Global Journal of Computer Science and Technology: E
Network, Web & Security
Volume 15 Issue 8 Version 1.0 Year 2015
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 0975-4172 & Print ISSN: 0975-4350

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

By Namrata Maharaja, Dr. B. K. Mishra & Rajesh Bansode
Thakur College of Engineering and Technology, India

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. Minimum Mean Square Error (MMSE) detector is near optimal and less complex. The performance of the proposed system is analyzed using MMSE under flat and frequency selective Rayleigh channel environment, different number of antenna configurations and various modulation techniques to provide an optimum solution.

Keywords: MIMO-OFDM, spatial multiplexing, ZF, MMSE, rayleigh channel, flat and frequency selective.

GJCST-E Classification : C.2.5

PERFORMANCEEVALUATIONOFSPATIALMULTIPLEXINGMIMOOFDMSYSTEMUSINGMMSEDETECTIONUNDERFREQUENCYSELECTIVERAYLEIGHCHANNEL

Strictly as per the compliance and regulations of:

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

Namrata Maharaja [α], Dr. B. K. Mishra [σ] & Rajesh Bansode [ρ]

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. Minimum Mean Square Error (MMSE) detector is near optimal and less complex. The performance of the proposed system is analyzed using MMSE under flat and frequency selective Rayleigh channel environment, different number of antenna configurations and various modulation techniques to provide an optimum solution.

Keywords: MIMO-OFDM, spatial multiplexing, ZF, MMSE, rayleigh channel, flat and frequency selective.

I. 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]. Evaluation of such system under Rayleigh flat and frequency selective channel for various digital modulation techniques is performed to present an optimum solution and achieve high data rates.

Author α σ ρ : Thakur College of Engineering and Technology, Mumbai, India. e-mails: mankad.namrata@gmail.com tcet.principal@thakureducation.org, rajesh.bansode1977@gmail.com

II. 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, diversity gain 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 [6].

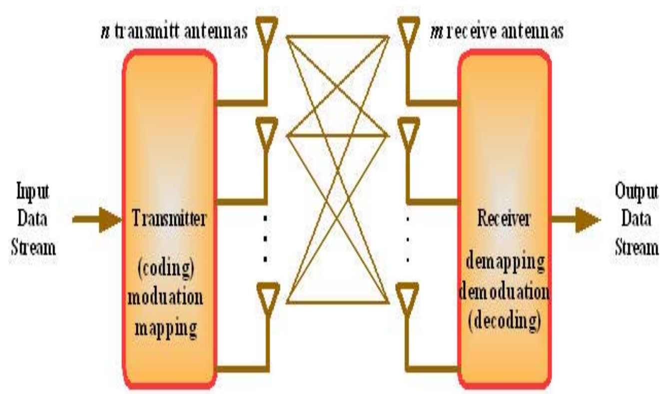

Fig. 1: MIMO system

a) 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 [7]. If the transmitter is provided with Nt antennas and the receiver has Nr antennas, the maximum spatial multiplexing order (the number of streams) is,

Global Journal of Computer Science and Technology (E) Volume XV Issue VIII Version I Year 2015

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

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

III. 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 [8].

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.

