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Performance Evaluation of Spatial Multiplexing MIMO-OFDM System using MMSE Detection under Flat and Frequency Selective Rician Channel

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Abstract— MIMO-OFDM (Multiple Input Multiple Output-Orthogonal Frequency Division Multiplexing) is a very promising technology providing high throughput and range without additional bandwidth or transmit power by using many antennas at transmitter and receiver eliminating Inter-Symbol-Interference (ISI).The capacities of MIMO-OFDM systems can be fully utilized by low complex and optimal signal detection scheme. The receiver's detector is supposed to maximize the Signal to interference plus noise (SINR) by cancelling the spatial interference and should separate the transmitted signals. Linear detector, Minimum Mean Square Error (MMSE) is a less complex detector than other non-linear detectors. The performance of the proposed system is analysed using MMSE under flat and frequency selective Rician channel environment, different number of antenna configurations and various modulation techniques to provide an optimum solution

Index Terms— flat and frequency selective; MIMO-OFDM; MMSE; Rician channel; spatial multiplexing; ZF

1 INTRODUCTION

HIGH data rate wireless communications, nearing 1Gb/s speed in 100MHz of bandwidth is trending in WLANs and home audio/visual networks. Research are directed at designing systems that are capable of handling high data rates while maintaining sufficient BER performance without increasing the bandwidth. MIMO combined with OFDM system is the best solution for this. MIMO systems use array of multiple antennas and take benefit of multipath effects of the propagation instead of combating it [1]. OFDM can transform frequency selective MIMO channels into a set of parallel frequency flat MIMO channels, thus decreases receiver complexity. Parallel increase in performance and spectral efficiency of MIMO systems is not achievable with all the available signal detection schemes as their associated computational complexity increases exponentially with the number of antennas. MMSE is a low complexity scheme giving sub-optimal performance [5]. Performance of a system and its detector is very important to be evaluated under different flat and frequency selective fading environments. Evaluation of the system under Rician flat and frequency selective channel for various digital modulation techniques and antenna sizes is performed to present an optimum solution and achieve high data rates.

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2 MIMO SYSTEM MODEL

MIMO system consists of majorly three components, the transmitter, channel and receiver as shown in Fig.1. It uses multiple antennas at both the ends of the wireless links, all operating at same frequency at same time.

$$r = Hs + n \quad (1)$$

Where, r is received signal vector, H is $N_r \times N_t$ channel matrix, s is transmitted vector and n is Gaussian noise vector. MIMO encoder uses Space time processing technique which has generally has two aims; one is to increase the data rate and next is to achieve maximum possible diversity. The space time processing techniques are: Space time coding and Spatial Multiplexing. The paper focuses on the use of Spatial Multiplexing MIMO which allows higher throughput, and interference reduction. It also fulfils the requirement by offering high data rate through spatial multiplexing gain and improved link reliability due to antenna diversity gain [2].

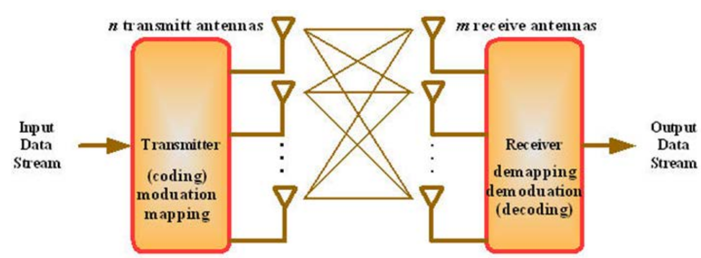

Fig. 1. MIMO System

2.1 Spatial Multiplexing

Spatial multiplexing is a transmission method to send several different data bits in streams through an independent spatial channel from each of the multiple transmit antennas to achieve the greater throughput at higher SNR values [2]. If the transmitter is provided with Nt antennas and the receiver has Nr antennas, the maximum spatial multiplexing order (the number of streams) is,

$$Ns = \min(Nt, Nr) \quad (2)$$

Therefore, the space dimension is reused or multiplexed more than once.

