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Performance Analysis of ZF-SIC and MMSE Equalizers for MIMO System in the Presence of Alpha(α)-MU(μ) Fading Channel

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Abstract: Fifth generation cellular networks are the key systems which are being deployed in the near future. The enabling technology, Multiple-In Multiple-Out (MIMO) wireless technology makes use of varied number of antennas at the transmitter and multiple antennas at the receiver for transmission of the information in cellular communication systems. This MIMO technology acts as a foundation and aims to improve the spectral efficiency and throughput in fifth generation wireless communication systems. The most common parameters we come across in wireless communications are Bit error rate (BER), Inter Symbol Interference (ISI), Signal to Noise ratio (SNR), Signal to Interference plus Noise ratio (SINR), Successive interference cancellation (SIC), etc. The primary objective of this paper is to improve the BER performance by minimizing SIC using Zero Forcing– Successive Interference Cancellation (ZF-SIC) with optimal ordering and suppress the noise enhancement prevailing in the channel by an extended detection technique, Minimum Mean Square Error (MMSE). As a purpose to improve the channel capacity, MIMO systems are utilized for transmission purpose lately. Quadrature Phase Shift Keying (QPSK) modulation technique is utilized in the system model, which makes use of the same channel bandwidth and carries twice the information and alongside Binary Phase Shift Modulation Technique (BPSK) is also made use of in the system model to provide a comparative analysis among the detection techniques and modulation techniques discussed previously. MIMO fading distribution such as alpha(α)- mu (μ) fading channel distribution is taken into consideration to generate a channel model.
The simulated results are analysed and compared with respect to their BER performance taking into account diverse values of alpha(α), mu(μ) parameters. The significance of this paper is to provide a channel efficient, minimized successive interference cancellation at the receiver end in order to make the system more reliable, less complex, interference negligent and simultaneously improve the BER performance. In the near future, these MIMO techniques form a foundation to produce more reliable systems with high terahertz bandwidth. This indeed will open to more seamless communication in various fields of technology.
Keywords: MIMO, ZF-SIC, MMSE, BER, ISI, α – μ fading.

I. INTRODUCTION

In 2020, the fifth generation (5G) wireless communication is the next big advancement of the wireless technology domain in the world of global connectivity engineered to greatly improve the responsiveness and speed of the communication network. Communications with numerous antennas appear to arrive as the latest development for high-speed wireless communications, as one of the most novel technologies to deliver improved performance [1,2]. The enabling technology which yields to the growth in wireless communication networks is the Multiple input multiple output (MIMO) technology. In the previous literature there exist many detection techniques which have been adapted to study BER performance of the MIMO system. A successive Interference Cancellation Zero-Forcing Equalizer (SIC-ZFE) was proposed to provide Inter symbol Interference (ISI) free communications over the ISI MIMO channels which do not require a long guard period. A flat fading Rayleigh multipath channel was assumed [3]. To reduce the computational complexity, a successive interference cancellation process was proposed in SIC-ZFE, instead of legacy method of element by-element interference cancellation mechanism. The methods under study were Maximum Likelihood detector, Zero Forcing (ZF) and the ZF-SIC equalizers in the presence of a classical fading channel distribution. It was noticed that the computational complexity of Maximum likelihood detector increases as the number of antennas increases for a given MIMO system [4]. The drawbacks of the ZF equalizer were observed, as a result an enhanced detector, MMSE Minimum mean square error equalizer acts as tradeoff between interference cancellation and noise reduction in the channel. A MMSE estimator was proposed to minimize the mean square error between actual signal and the detected signal [5,6].

In general, the most widely used fading channel is the Rayleigh fading distribution channel [7]. The major drawback with such distribution channels is that they are precise and accurate only when the scattering is homogenous in nature. This impractical approach can be combated by generalized fading channels such as alpha(α)-mu(μ) fading channel which has been designed in this paper. In this paper a more reliable, flexible, heterogenous, generalized fading channel distribution is taken into consideration to study the system performance. This generalized fading channel distribution model describes the small-scale variations of the signal in a highly diffuse scattering environment [8]. The non-linearity of the propagation medium are given by **'α'** and multipath clustering, 'μ' parameters [9]. Currently, there is continuous demand for reliable communication systems with the following factors: lower latency, high data rate and easily accessible. This brings about an urge to produce diverse channel modelling distributions which are used to evaluate the system design and thereby improve the system performance.

