) is the commonly used to transmit signal while signals travel from the channel and simulate background noise of channel. The mathematical expression in received signal r(t) = s(t) + n(t) that passed through the AWGN channel where s(t) is transmitted signal and n(t) is background noise.

4. OFDM Technology

As the data rate increases in a multipath environment, the interference goes from flat fading to frequency selective (last reflected component arrives after symbol period). This results in heavy degradation.

The OFDM is a technique in which the total transmission bandwidth is split into a number of orthogonal subcarriers so that the wideband signal is transformed in a parallel arrangement of narrow band orthogonal signals. In this way a high data rate stream that would otherwise require a channel bandwidth far beyond the actual coherence bandwidth can be divided into number of low rate streams. The mobile channel is characterized by multipath which gives rise to ISI at the receiver side. Hence to prevent the performance degradation the filter should be designed that counteracts ISI. For this purpose we use Orthogonal Frequency division Multiplexing (OFDM) which have a robustness against ISI and Simplicity in its hardware implementation with the ability to transmit data in high speed. 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×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].

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:

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

$$t_s \leq t \leq t_s + T$$

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

where:

N_S is the number of subcarriers

T is the symbol duration

f_c is the carrier frequency

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. Finally OFDM symbols with pilots are transmitted over the multipath channel.

Inverse Fast Fourier Transform FFT to Create the OFDM Symbol

IFFT is a fast algorithm to perform inverse (or backward) Fourier transform (IDFT), which undoes the process of DFT. 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].

5. Channel Estimation

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 reduce 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 modelled 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.

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

$$Y = Xh + nY \quad (5)$$

Where Y is the received vector, X is a matrix containing the transmitted signalling 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.

6. Maximum Likelihood

Maximum likelihood (ML) is optimal decoding method that compares between the received signal and possible transmitted signal. As the transmitted signal is modified by channel matrix, we need to estimate transmit symbol by using maximum likelihood detection algorithm [9].

$$\hat{x} = \arg x_k \in \{x1, x2, \ldots\ldots, x_N\} min\|r - H_{xk}\|$$
(2.6)

Where $\|$r-Hxk$\|^2$is ML metric which achieve maximum performance when transmitted vectors are equally likely [9] [10]. Where r is the received signal and H be the channel matrix.

For an optimized detector for digital signals the priority is not to reconstruct the transmitter signal, but it should do a best estimation of the transmitted data with the least possible number of errors. The receiver emulates the distorted channel. All possible transmitted data streams are fed into this distorted channel model. The receiver compares the time response with the actual received signal and determines the most likely signal. In this case, root mean square deviation can be used as the decision criterion for the lowest error probability So we use Maximum likelihood sequence estimation (MLSE) is a mathematical algorithm to extract useful data out of a noisy data stream.

7. Performance Metrics

Performance analysis of wireless system requires the averaging of performance metrics over these fading models. The main performance metrics are the Signal to Noise Ratio(SNR) and Bit Error Ratio(BER) Energy per bit to noise power spectral density ratio.

Signal to Noise Ratio (SNR): This is one of the vital performance measures of the communication system.It is usually measured at the output of the receiver side[2]. SNR is the ratio of the received signal strength over the noise strength in the frequency range of the operation. BER is inversely related to the SNR, i.e. high BER causes low SNR. It is measured in decibels and represented as [6]

$$SNR = \ log10 \left(\frac{Signal\ Power}{Noise\ power}\right) db$$

Average Bit Error Ratio(BER): This is also one of the most informative indicators about the performance of the system. This is measure from the number of bits received in error divided by the number of bits transmitted. In digital transmission the number of bit errors is the number of received bits of a a data stream over a communication channel that has been altered due to noise interference distortion or bit synchronization errors [6]. It is given by

$$BER = \frac{Bits\ in\ error}{Total\ bits\ received}$$

The analytical BER expression for BPSK signalling in AWGN, RAYLEIGH and RICIAN channels are respectively given by,

$$Pb = \frac{1}{2}\left(1 - \sqrt{\frac{\frac{eb}{N0}}{1 + \frac{Eb}{N0}}}\right) \text{ For Rayleigh}$$

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_o}}\right) \text{ For AWGN}$$

$$P_b = \frac{1}{2} erfc\left[\sqrt{\frac{K\left({E_b}/{N_O}\right)}{\left(K + {E_b}/{N_O}\right)}}\right] \text{ For Rician}$$