3 OFDM

OFDM is a special form of multicarrier modulation (MCM) with closely spaced subcarriers overlapping spectra as shown in Fig 2. MCM works on the principle of transmitting data by dividing the stream into several bit streams, each of which has a much lower bit rate, and by using these sub-streams to modulate several carriers [3]. The information data is mapped into symbols, distributed and sent over the N sub-channels, one symbol per channel. To have minimum interference, the carrier frequencies must be chosen carefully. Orthogonal FDM's spread spectrum technique distributes the data over a large number of carriers that are spaced apart at perfect frequencies. This spacing provides the "Orthogonality" which prevents demodulators from viewing frequencies other than their own. With the find of FFT/IFFT it became possible to generate OFDM using the digital domain for orthogonality of sub carriers. In OFDM, an N complex-valued data symbol modulates N orthogonal carriers using the IFFT forming. The transmitted OFDM signal multiplexes N low-rate data streams, each experiencing an almost flat fading channel when transmitted.

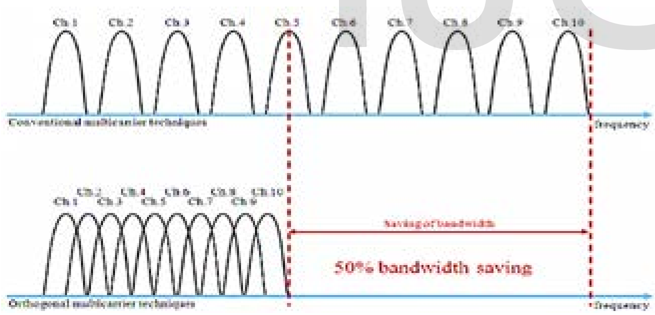

Fig.2. OFDM Subcarriers

4 MIMO-OFDM

A combination of MIMO and OFDM has been considered as a potential technology for high speed data wireless transmission networks such as WLAN, 3GPP, LTE & WiMAX. The Spatial Multiplexing(SM) can significantly increase channel capacity by simultaneously transmitting multiple independent streams with same data rates and power level [3]. Other side the OFDM technology can efficiently utilize the spectrum and eliminate the effect of multipath fading. All the blocks of OFDM like, FFT, IFFT and CP when applied to every single transmit and receive antennas (MIMO) makes it MIMO-OFDM as shown in Fig.3

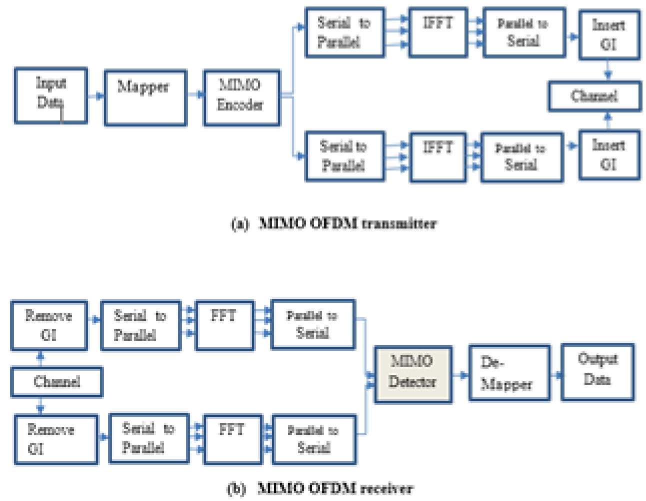

Fig.3 System Block diagram (a) MIMO-OFDM transmitter (b) MIMO-OFDM receiver

5 LINEAR DETECTORS

5.1 Zero Forcing Detectors (ZF)

The ZF is a linear detection technique, which inverse the frequency response of received signal, the inverse is taken for the restoration of signal after the channel. The estimation of strongest transmitted signal is obtained by nulling out the weaker transmit signal. Considering 2x 2 MIMO channel,

$$y = Hx + n \quad (3)$$

Where, Y=Received Symbol Matrix., H=Channel matrix, X=Transmitted symbol Matrix, N=Noise Matrix. To solve for x, we need to find a matrix W which satisfies $WH = I$, The Zero Forcing (ZF) detector for meeting this constraint is given by,

$$W = (H^H)^{-1} H^H \quad (4)$$

Where, W=Equalization Matrix and H=Channel Matrix. This matrix is known as the Pseudo inverse for a general m x n matrix. [9], [10]. Theoretically ZF sounds efficient but in practical situations, it is very susceptible to noise as the inverse of the received noise is also applied to the signal since the channel response includes noise as depicted.