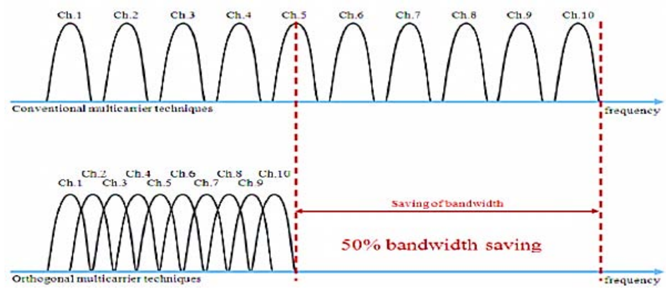

Fig. 2 : OFDM Subcarriers

IV. 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 [10]. 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.

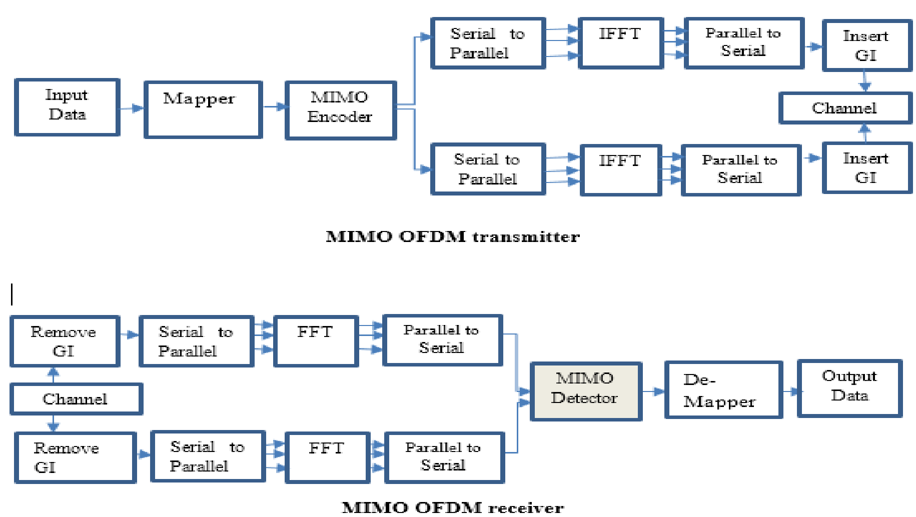

Fig. 3 : MIMO-OFDM system block diagram

The IEEE 802.11n WLAN standard is used to design the base system [11]. This standard includes MIMO- OFDM as a compulsory feature to enhance data rate. Initial target was to achieve data rates in excess of 100 Mb/s. However, current WLAN devices based on 802.11n Draft 2.0 are capable of achieving throughput up to 300 Mb/s utilizing two spatial streams in a 40 MHz channel in the 5 GHz band [12].

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.

V. Linear Detection

a) Zero forcing(ZF) detector

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,

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

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,

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

Where, W=Equalization Matrix and H=Channel Matrix. This matrix is known as the Pseudo inverse for a general m x n matrix. [13]-[14]. 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.

b) Minimum Mean Square Error(MMSE) detector

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,

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

To solve for *x*, we need to find a matrix *W* which satisfies WH= I. The Minimum Mean Square Error (MMSE) detector for meeting this constraint is given by

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

The MMSE detector considers the noise variance when inverting the channel matrix. 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 [7]-[17].

VI. Fading Channels

In recent years, theoretical and practical investigations have shown that it is possible to realize enormous channel capacities, far in excess of 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 diversity 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.

a) Rayleigh Flat Fading

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 ,

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

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:

$$p(r) = \frac{r}{\sigma 2} e^{\frac{r2}{2\sigma 2}} \quad 0 \leq r \leq \infty \qquad (8)$$

where, σ^2 is the time-average power of received signal [18]-[19]

b) Rayleigh Frequency Selective Fading

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 [18]-[19].

VII. Results & Discussions

a) Performance under flat and frequency selective Rayleigh Channels

A 2×2 MIMO-OFDM uncoded system is considered with QPSK modulation under flat fading Rayleigh channel and the performance of ZF and MMSE detectors are compared in terms of BER Vs Eb/No.