II. SYSTEM MODEL

We consider a 2 x 2 MIMO system, where a stream of bits x_1, x_2, x_3,...x_n are generated and transmitted across the Tx transmitter in form of groups. The system model helps to create a link among all the components involved to fulfill the need of communication. The prominent sections in any wireless communication system are the transmitter, channel, and the receiver. Fig. 1 gives an illustration of the various methodologies and techniques adapted to devise the MIMO system model. It is a three-stage process which outlines the BPSK/QPSK modulation schemes adapted at the transmission section followed by a heterogenous, generalized α-μ fading channel distribution and the receiver section at the end stage. Performance analysis of the system using ZF-SIC and MMSE robust detection techniques are performed at the end stage of the wireless communication link. In the system model designed, the communication between the transmitter and receiver happens via a fading channel, α-μ fading channel. This fading distribution is robust in nature to study the behavior of the system model in a heterogenous, non-linear enviornment.

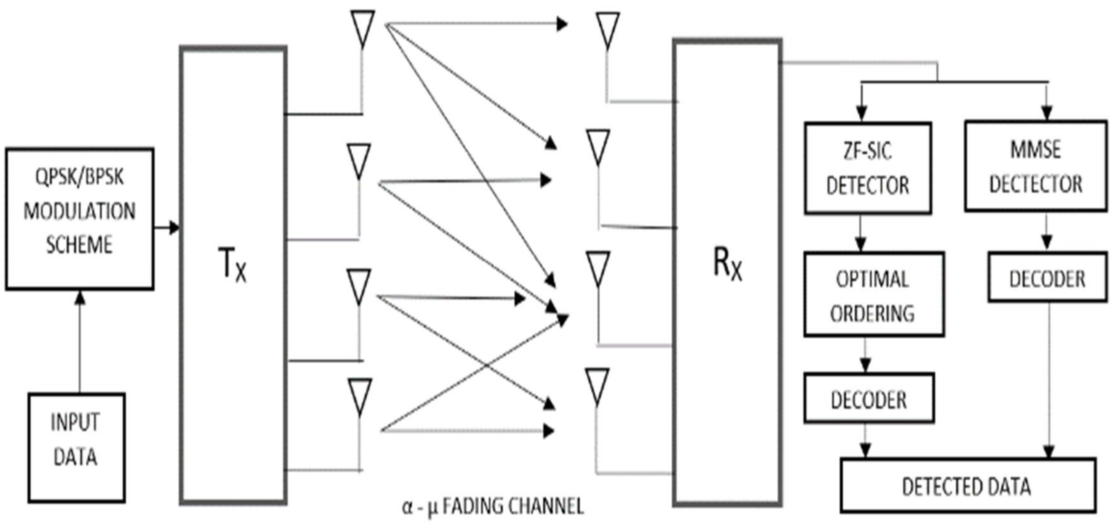

Fig.1. MIMO System Model

The generalized matrix expression of the received signal is given in equation (1)

$$y = H * x + n \quad (1)$$

1) * represents convolution
2) H is the channel matrix, which represents the channel impulse response of the α-μ fading channel
3) x is the input signal
4) n is the additive white Gaussian noise

Dimensionally

a) y is $N_r \times 1$ matrix
b) H is $N_r \times N_t$ matrix
c) x is $N_t \times 1$ matrix
d) n is $N_r \times 1$ matrix

III. CHANNEL DISTRIBUTION AND MIMO DETECTION TECHNIQUES

There are multiple MIMO detection techniques for suppression and cancellation of interference. The low complex detection techniques, ZF-SIC and MMSE haven been adapted, and the system performance is analyzed in the presence of α-µ fading channel.

A. ALPHA(α)-MU(µ) Fading Channel

In the generalized alpha(α)- mu(µ) distribution it is considered that the received signal at any given point constitutes of n number of multipath components (MPCs) and the received envelope is represented as a non-linear expression having a power parameter, α. The condition for the power parameter is **α>0.** The other parameter used in the fading distribution is µ, which indicates the cluster size [9]. The channel matrix H is generated with the help of α and µ parameters. The step wise methodology for the implementation of α-µ fading channel distribution is given in the form of an algorithm [10]. The algorithm for alpha-mu is given in Fig. 2.