5.2 Minimum Mean Square Error Detector (MMSE)

MMSE equalizer minimizes the mean square error between the output of the equalizer and the transmitted symbol, which is a stochastic gradient algorithm with low complexity. This approach tries to find a coefficient W which minimizes the criterion,

$$E\left\{[W_{y-x}][W_{y-x}]^H\right\} \quad (5)$$

To solve for x, we need to find a matrix W which satisfies

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WH= I. The Minimum Mean Square Error (MMSE) detector for meeting this constraint is given by

$$W = [(H^H + N_0 I)^{-1} H^H] \quad (6)$$

The MMSE detector considers the noise variance when inverting the channel matrix [9]. Instead of removing ISI completely, an MMSE equalizer allows some residual ISI to minimize the overall distortion. Most of the finite tap equalizers are designed to minimize the mean square error performance metric but MMSE directly minimizes the bit error rate [10], [12].

6 Fading Channels

In recent years, theoretically and practically it is proved that it is possible to realize enormous channel capacities, much better than the point-to-point capacity given by the Shannon-Hartley law, if the environment is sufficient multipath. The majority of work to date on this area has assumed flat sub-channels composing the MIMO channel. As the aim of MIMO systems is often to increase the data transmission rate of a communication system, a wideband and hence highly time-dispersive model would be more appropriate. To properly exploit this environment to realize these capacity increases, the MIMO channel must be equalized so that the performance of any system attempting to harness the multipath can do so while maintaining a satisfactory BER performance. Assuming that the response of the MIMO channel is known at the receiver, a method to create a suitable equalizer is to analytically invert the frequency selective, or time-dispersive.

6.1 Rician Flat Fading Channel

Flat fading channels can be approximated by Rayleigh distribution if there is no line of sight which means when there is no direct path between transmitter and receiver. The received signal can be simplified as,

$$r(t) = s(t) * h(t) + n(t) \quad (7)$$

where, h(t) is the random channel matrix having Rayleigh distribution and n(t) is the additive white Gaussian noise. The Rayleigh distribution is basically the magnitude of the sum of two equal independent orthogonal Gaussian random variables and the probability density function (pdf) given by:

$$p(r) = \frac{r}{\sigma 2} e^{\frac{-r2}{2\sigma 2}} \; 0 \le r \le \infty \quad (8)$$

where, σ^2 is the time-average power of received signal. Rician channel is same as Rayliegh channel except it has the LOS (Line of sight component). In the presence of an LOS component between the transmitter and receiver, the MIMO channel may be modelled as the sum of a fixed component and a fading component and given by the equation:

$$H = \sqrt{\frac{k}{k+1}} e^{j\emptyset} H_{LOS} + \sqrt{\frac{1}{k+1}} H_{Rayleigh} \quad (9)$$

In environments where there is a dominant Line-of-Sight (LOS) path between the transmitter and the receiver, the complex Gaussian distributed fading coefficient should be modelled with a non-zero mean, giving rise to the Rician fading. Or also say that, Rayleigh fading with a strong line of sight (LOS) content is said to have a Rician distribution, or to be Rician fading [13], [14]. The Rician distribution is usually characterized by the rice factor k,

$$k = m^2/2\sigma^2 \quad (10)$$

which shows the relative strength of the direct LOS path component of the fading coefficient. The k factor is the ratio of power of specular (Line of Sight) component m to the power of the multipath (random) component σ. When $\kappa = 0$ this model reduces to Rayleigh fading and as $\kappa = \infty$ the fading becomes deterministic giving grow to an AWGN channel

