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Channel Capacity Enhancement of Different Fading Channels using Hybrid Algorithm in MIMO-OFDM System

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Abstract: The growing demand for increased channel capacity in wireless communication has been rapidly increased due to increase in multimedia services. The combination of MIMO with OFDM is regarded as a promising solution for next generation wireless communication system. A hybrid algorithm is applied on the MIMO-OFDM system to enhance the capacity of different fading channels. The simulation has been carried out in MATLAB 2010a using different antenna arrangements over Rayleigh, Rician and Nakagami fading channels. BER performance is also compared for different modulation techniques.

Keywords: MIMO (Multiple Input and Multiple Output), OFDM (Orthogonal frequency Division Multiplexing), iterative water filling algorithm, SVD (Singular Value Decomposition), EVD (Eigen Value Decomposition), SNR (Signal to Noise ratio), channel capacity and BER (Bit Error Rate).

I. INTRODUCTION

The wireless communication is growing day by day which creates the demand for high speed, reliable and spectrally efficient communication over wireless medium. The next generation wireless communication systems are expected to provide high data rates for high quality multimedia services. To achieve this requirement several wireless technologies for transmission have been introduced such as MIMO (Multiple Input and Multiple Output), OFDM (Orthogonal Frequency Division Multiplexing), MC-CDMA (Multi Carrier Code Division Multiple Access) and so on. [1]

Wireless communication system face high level of ISI (Inter Symbol Interference) which originates from multipath fading and inherent delay spread. A multicarrier based technique such as OFDM can be used to extenuate ISI to improve capacity and spectral efficiency in a wireless system. In addition MIMO is a promising technique to increase the performance of a communication system by using a number of antennas at the transmitter and receiver with acceptable BER (Bit Error Rate). [7] MIMO system uses fading to increase the system capacity which is considered as the problem in communication system.[1] So as to enhance the capacity of different fading channels the MIMO and OFDM systems are combined to form a hybrid system called as MIMO-OFDM system. MIMO–OFDM is considered as a key technology in IEEE802.11n for WLAN standards (Wireless Local Area Network), IEEE 802.16a for WiMAX standards (Worldwide Inter-operability for Microwave access), LTE (Long Term Evolution), 4G and many more. The use of MIMO-OFDM into these standards makes it possible to get increased data throughput and range required by many devices without any increase in transmission power and bandwidth. To further enhance the capacity of different fading channel a hybrid algorithm combination of IWFA (Iterative Water Filling Algorithm), SVD (Singular Value Decomposition) and EVD (Eigen Value Decomposition).

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II. MIMO-OFDM SYSTEM MODEL

MIMO is in combination with OFDM is widely used now-a-days because of its best performance in terms of channel capacity and high data rates. By adopting MIMO-OFDM technology indoor wireless system could reach data rates up to several hundred of Mbps and achieve spectral efficiency of several tens of bits/sec/Hz.

OFDM is a multicarrier modulation technique. The basic principle of OFDM is to split high data rate stream into a number of low data rate stream so that lower data rate can be transmitted simultaneously over a number of subcarrier. [7] Due to lower data rate of subcarrier the symbol rate is increased and therefore the dispersion caused by the multipath propagation is decreased. The orthoganality of all sub carriers make interference negligible. [3] MIMO system utilizes space multiplexing by using multiple antennas both at the transmitter and receiver to enhance the efficiency. In an N subcarriers MIMO-OFDM system, the individual data streams are first passed through an OFDM modulator. Then resulting symbols are launched simultaneously and passed through the transmit antennas. In the receiver side, the individual received signals passed through OFDM demodulator. The output of the OFDM demodulator are decoded and arranged to get the desired output. [9]

The MIMO-OFDM system with fading is considered i.e. wireless channel undergoes three different fading environments are Rayleigh fading, Rician fading and Nakagami fading. MIMIO-OFDM system is considered in which source is equipped with $\mathrm{N_t}$ transmit antenna and receiver is equipped with $\mathrm{N_r}$ receiver antenna. [12] In MIMO system transmitter sends multiple streams by multiple transmit antenna. The transmitted streams passed through a channel matrix which consists of all $\mathrm{N_t\,N_r}$ paths between the $\mathrm{N_t}$ transmit antenna and $\mathrm{N_r}$ receive antenna. Then the receiver gets the received signal vectors by multiple receive antennas and decoded the received signal vectors into original information. [5]