1) function H=alpha_mu_channel (alpha, mu, N_r, N_t)
2) a_inv=1/alpha
3) n=zeros(N_r , N_t);
4) For i=1:2*mu
5) n=n+randn(N_r, N_t)^2 ;
6) end
7) n=n/(2*mu);
8) phi=2*pi*rand(N_r, N_t);
9) H=(n.*a_inv).exp(j*phi);

Fig.2. alpha-mu algorithm

B. Zero Forcing With Successive Interference Cancellation Equalization

The successive interference cancellation (SIC) is a modification of the Zero forcing detector. In ZF detector, the main function is to detect each symbol separately and decode them one by one. The ZF detector suppresses the other symbols received and only the desired output is present at the receiver [3]. This is done with the help of a pre-processor W, expressed as

$$H^{+} = W_{ZF}^{H} = (H^{H}H)^{-1}H^{H} \qquad (2)$$

The estimated symbols are represented in terms of the preprocessor which is

$$\hat{x} = W_{ZF}^{H}\, y = H^{+} y = x + H^{+} n \qquad (3)$$

The ZF-SIC detector subtracts the effect of one of the estimated symbols ($\hat{x}$) from the received matrix y using the nearest neighborhood rule. ZF-SIC focuses on cancelling the interference from the previously detected symbols, as a result this reduces the interference and improves the effective (SINR) Signal to Noise Interference ratio [11].

QR decomposition method is used to implement the ZF-SIC detector. H matrix is decomposed into Q and R matrices, which is given in the equation below

$$H = QR \qquad (4)$$

The generalized Q matrix is given as.

$$Q = \begin{bmatrix} \vdots & \vdots & \vdots & \vdots \\ q_1 & q_2 & \cdots & q_{N_r} \\ \vdots & \vdots & \vdots & \vdots \end{bmatrix}$$

The matrix R is a upper triangular matrix with dimensions N_t x N_t and is expressed as

$$R = \begin{bmatrix} R_{11} & R_{12} & \cdots & R_{1N_{t-1}} & R_{1N_t} \\ 0 & R_{21} & \cdots & R_{2N_{t-1}} & R_{2N_t} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & \cdots & 0 & R_{N_{t-1}N_{t-1}} & R_{N_{t-1}N_t} \\ 0 & \cdots & 0 & 0 & R_{N_tN_t} \end{bmatrix}$$

The received signal is expressed in terms of Q and R and is given as

$$y = Q^H r = Q^H(Hx + n) = Q^H(QRx + n) = Rx + Q^H n \quad (5)$$

The received signal at the receiver end for estimation purpose is given as

$$y_{N_T-1} = R_{N_T-1N_T-1}\, x_{N_T-1} + R_{N_T-1N_T} x_{N_T} + z_{N_T-1} \quad (6)$$

The algorithm for successive interference cancellation is given [12] in Fig. 3

1) Perform a QR decomposition of H = QR
2) Computing y in the form of

$$y_i = \sum_{j=1}^{N} R_{ij}\, x_j + 2i$$

3) Detect i= N_t, estimation of (x_{N_t})
4) Removal of x_{N_t} from y_{Ni} and successively detect x_{N_t} -1 from Eq (6)
5) If $\hat{x}_{N_t} = x_{N_t}$, estimation is correct.

Fig.3. ZF-SIC algorithm

C. Minimum Mean Square Error Equalization

In MMSE detector, this technique makes use of mean square error between the detected signal and the actual signal and minimizes the difference. The pre-processor present in MMSE is like that of the Zero-forcing technique, but in addition the MMSE algorithm reduces the noise enhancement that is generated in the channel as well, which the ZF detector does not. In the MMSE algorithm the noise in channel is also considered in the equalization process [6, 11]. The generalized matrix expression of the received signal is expressed as