6.2 Rician Frequency Selective Fading Channel

Frequency-selective fading can be viewed in the frequency domain, although in the time domain, it is called multipath delay spread. The simplest measure of multipath is the overall time span of path delays from the first pulse to arrive at the receiver to the last pulse to arrive at the receiver. When viewed in the frequency domain, a channel is referred to as frequency-selective if $f_0 < 1/Ts = W$, where the symbol rate, $1/Ts$ is nominally taken to be equal to the signal bandwidth W. Flat fading degradation occurs whenever $f_0 > W$. Here, all of the signal's spectral components will be affected by the channel in a similar manner (e.g., fading or no fading). In order to avoid ISI distortion caused by frequency-selective fading, the channel must be made to exhibit flat fading by ensuring that the coherence bandwidth exceeds the signalling rate. Narrowband channel belongs to flat fading channels, where all the frequency components of the transmitted signal behave similarly. For wideband signal, the signal bandwidth, Ws, may be significantly higher than the coherence bandwidth. Consequently, two frequency components separated by a frequency of the coherence bandwidth or beyond may behave significantly differently. Hence, wideband channels are typically frequency-selective fading channel [13], [14].

6 Simulation and Implementation

The project is designed and simulated using Matlab Software and the system parameters are based on the design and parameters of 802.11n WLAN parameters and model [8]. The aim of the proposed system is to evaluate the performance of the receivers in terms of BER Vs SNR under flat and frequency selective Rician channel and thus subsequently to achieve maximum channel capacity using MMSE detection so the parameters of the system are chosen and based on Spatial Multiplexing MIMO-OFDM 802.11n WLAN system parameters.

The proposed system shown in Fig. 3 includes the available modulation schemes like QPSK, 16-QAM and 64-QAM and is designed for basic 2×2 antenna configuration which is extended up to 8×8 Here, the MIMO techniques adopted includes Open-loop MIMO (OL-MIMO) techniques which do not require channel state information (CSI) at the transmitter. MMSE detection has primarily been considered so as to minimize the complexity associated with MIMO detection while ensuring reasonably good performance. The complete algorithm of the proposed system is shown in Fig.4.

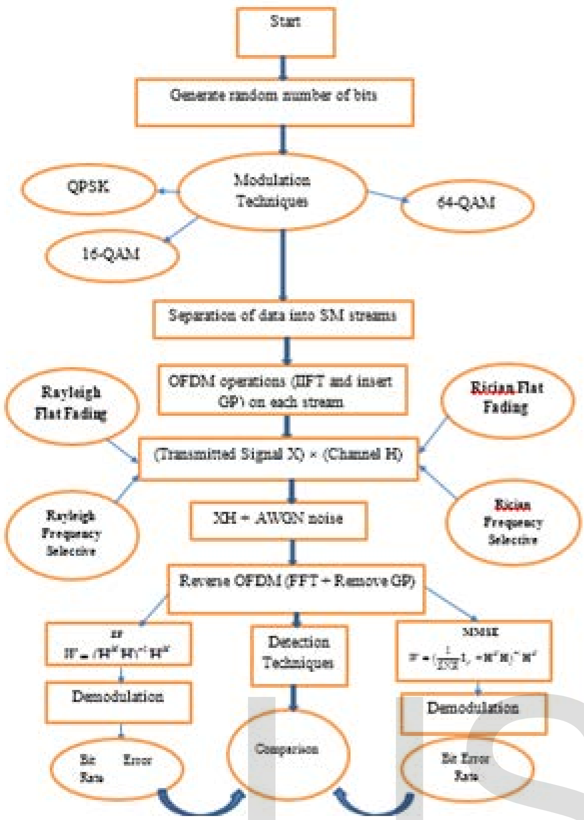

Fig.4 Complete algorithm of the proposed system

6 Results and Discussions

6.1 Performance under Rician Flat and Frequency Selective Channel

2×2 MIMO-OFDM un-coded system is considered with QPSK modulation under flat fading Rician channel and frequency selective Rician channel is considered. The performance of ZF and MMSE detectors are compared in terms of BER Vs Eb/No. Here, the k-factor is taken 3.