$$Y= HX + n \qquad (1)$$

Here Y is received signal vector y= $[y_1, y_{2,\dots} y_{N_r}]^T$is $N_r \times 1$ vector, X is transmitted signal vector

x= $[x_1, x_2, \dots, x_{n_t}]^T$ x is $N_t \times 1$ vector, n [1×n] is noise factor n and H is channel matrix is n×n vector,

$$\mathrm{H}=\begin{bmatrix} \mathrm{h}_{1,1} & \cdots & \mathrm{h}_{1,\mathrm{N_t}} \\ \vdots & \ddots & \vdots \\ \mathrm{h}_{\mathrm{N_{r,1}}} & \cdots & \mathrm{h}_{\mathrm{N_r,N\,t}} \end{bmatrix}$$

Spatial multiplexing techniques make the receiver very complex so therefore MIMO systems are typically combined with OFDM system, where problem created by multipath is handled efficiently.

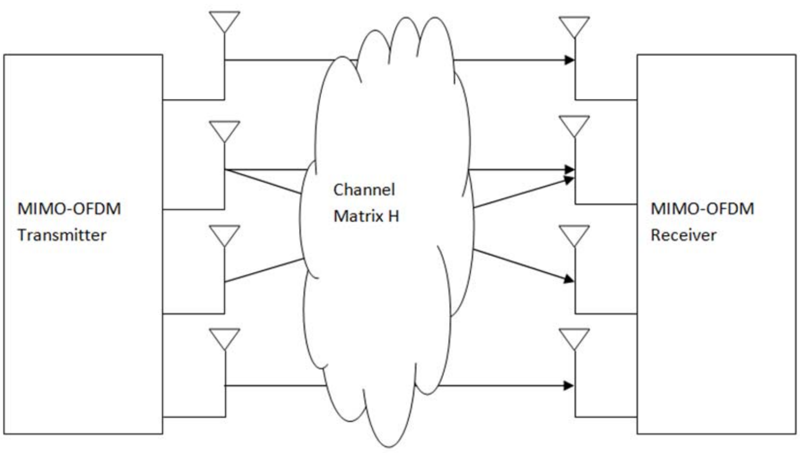

Fig.1 Basic MIMO-OFDM system with 4 transmitting and 4 receiving antennas

In proposed system model 4×4 MIMO system is used i.e. number of transmit and receive antenna is 4 and different arrangement of antennas are 1×1, 2×2, 2×3, 3×2, 4×4.

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III. FADING CHANNELS

Fading channel is a communication channel comprising fading. In wireless systems fading may occur due to multipath propagation .The presence of reflectors and obstacles in the path of propagation causes multipath propagation, which creates multiple paths for transmitted signal. As a result, receiver receives superposition of multiple copies of transmitted signal. Each signal copy will experience differences in attenuation, delay and phase shift while travelling from transmitter to receiver. This will result in amplifying or attenuating the signal power at receiver. Sometimes fading may be deep which causes temporarily failure of communication due to several drops in the channel SNR (Signal to Noise Ratio). Mathematically, fading is a time varying random change in amplitude and phase of transmitted signal. In wireless communication system channel fading is the degrading feature. [6] In this paper, the performance analysis of MIMO-OFDM system is discussed over Rayleigh fading, Rician fading and Nakagami fading channel.

A. Rayleigh Fading

Rayleigh fading is caused by multipath reception of signal. Receiver antenna receives a large number of reflected or scattered replicas of same signal and there is no direct path between the transmitter and receiver.[4] In Rayleigh fading model the magnitude of the signal will vary randomly or fade according to Rayleigh distribution function.

B. Rician Fading

Rician fading is similar to Rayleigh fading except that there exists a line of sight (LOS) component along with the reflected wave. Rician fading is caused by partial cancellation of radio signals by itself. Then receiver receives the signal from different paths which cause multipath interference. In Rician fading LOS component is much stronger than others and amplitude gain is characterized by Rician distribution.

C. Nakagami Fading

Nakagami fading caused by multipath scattering with relatively large time delay spreads with different clusters of reflected waves. Within a cluster, the phase of individual waves are random but the time delays are approximately equal for all the wave, which results in Rayleigh distribution for signals in each cluster. The average time delay is assumed to differ between the clusters. The magnitude of received signal is characterized by Nakagami distribution.