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (7)$$

Where,
y_1, y_2 are the received bits
x_1, x_2 are the transmitted bits
n_1, n_2 are noise present at the receiver
$h_{11}, h_{12}, h_{21}, h_{22}$ are the characteristics of the channel
MMSE introduces an estimator which minimizes the difference between the detected symbol and the actual signal. The estimator is given as

$$E\{[W_{y-x}][W_{y-x}]^H\}$$

The pre-processor (W) in the MMSE equalization process is given as N_0I, this represents the noise component present in the channel. It is represented as

$$W = [H^H H + N_O I]^{-1} H^H \quad (8)$$

The estimated pre-processor output is given as

$$\hat{x} = W_{MMSE}^H\, y = [H^H H + N_O I]^{-1} H^H y \quad (9)$$

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The MMSE detection algorithm is given in Fig.4

1) Compute the pre-processor W using Eq (8)
2) Pre-multiply the receiver matrix by the pre-processor W.
3) The pre-processor output is given by $\hat{x} = W.y$
4) Estimation of the transmitted bit stream using de-correlation technique.

Fig.4. MMSE algorithm

IV. RESULTS AND DISCUSSION

The BER performance analysis of QPSK and BPSK of a MIMO system employing over alpha(α)–mu(μ) fading channel distribution has been carried out. In this chapter, first a random binary sequence of 0's and 1's were generated, where the total number of input bits are 10^6. A comparative study of the modulation schemes BPSK and QPSK has been done in the simulations. Each of the generated bits underwent the modulation schemes mentioned above. A pair of two symbols are grouped together and sent in one time slot across the transmitter. These symbols are then multiplied with the channel and white Gaussian noise is added. Equalization of the received bits using ZF-SIC and MMSE algorithms has been done. Later, MRC followed by hard decision coding is performed to find the number of error bits in case of ZF-SIC with optimal ordering. The same process is repeated for various values of E_b/N_0 and the simulations for various values of alpha(α) and mu(μ) are plotted [13]. A comparative study is provided taking into consideration BPSK, QPSK modulation schemes and ZF-SIC and MMSE equalizers.

Fig 5-8 show the BER over α- μ fading channel for a 2 x 2 MIMO system using ZF-SIC technique for QPSK and BPSK modulation schemes using different α and μ values.

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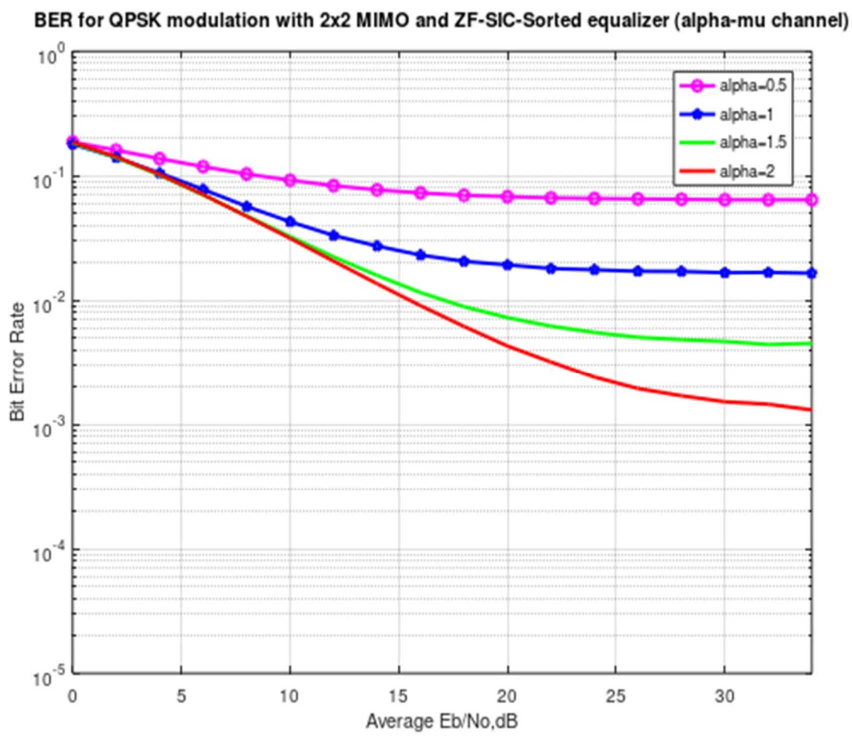

Fig. 5. BER performance of ZF-SIC detector in 2 x 2 MIMO system using QPSK modulation for different values of α

In Fig.5, as the average E_b/N_0(dB) increases the BER rates for corresponding α values 0,5, 1, 1.5, 2 decreases, indicating the effect of α parameter on the system performance. The value of μ=3 is kept constant for the above simulations. It can also be observed that initially the BER difference for the α values is not largely distinguishable, but from 15dB onwards there is a clear gap in the BER curves as each curve is getting steeper with an increase in E_b/N_0 values.