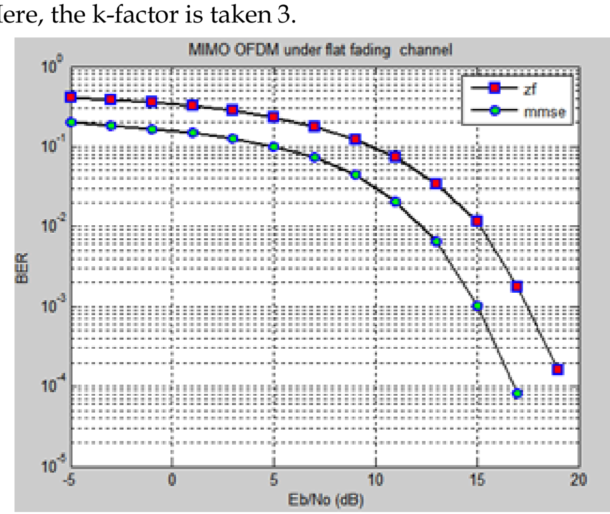

Fig.5 ZF and MMSE comparison under Rician Flat Channel

For Rician frequency selective channel, M×N uncorrelated channels are generated with uniformly distributed 6 taps for which the normalized Rician distributed channel gains are obtained over the channel length L=85.

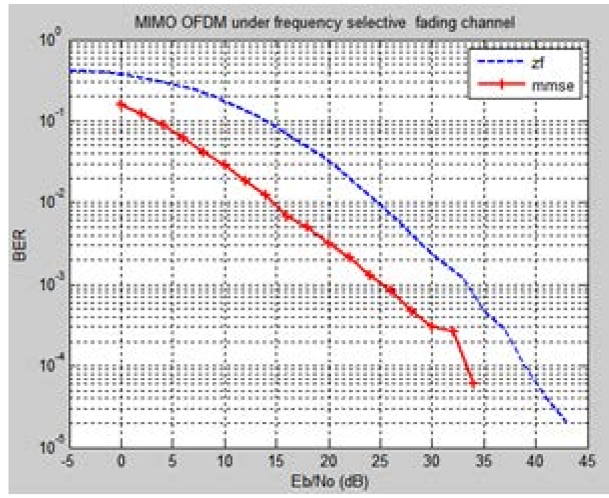

Fig.6 ZF and MMSE under Rician Frequency Selective Channel

As shown in the graph of Fig.5, under flat fading Rician channel, target BER of 10^{-3} is achieved at 15 dB with MMSE detector and at 17 dB with ZF detector. The difference between ZF and MMSE performance is 2 dBAs shown in the graph of Fig.6, under frequency selective fading Rician channel, target BER of 10^{-3} is achieved at 25 dB with MMSE detector and at 34 dB with ZF detector. The difference between ZF and MMSE performance is 9 dB.

The performance of MMSE and ZF deteriorates in Rician frequency selective channel than flat fading channel. Also the SNR gap between MMSE and ZF is 7 dB more in Rician frequency selective channel than Rician flat fading channel. In all the cases, MMSE performs better than ZF.

6.2 Performance under various modulation schemes

For 2×2 configuration, the performance of ZF and MMSE is checked under various modulation techniques, such as, QPSK, 16-QAM and 64-QAM for Rician flat and frequency selective channel for target of 10^{-3} BER.