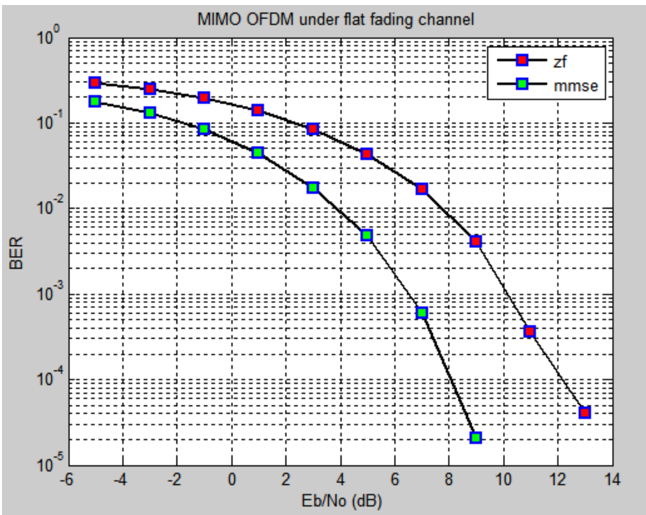

Fig.4 : ZF & MMSE under flat fading Rayleigh channel

At SNR of 7dB, the target of 10^{-3} BER is achieved using MMSE detector and the same is achieved at the SNR of 10 dB with ZF detector as shown in Fig.3. The MMSE detector considers the noise variance when inverting the channel matrix thus it has a better estimate to that of the ZF, which amplifies the channel noise. Thus, by suppressing both the interference as well as the noise components MMSE is a superior receiver than ZF which only suppresses the interference components. OFDM divides a communications channel into a number of equally spaced frequency bands called a subcarrier which carries a portion of the desired information and is transmitted in each band. OFDM converts a wide band frequency selective channels in to multiple flat channels. Here, the channel used is Rayleigh flat fading channels. Hence, the performance is better of the MIMO-OFDM system close to as in AWGN channel.

For the same input scenario, the performance of the system is evaluated under Rayleigh Frequency Selective Channel. An M×N uncorrelated Rayleigh channel with uniformly distributed 6 taps over the channel length L=85 is considered.

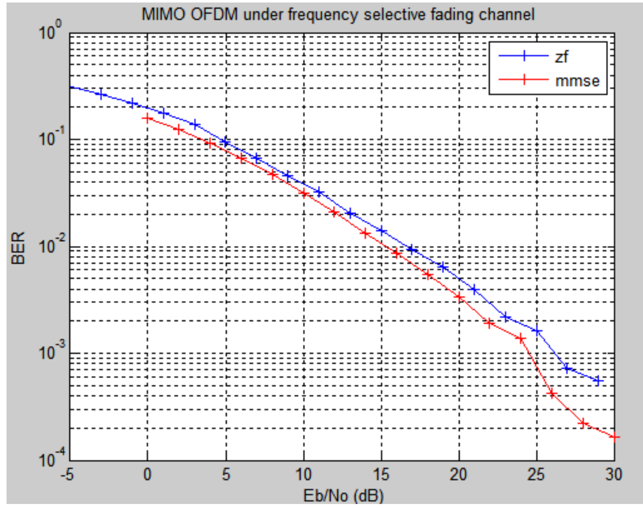

Fig.5 : ZF & MMSE under frequency selective Rayleigh fading channel

System capacity could be linearly increased with the number of antennas when the system is operating over flat fading channels. In real situations, multipath propagation usually occurs and causes the MIMO channels to be frequency selective. OFDM transforms the frequency-selective fading channels into parallel flat fading sub channels. MIMO OFDM significantly simplifies MIMO baseband receiver processing by eliminating the need for a complex MIMO equalizer. The performance of MMSE receiver though degrades under frequency selective channel as compared to flat fading channel. At SNR of 24dB, the target of 10^{-3} BER is achieved using MMSE detector and the same is achieved at the SNR of 27 dB with ZF detector as shown in Fig.3. In this case also, MMSE performs better than ZF.

b) Performance with 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 Rayleigh flat and frequency selective channel for target of 10^{-3} BER.

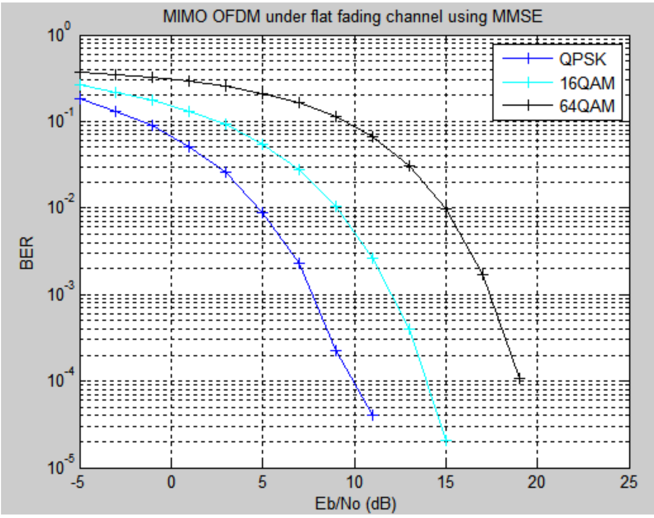

Fig. 6 : MMSE performance for different modulation schemes under flat fading Rayleigh Channel