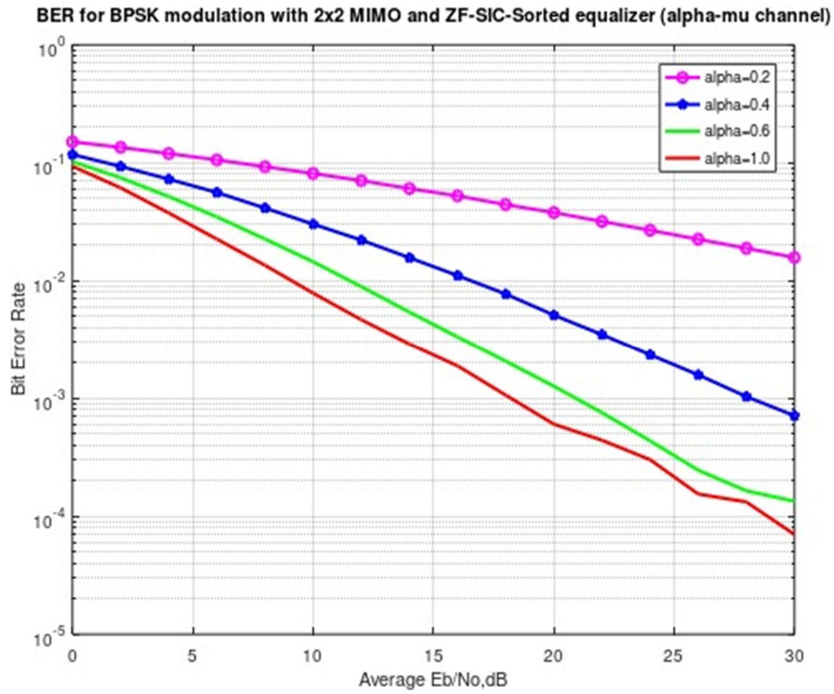

Fig. 6. BER performance of ZF-SIC detector in 2 x 2 MIMO system using BPSK modulation for different values of α

Fig. 6 shows that when fading parameter α increases the BER gets reduced, implying an enhancement in the system performance. The plot depicts the BER change for α values 0.2, 0.4, 0.6, 1 keeping μ=3 constant. When compared to Fig. 5 the BER for BPSK modulation is lower, indicating greater suitability for wireless communications.

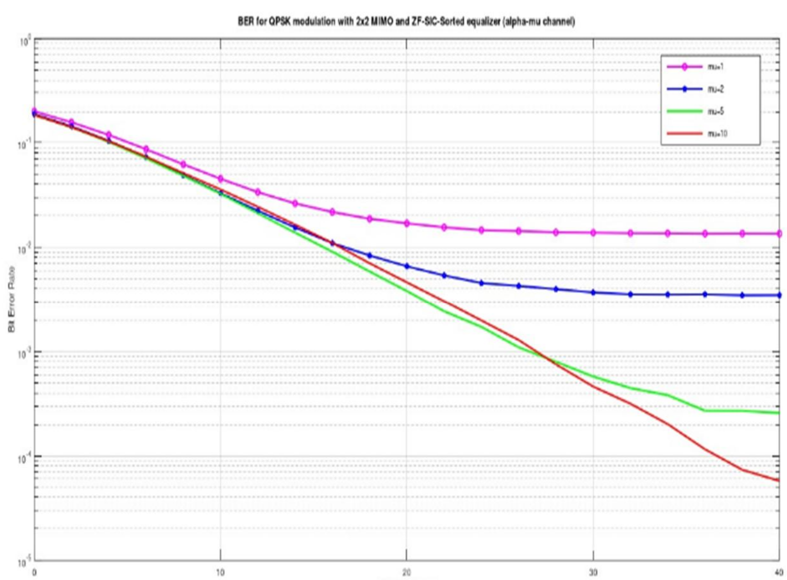

Fig. 7. BER performance of ZF-SIC detector in 2 x 2 MIMO system using QPSK modulation for different values of μ.