Channel Capacity- is the measure of maximum information that can be transmitted reliably over a communication channel or maximum possible transmission rate when the probability of error is almost zero. Claude Elwood Shannon developed the following equation for the theoretical channel capacity is

$$C=B\log_2(1+SNR) \quad (2)$$

Where C is capacity of channel in terms of bits/ second, B is Bandwidth in Hertz, SNR is Signal to Noise ratio i.e. ratio of signal power to associated noise power.

In case of MIMO system Shannon capacity depends on the number of antennas and capacity is given by following equation

$$C_{MIMO}=MB\log_2(1+SNR) \quad (3)$$

Where M is the minimum of N_t transmit and N_r receive antennas which represents the number of spatial streams. In this case capacity increases logarithmically with the number of antennas. [9]

When wireless channel is under fading the capacity of system reduces significantly and capacity of system in terms of spectral efficiency (bits/sec/Hz) is

$$C= B\log_2(1+\frac{S}{N}\,|h|^2) \quad (4)$$

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Where ǀhǀ² is average channel fading gain, ǀhǀ²=HH^H , H is the channel matrix.

IV. PROPOSED WORK

To meet the requirements of high data rates for high quality multimedia services many technologies are proposed. Here MIMO system is combined with OFDM system to meet the requirements of high data rate by increasing the capacity of the system. But to further enhance the capacity of the system in terms of reduced complexity and in efficient way a hybrid algorithm is proposed which is a combination of SVD (Singular Value Decomposition), IWFA (Iterative Water Filling Algorithm) and EVD (Eigen Value Decomposition). Hybrid algorithm increases the system capacity considerably. Previously water filling algorithm and EVD method was applied to MIMO-OFDM system to increase the capacity of the system, but this hybrid algorithm has enhanced results in terms of capacity and reduced complexity. In proposed work SVD is applied to decompose MIMO channel into parallel sub SISO channels after that iterative water filling algorithm is applied which allocate total power to all sub channels according to channel needs then EVD is applied to improve the capacity of the system.

A. Singular Value Decomposition (SVD)

MIMO channels can be decomposed into parallel sub SISO channels to reduce complexity of the system. [2] SVD technique decouples the channel matrix into spatial domain similar to DFT decoupling of channel in frequency domain. SVD yields

$$H= U\sum V^h \quad (5)$$

Where H is $N_t \times N_r$ channel matrix where N_t is number of transmitting antenna and N_r is the number of receiving antenna, U and V are unitary matrices and V^h is hermitian of V. U has the dimension of $N_r \times N_r$ and V has the dimension of $N_t \times N_t$.

If $N_t = N_r$, then $\sum$ becomes a diagonal matrix. If $N_t > N_r$ then $\sum$ becomes $N_r \times N_r$ diagonal matrix followed by N_t- N_r zero column. And if $N_t < N_r$, then $\sum$ becomes $N_t \times N_t$ diagonal matrix followed by N_r-N_t zero row. This operation is called Singular Value Decomposition of H. In case where $N_t \neq N_r$, i.e. number of transmitter is not equal to number of receiver the number of spatial channel becomes restricted to minimum of N_t and N_r. In proposed algorithm 4×4 MIMO system, the number of transmitter antenna is equal to the number of receiver antenna the $\sum$ becomes the diagonal matrix of $N_t \times N_r$.

B. Iterative Water Filling Algorithm (IWFA)

As water filling algorithm is used to allocate power efficiently to all sub channels exactly in the same way as pouring water in the vessel.[3] The capacity achieving solutions has visual interpretation of pouring water over the surface given by inverse channel gain hence the name of the algorithm is Water filling or Water pouring. Water filling is used to determine the maximum power transmitted in each channel to achieve the greatest possible capacity. [4] When the transmitter had no knowledge of channel then equal power is allocated to all sub channels. But when transmitter has perfect knowledge of channel water filling theorem is applied so that the division of total power in such a way that greater portion goes to sub channel with higher gain and less or even none to channel with small gain.[8] The channel with high gain and SNR (signal to noise ratio) is given more power. As the total transmitted power of MIMO system is denoted by P_t is allocated among different channels and H is channel matrix of the system. The capacity of a MIMO system is the algebraic sum of all capacities of all the channels is given by

$$\text{Capacity}= \sum_{i=1}^{n} \log_2(1 + \text{power allocated} * H) \quad (6)$$

In order to find the optimal solution Iterative Water Filling algorithm has been proposed.