Where,

k= m/2σ2

$$\sigma = \frac{1}{2*(k+1)}$$

$$m = \sqrt{\frac{k}{(k+1)}}$$

Also the probability density function for M-ary QAM for OFDM signal is

$$Pb= \frac{2(M-1)}{M\log_2 M}\, Q\left(\sqrt{\frac{6E_b}{N_o}\cdot\frac{\log_2 M}{M^2-1}}\right)$$ For AWGN channel for M-aryQAM

$$P_{e}= \frac{2(M-1)}{M\log_2\ M}\left(1-\sqrt{\frac{3\gamma\log_2{}^{M}/(M^2-1)}{3\gamma\log_2{}^{M}/(M^2-1)+1}}\right)$$ For Rayleigh Channel for M-ary QAM

E_b/N_0(Energy per bit to Noise power spectral density ratio): This is another important parameter for calculating performance measurement in digital communication. It is also known as signal to noise ratio per bit.E_b/N_0 is equal to the SNR divided by the Gross link spectral efficiency in bits/Hz. Itis generally used to relate actual transmitted power to noise.[6]

8. Simulation

A. Description of simulation process

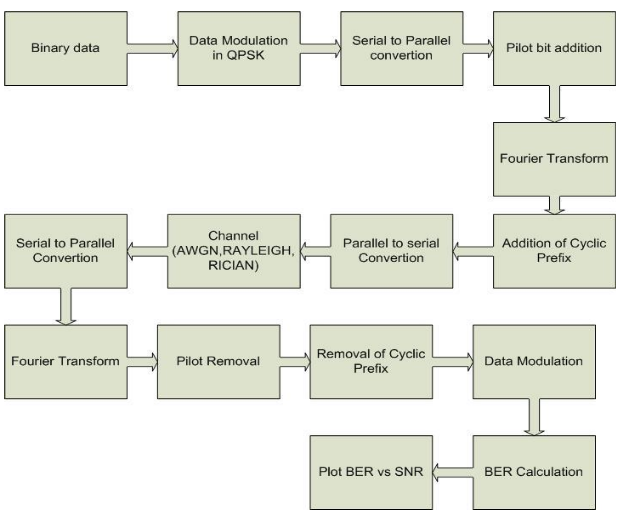

Figure 8.1: Block Diagram of simulation process

B. Simulation Parameters

PARAMETERS	SPECIFICATION
FFT Size	64
Number of carrier in OFDM	52
Channel	RAYLEIGH,RICIAN
Signal constellation	QPSK
Doppler shift	5 Hz- 300Hz

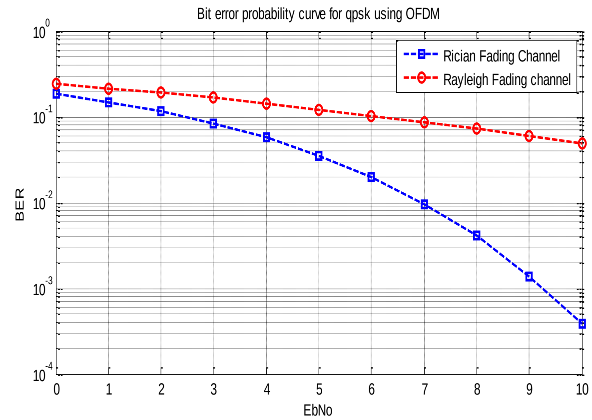

Figure 8.2*:* Simulation Plot using QPSK Modulation technique under different channel for Doppler shift

C. Comparison between Rayleigh and Rician Channel

Doppler shift (Hz)	SNR (dB)	BER (Rayleigh Channel)	BER (Rician Channel)
10	10	0.04957	0.04699
50	10	0.0659	0.05494
100	10	0.08089	0.06574
300	10	0.1033	0.08769
500	10	0.1119	0.09698
1000	10	0.1147	0.1021