Fig. 7 depicts BER performance for different values of μ= 1, 2, 5, 10 and α=2 constant. In the generalized fading channel distribution, μ signifies the cluster size. The variation in μ has a great impact on the BER performance which is observed from the simulations above. As the μ value increases from 1 to 10 the BER drastically decreases. Upon comparison with Fig. 5, μ has greater impact on BER than α parameter.

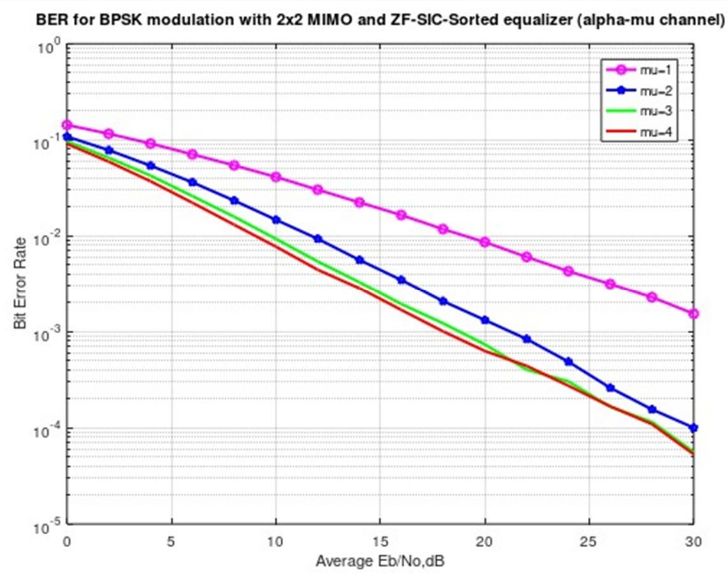

Fig. 8. BER performance of ZF-SIC detector in 2 x 2 MIMO system using BPSK modulation for different values of μ.

In Fig. 8, the graphs are obtained by varying the values of μ in an increasing order by a factor of 1. it is clearly observed that the lowest BER is noticed for highest values of cluster size, μ=4. Thereby the system performance is improved. Upon comparing Fig. 5-8, for ZF-SIC equalizer it is derived that higher value of μ, keeping α value comparatively small is most suitable for a refined system model.

Fig. 9-12 depict the BER for Average E_b/N_0(dB) over α-μ fading channel using MMSE equalizer.

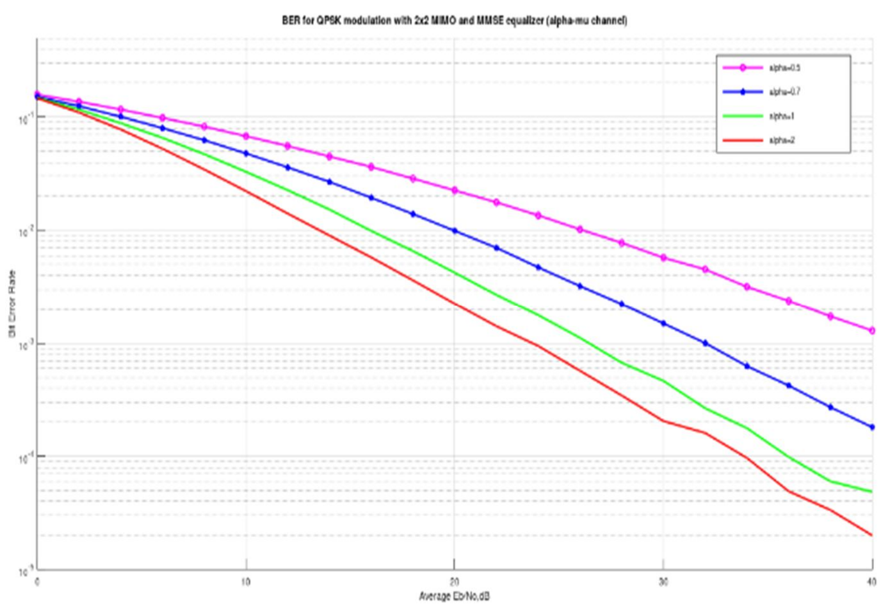

Fig. 9. BER performance of MMSE detector in 2 x 2 MIMO system using QPSK modulation for different values of α

In Fig. 9, the BER significantly decreases with an increase in α value, keeping μ=2 constant. The BER for α=2, μ=2 tends to 10^{-5}. The reduction in BER reveals an increase in SNR values. This proves that MMSE is a better detector than ZF-SIC, thereby showing better SNR and SINR values.