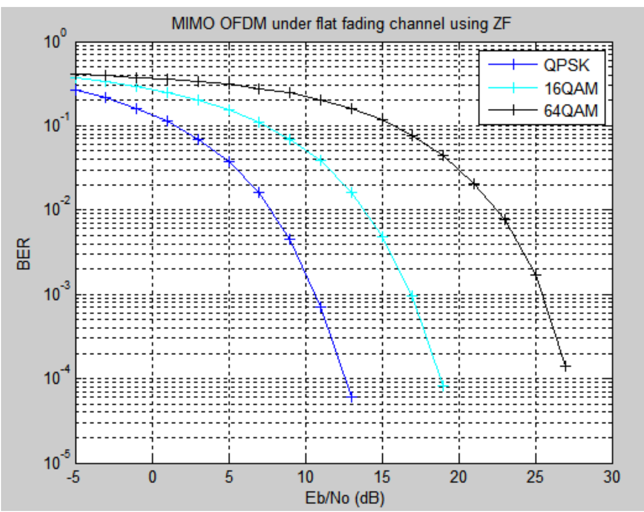

Fig. 7 : ZFperformance for different modulation schemes under flat fading Rayleigh Channel

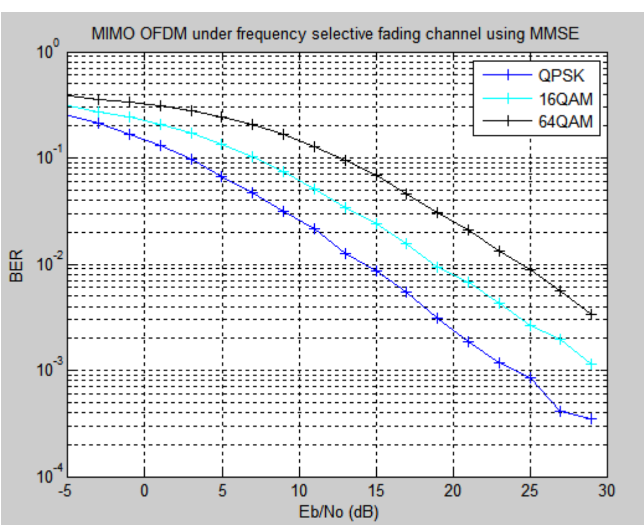

Fig. 8 : MMSE performance for different modulation schemes under frequency selective Rayleigh Channel

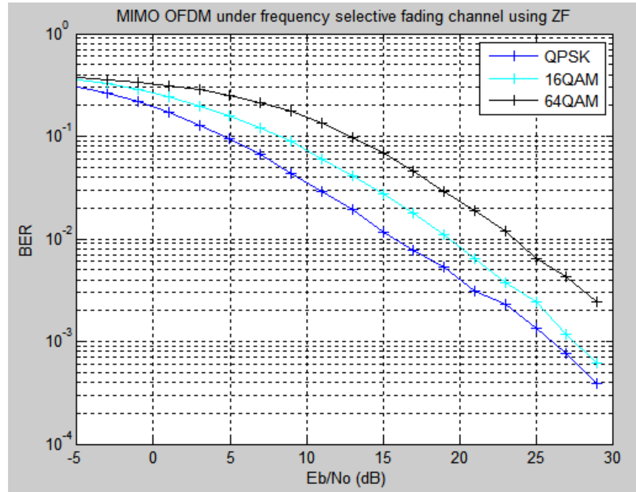

Fig.9 : ZF performance for different modulation schemes under frequency selective Rayleigh fading Channel

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

In all the cases though, the performance of MMSE is better than ZF.