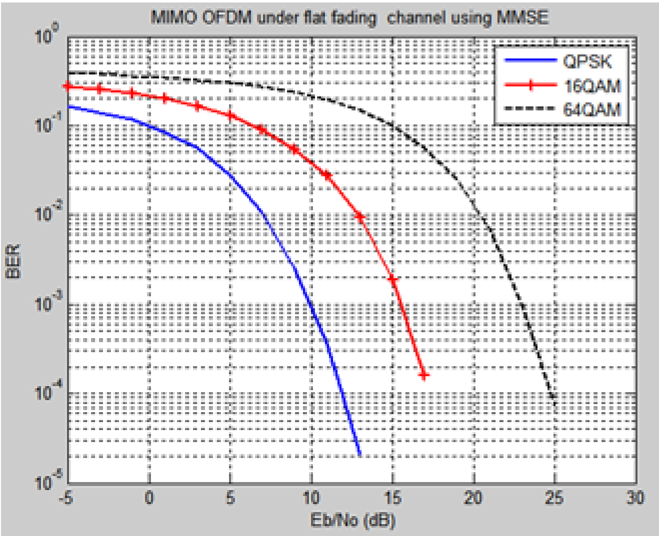

Fig.7. Modulation schemes using MMSE under Rician Flat Fading

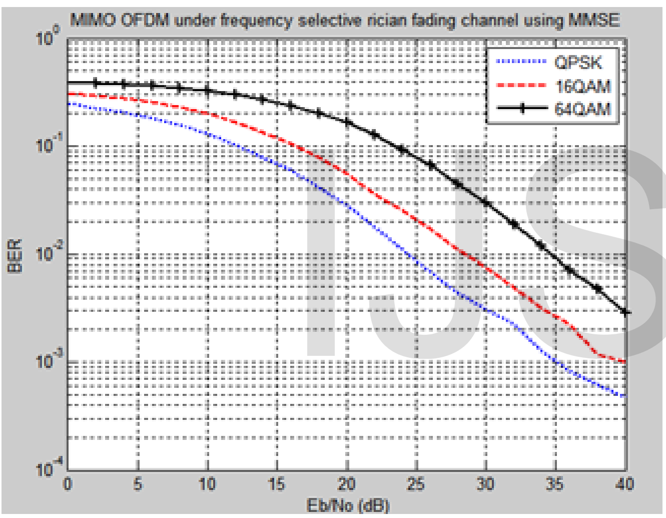

Fig.8. Modulation schemes under Rician Frequency selective Fading

Under QPSK modulation, lowest BER is achieved and 64-QAM the highest. BER increases as the order of the modulation order i.e. M increases. This increase is due to the fact that as the value of M increases distances between constellation points decreases which in turn makes the detection of the signal corresponding to the constellation point much tougher The solution to this problem is to increase the value of the SNR so, that the effect of the distortions introduced by the channel will also goes on decreasing, as a result of this, the BER will also decreases at higher values of the SNR for high order modulations. The performance of MMSE with higher modulation techniques deteriorates in Rician Frequency Selective Channel in comparison to Rician Flat Fading channel for the same target BER as shown in Fig.7 and Fig.8 and depicted in Table 1.

TABLE 1
PERFORMANCE OF MMSE UNDER RICIAN FLAT AND FREQUENCY SELECTIVE CHANNEL

At 10^{-3} BER	Rician Flat Fading	Rician Frequency Selective
Modulation Scheme	SNR in dB	SNR in Db
QPSK	11	34
16-QAM	15.5	36
64-QAM	23	43

6.3 Performance with various antenna sizes

From basic 2 × 2, the antennas configuration at the transmitter and receiver is increased equally to 4 × 4 and 8 × 8 sizes and the performance in terms of BER Vs SNR is evaluated for MMSE detector using QPSK, 16-QAM and 64-QAM modulation.

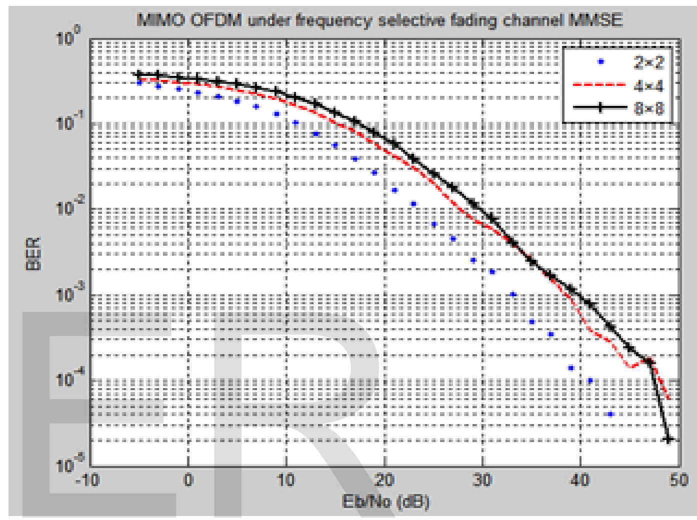

Fig.9. Different antenna sizes for QPSK modulation using MMSE under Rician Frequency Selective Channel