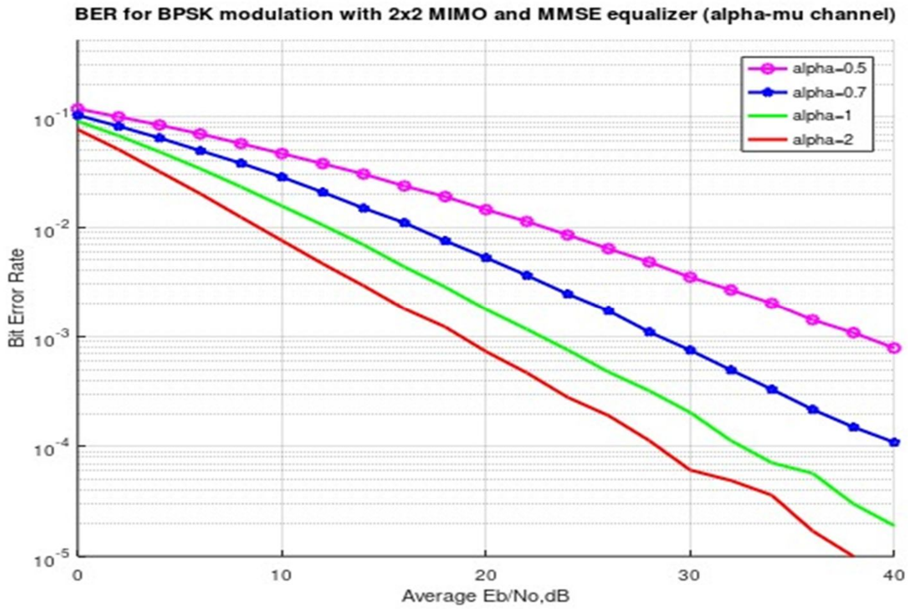

Fig. 10. BER performance of MMSE detector in 2 x 2 MIMO system using BPSK modulation for different values of α.

Fig. 10 shows the BER for various values of α over average E_b/N_0(dB) ranging from 0 to 40dB. The BER values decrease evidently with an increase in α value. As the average E_b/N_0 increases for corresponding values of α there is significant gap in BER, indicating an improvement in system performance. The BER values are lower for BPSK modulation in comparison with Fig. 9.