D. Graph for comparison between two channels

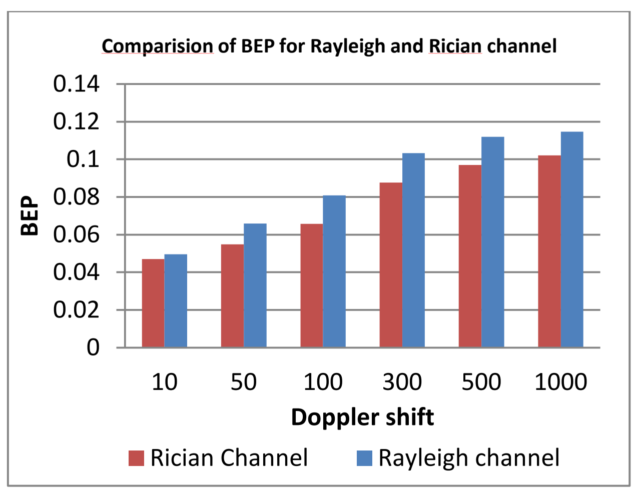

Figure 8.3 Chart for comparison of BEP for different channel due to different Doppler shift

From the table and the simulated data we can see that the BER increases with the increase in the Doppler shift for the same value of SNR in both Rayleigh and Rician channel models. Also we can see that the BER is slightly higher in Rayleigh channel.

D. Simulation Parameters for ML Detection

Parameters	Specification
MIMO	2*2, 4*4
SISO	1*1
Channel	AWGN,RAYLEIGH
Modulation	BPSK

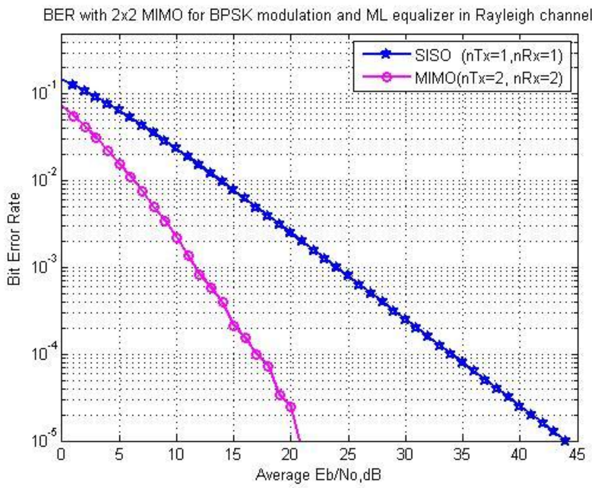

Figure 8.4: E_b/N_o Plot with ML estimation (2*2)

The above simulation graph shows that the BER for MIMO is less as compared to the SISO for the same E_B/N_0. That is the noise that are added in the channel affects SISO channel more than the MIMO channel. The ML receiver used as a receiver detects more signal in the receiver in the MIMO channel than in SISO channel. Hence for the good detection of signal through ML detector MIMO channel is far more efficient than SISO channel.

9. Conclusion

From the simulation results it can be observed that the increase in the Doppler shift in the different channel models for OFDM signal increases the BER rate for the constant SNR, whereas the BER decreases with the increase in SNR for the same Doppler Shift. Also Due to the Doppler fading caused by the Doppler shift it can be observe that the signal at the receiver side varies. In low Doppler shift the BER vary less for Rayleigh and Rician channel but with the increase in Doppler shift the Rician channel have less BER as compared with the Rayleigh channel with the presence of a dominant LOS component. Also the effect of noise is more in SISO than in MIMO and is less in 16 QAM modulation than AWGN channel with the presence of Gaussian noise in the channel while detecting through ML detector.

10. Limitations and Future Enhancement

The expression for the outage probability, Average BER and High SNR approximations has been derived under Rayleigh and Rician channel model. Simulation and Validation has been performed by implementing the Doppler shift theory in OFDM signal and in the second part by the implementation of the Maximum likelihood sequence estimation (MLSE) algorithm. While evaluating the effect the simulation parameters don't hold an exact result for the Doppler shift very much greater than 10Khz.

The study is based on the effect of Doppler shift in fading channel and imperfect channel estimation for OFDM signal in wireless communication. Some of the recommendation to the possible extensions of the work can be the study of effect in other channel models such as in Nakagami-m channel models, Weibull, Beckmann channel models. Also different modulation technique can be used with different coding techniques, such as 64- QAM modulation techniques. Different MIMO detection schemes can be used in the receiver side to detect the signal from the noise channel such as V-Blast techniques.

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