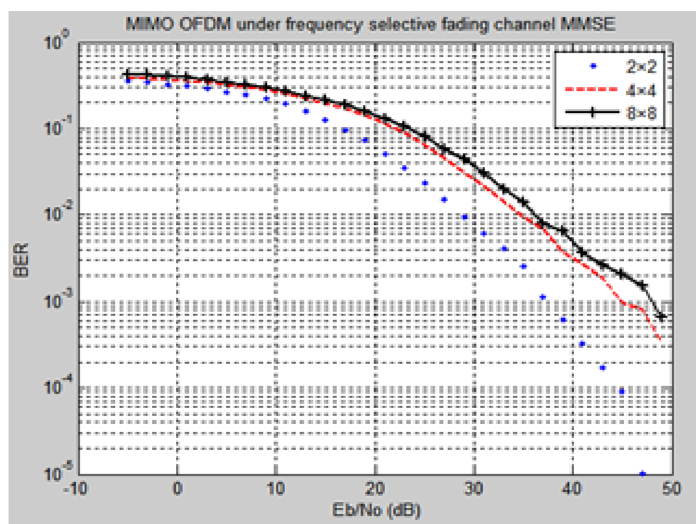

Fig.10. Different antenna sizes for 16-QAM modulation using MMSE under Rician Frequency Selective Channel

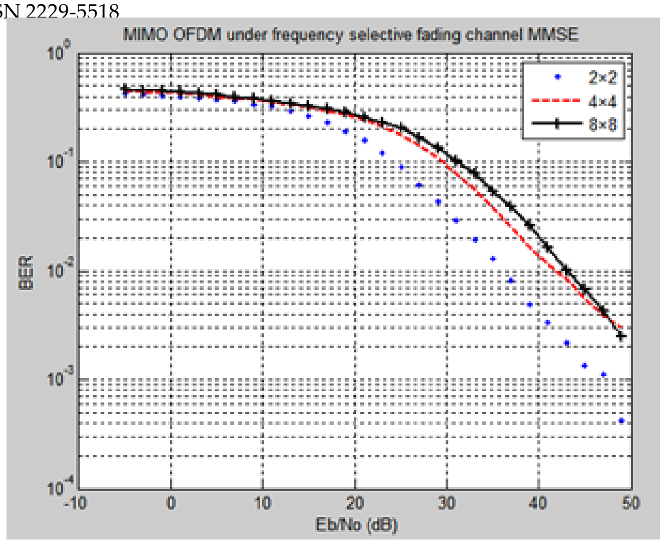

Fig.11. Different antenna sizes for 64-QAM modulation using MMSE under Rician Frequency Selective Channel

The Fig.9, Fig.10 and Fig.11 depicts that if antenna configurations are increased from 2×2 to 4×4 and similarly from 4×4to 8×8, an increment in SNR (dB) of around 2 dB to 3 dB is required to achieve same amount of BER. Thus the spectral efficiency gets doubled in case of MIMO SM technique at the expense of small amount of increment in SNR (0 to 3db). With higher antenna configuration, higher channel capacity is achieved with a small expense of SNR as depicted in Table 2. This is the benefit of spatial multiplexing and spatial multiplexing detectors.

TABLE 2
PERFORMANCE OF MMSE UNDER RICIAN FREQUENCY SELECTIVE CHANNEL FOR VARIOUS ANTENNA SIZES

At 10^{-3} BER	QPSK	16-QAM	64-QAM
Antenna configurations	SNR in dB	SNR in dB	SNR in dB
2×2	32	37	44
4×4	39	44	50
8×8	40	48	52

6 CONCLUSION

MIMO-OFDM spatial multiplexing is a promising solution to achieve high data rates and robust communication for future wireless systems. The performance of Minimum Mean Square Error (MMSE) detector is near optimal and of low complexity to achieve good SINR (signal-to-interference-plus noise) ratio. Among linear receivers, performance of MMSE is better than ZF in both, flat fading and frequency selective Rician channel environment. In real-world scenarios, MIMO channels undergoes frequency selective fading, so the performance of a system and its detector is very important to be evaluated under frequency selective channel condition. Using MMSE as a detector and QPSK as a modulation scheme, minimum BER and best performance is achieved. Increasing the modulation order will increase the BER but at the same time it will increase the capacity. Using MMSE with 64-QAM gives maximum throughput than other modulation techniques. Increasing the antenna configuration from 2×2 to 4×4 to 8×8, an increment in SNR (dB) of around 2 to 3 dB is required to achieve same amount of BER but at the same time spectral efficiency is enhanced due to multiplexing gain thus leads to an increased channel capacity.

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