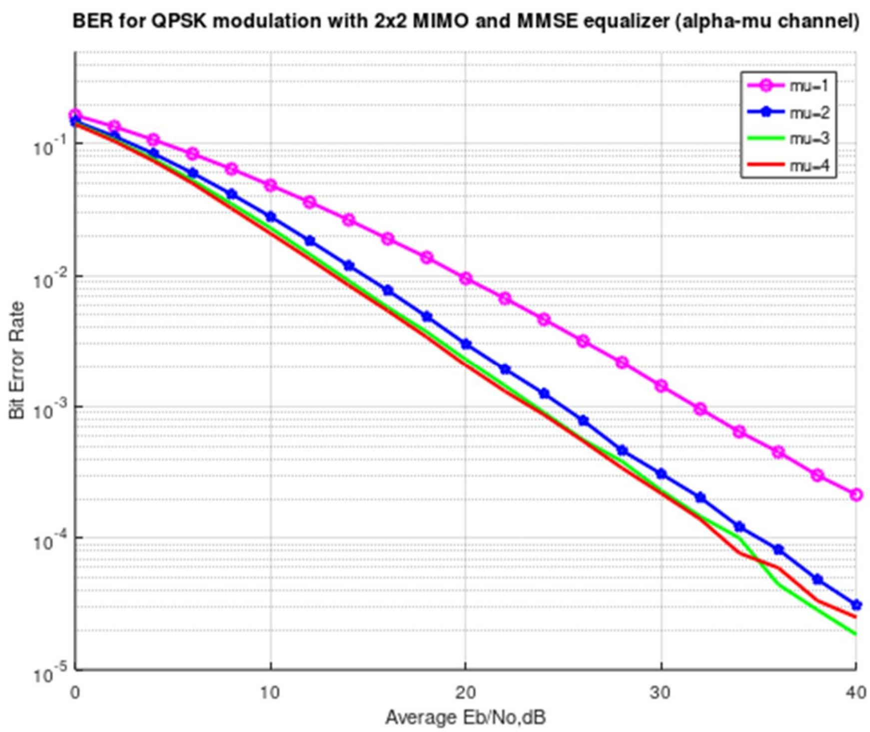

Fig. 11. BER performance of MMSE detector in 2 x 2 MIMO system using QPSK modulation for different values of μ

Fig. 11 shows the decrease in BER as the value of μ increases from 1 to 4. This lowering of BER values depict the degree of severity of fading of the channel. As the cluster size increases, the degree of fading is decreased consequently.

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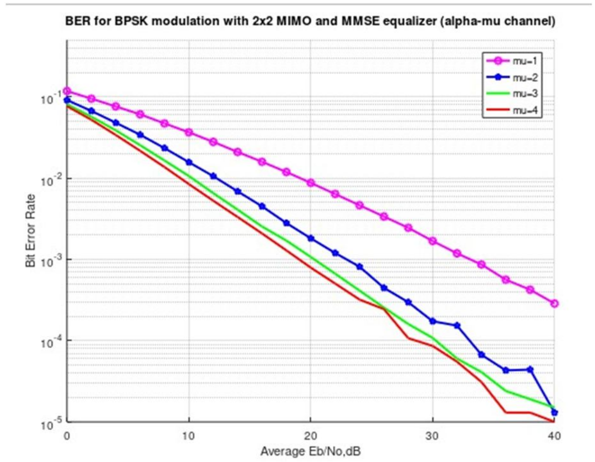

Fig. 12. BER performance of MMSE detector in 2 x 2 MIMO system using BPSK modulation for different values of μ

In Fig. 12, the BER values lower to 10^{-5}, as the cluster size increases and with an increase in E_b/N_0(dB) values. The most suitable technique to suppress the interference and noise generated at the channel and receiver are the MMSE equalizer and the importance of α-μ fading channel which acts as a heterogenous, flexible channel distribution which can be adapted to present day high frequency bandwidth applications.

V. CONCLUSION

This paper provides a comparative analysis of BER performance for different values of alpha(α) and mu(μ) using ZF-SIC and MMSE equalizers. The performance of a MIMO system is determined by its Bit Error Rate (BER). The common factors which effect the BER performance are interference and fading caused in the channel which leads to degradation of the signal. As a result, low complex, flexible equalizers and heterogenous fading channels are utilized in this paper to simulate optimal results thereby enhancing the productivity of wireless communication. The importance of alpha(α) and mu(μ) parameters is observed from the simulated results. These parameters help in controlling the fading caused by the channel and consequently decrease the BER performance which results in an increase in SINR and SNR values. Thus, higher SNR values and low BER values exhibit an improvement in the MIMO system model. From the simulated results it can be deduced that the performance of the 2 x 2 MIMO system is superior when an MMSE equalizer is used when compared to ZF-SIC equalizer. Another observation made from the results are that as the channel parameters (α, μ) increase there is a clear decrement in BER which points out the significance of alpha(α)-mu(μ) fading channel. These parameters help in restraining the fading caused due to multipath propagation of the signal. MIMO technology provides a foundation to the latest generation of wireless mobile communications and helps to build a reliable, spectral efficient, high data rate wireless communication network.

VI. FUTURE SCOPE

The most recent mm Wave innovation and Tera Hertz bandwidth are the open examination issues which are right now existing. Channel estimations of mm Wave is a significant worry because of the powerful properties of the environment. Improvement of summed up engendering channel models thinking about multilink displaying, high exactness estimations and proliferation conditions is yet an open exploration issue. The rise of MIMO extends the chances to the development of Massive MIMO frameworks, which shapes a structure for the present-day fifth generation correspondence frameworks.

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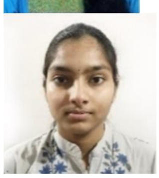

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