Steps involved in IWFA are:

1. Take the inverse of channel gain.
2. Water filling has non uniform structure because of inverse channel gain.

3. Initially take the sum of total power transmitted and inverse channel gain. It gives complete area in water filling is

$$P_t + \sum_{i=1}^{n} \frac{1}{H_i} \quad (7)$$

4. Deciding the initial level of water by taking average power allocated is $\frac{P_t + \sum_{i=1}^{n} \frac{1}{H_i}}{\sum \text{channel}}$ (8)

5. The power allocated to each sub channel is calculated by subtracting the inverse channel gain of each channel

6. Power allocated = $\frac{P_t + \sum_{i=1}^{n} \frac{1}{H_i}}{\sum \text{channel}} - \frac{1}{H_i}$ (9)

7. Stop iteration when power allocation value is negative.

C. *Eigen Value Decomposition (EVD)*

EVD is used to find the maximum and minimum of function involving in the system. Eigen value and Eigen vectors are the number and vector associated to square matrices and together they provide the decomposition of a matrix which analyzes the structure of matrix. Eigen values of the channel matrix directly give the gain of the sub channels in MIMO system.[10] When the transmitter knows the eigen values and eigen vectors of H matrix and noise power, system uses this information to transmit in a smarter way. After EVD the capacity of the system becomes

$$C = \sum_{i=1}^{n} \log_2\left(1 + \frac{S}{N}\lambda_i\right) \quad (10)$$

Where λ = $\lambda_1, \lambda_2, \ldots, \lambda_n$ are non zero eigen values of system. λ values are introduced in the system to get optimal value of capacity.

Steps involved in proposed work:

1. OFDM system is combined with MIMO system to enhance the capacity of the system.

2. Firstly MIMO system is created. 4×4 MIMO system is created i.e. number of transmitter antenna and receiving antenna are 4 and there are five different antenna arrangements 1×1, 2×2, 2×3, 3×2, 4×4.

3. Calculating the SNR of the channels.

4. Then hybrid algorithm is applied. Firstly SVD which decompose the MIMO system into parallel SISO (Single Input and Single Output) channels. Iterative water filling algorithm is applied in which power is allocated to all the sub channels according to SNR value. Then EVD introduces Eigen value to get optimal capacity.

5. Finally we get the enhanced results i.e. capacity of the system is increased.

V. SIMULATION RESULTS

The proposed algorithm is implemented in MATLAB. It is assumed that transmitter has perfect channel knowledge of fading channels are Rayleigh, Rician and Nakagami fading channel. The capacity of MIMO-OFDM channel has been simulated for various number of transmitter and receiver antenna using hybrid algorithm. Different arrangements of transmitting and receiving antenna are 1×1, 2×2, 2×3, 3×2 and 4×4 which are studied for different value of SNR. BER (bit error rate) performance is also studied for different modulation scheme.

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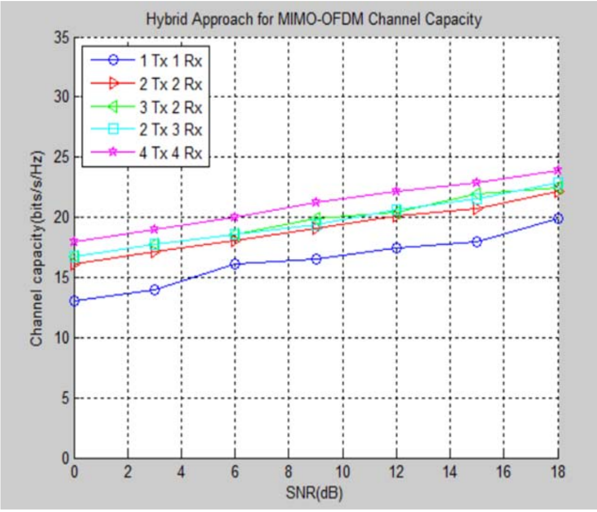