At 10^{-3} BER	Rayleigh Flat Fading (ZF)	Rayleigh Flat Fading (MMSE)	Rayleigh Frequency Selective (ZF)	Rayleigh Frequency Selective (MMSE)
Modulation Scheme	SNR in dB	SNR in dB	SNR in dB	SNR in dB
QPSK	11	7	26	24
16-QAM	16.5	11.5	27.5	29
64-QAM	26	17	33	31

Table.1 : MMSE and ZF performance for different modulation schemes under frequency selective and flat Rayleigh Channel

a) Performance with different antenna configurations

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 and 64-QAM modulation.

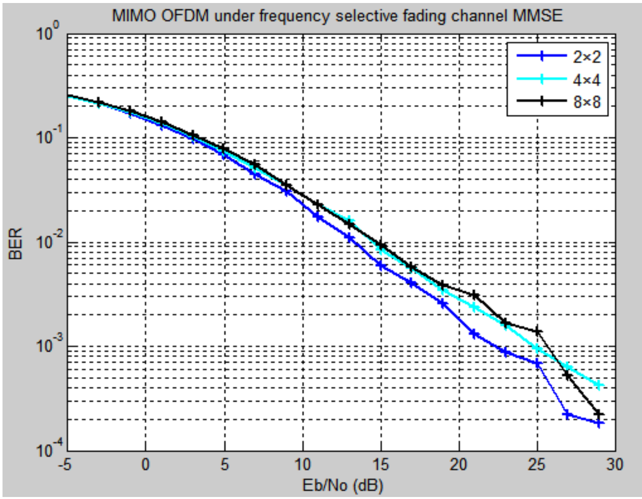

Fig. 10 : Performance for different antenna configurations using QPSK modulation with MMSE

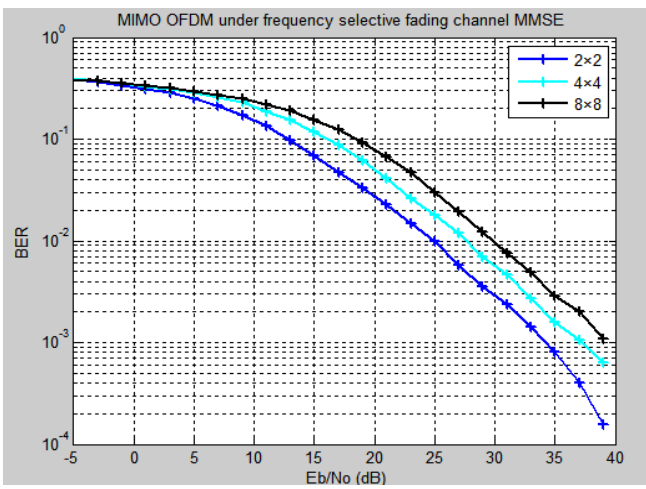

Fig. 11: Performance for different antenna configurations using 64-QAM modulation with MMSE

Figure 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 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. This is the benefit of spatial multiplexing and spatial multiplexing detectors

VIII. 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 by 3 dB in all conditions. BER of 10^{-3} is achieved at 7 dB SNR under Rayleigh flat fading environment and 24 dB under Rayleigh frequency selective 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 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.

References Références Referencias

1. A. J. Paulraj, D. A. Gore, R. U. Nabar and H. Bolcskei, "An Overview of MIMO Communications—A Key to Gigabit Wireless", *Proc. IEEE*, vol. 92, pp. 198-218, Feb. 2004.
2. A. Lozano and N. Jindal, "Transmit diversity Vs Spatial Multiplexing in Modern MIMO Systems", *IEEE Trans. on Wireless Comm.*, vol. 9, pp.186-197, Jan. 2010.
3. A. G. Gravalos, M. G. Hadjinicolaou and N Qiang "Performance Analysis of IEEE 802.11n under different STBC rates using 64 QAM", presented at the *IEEE International Symposium on Wireless* Pervasive Computing, San Juan, Feb 5-7, 2007.
4. M. Jiang and L. Hanzo, "Multiuser MIMO-OFDM for next generation Wireless Systems—A Key to Gigabit Wireless", *Proc. IEEE*, vol. 95, pp. 1430-1469, Jul. 2007.
5. Y. S. Cho, J. Kim, W. Y. Yang, C. G. Kang, *MIMO OFDM Wireless Communication with Matlab.* Singapore: John Wiley and Sons, 2010
6. N. T. Hieu, N. T. Tu, A. N. Duc and B. H. Phu (2013 August). FPGA Design and Implementation of MIMO-OFDM SDM Systems for High Speed Wireless Communications Networks. *International Journal of Research in Wireless Systems*. vol. 2, pp. 26-33.
7. J. Penketh and M. Collados, "Performance and Implementation Complexity of Receiver Algorithms for MIMO-OFDM Based Wireless LAN Systems", in *IEEE Int. Symp. Personal, Indoor and Mobile Radio Communications*, 2004, vol. 3, pp.1522-1526.
8. Y. Chen, J. Zhang and D. Jayalath, "Multiband-OFDM UWB vs IEEE802.11n: System Level Design Considerations" in *IEEE Conf. Vehicular Technology,* Melbourne, Australia, 2006, pp. 1972-1976.

9. P. Samundiswary and S. Kuriakose, "BER Analysis Of MIMO-OFDM using V-Blast System For Different Modulation Schemes", in *IEEE Int. Conf. Computing Communications and Network Technologies*, Coimbatore, 2012, pp. 1-6.
10. I. Medvedev, B. A. Bjerke, R. Walton, J. Ketchum, "A Comparison of MIMO Receiver Structures for 802.11n WLAN- Performance and Complexity", in *IEEE Int. Symp. Personal, Indoor and Mobile Radio Communications*, Helsinki, 2006, pp.1-5.
11. S. Lee, J. Lee and S. C. Park, "Performance and complexity comparison of the Schemes to increase data rate in MIMO-OFDM with various Decoding Schemes", in *Asia Pacific Conf. Communications*, Busan, 2006, pp.1-4.
12. R. V. Nee, V. K Jones, G. Avater, A. V. Zelst, J. Gardener and G. Stelle. (2006, June). The 802.11n MIMO-OFDM standard for Wilress LAN and beyond. *Springer International Journal on Wireless Personal Communications*. vol.37. pp.445-453.
13. R. Pierre and F. Hoefel, "IEEE 802.11n: Om Performance with MMSE and OSIC Spatial Division Multiplexing Transceivers", in *IEEE Int. Symp. Wireless Communication Systems*, Paris, 2012, pp.376-380.
14. W. Zhang, X. Ma, B. Gestner, D. Anderson. (2009, Feb 10). Designing Low complexity Equalizer for Wireless Syatems. *IEEE Communication Mag*. pp. 56-62.
15. C. Michalke, E. Zimmermann and G. Fettweis, "Linear MIMO Receivers vs. Tree Search Detection: A performance Comparison Overview", in *IEEE Int. Symp. Personal, Indoor and Mobile Radio Communication*, Helsinki, 2006, pp.1-7.
16. A. Zanella, M. Chiani and M. Z. Win, "MMSE Reception and Successive Interference Cancellation for MIMO Systems With High Spectral Efficiency", *IEEE Trans. Wireless Comm.*, vol. 4, pp. 1244-1253, May. 2005.
17. E. Suikkanen, J. Ketonen and M. Juntti, "Detection and channel estimation in 8×8 MIMO-OFDM", in *IEEE Int. Conf. Personal, Cognitive Radio Oriented Wireless Networks and Communications*, Oulu, 2014, pp. 299-304.
18. J. G. Proakis, Digital Communications. McGraw Hill series in electrical and computer engg.,1995
19. T. S. Rappaport, Wireless Communications, Principles and Practice, Pearson Edu., vol.1, 2002

Global Journals Inc. (US) Guidelines Handbook 2015

www.GlobalJournals.org