Fig.2 capacity (b/s/Hz) vs SNR (db) for Rayleigh fading channel

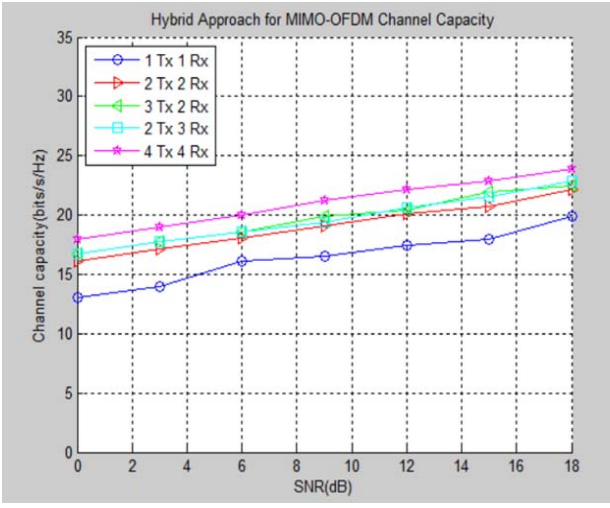

Fig.3 capacity (b/s/Hz) vs SNR (db) for Rician Fading Channel

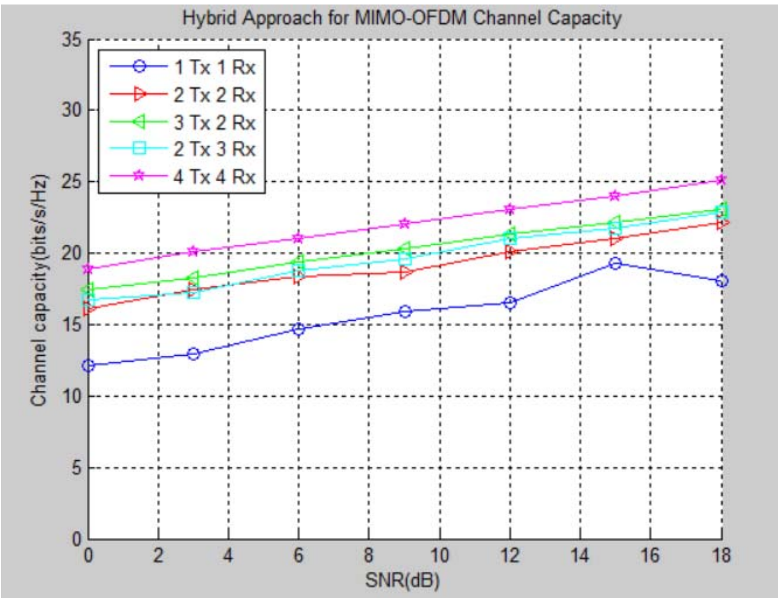

Fig.4 capacity (b/s/Hz) vs SNR (db) for Nakagami Fading channel

The above figures2, 3,4 shows the graph between channel capacity and SNR for Rayleigh ,Rician and Nakagami fading channels respectably. The graph shows that the capacity of MIMO channel increases with the increase in SNR value. This shows that 4×4 MIMO system provides better channel capacity after applying hybrid algorithm. From graph it is clear that the system performance remains almost same when the number of transmit and receive antenna is altered i.e. 2×3 and 3×2 MIMO system. When the value of SNR is low capacity varies unobvious but differs greatly for high SNR values. The simulation results show that the Rician fading channel has enhanced capacity for the proposed algorithm.

Comparison of proposed and previous work:

In proposed work hybrid algorithm which is the combination of IWFA, SVD and EVD is applied to MIMO-OFDM system to enhance the channel capacity of the system. Previously there is only WFA (Water Filling Algorithm) and EVD is applied which makes the system somewhat complex and had less capacity achieved than that of proposed algorithm. Graphs given below show the comparison of previous and proposed algorithm.

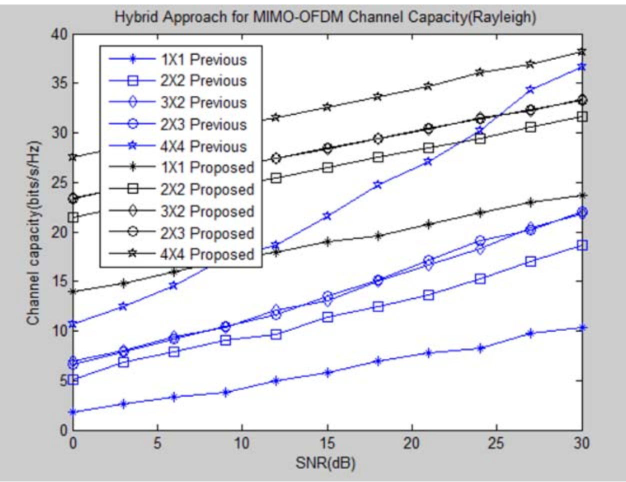

Fig.5 comparison of previous and proposed algorithm for Rayleigh fading channel

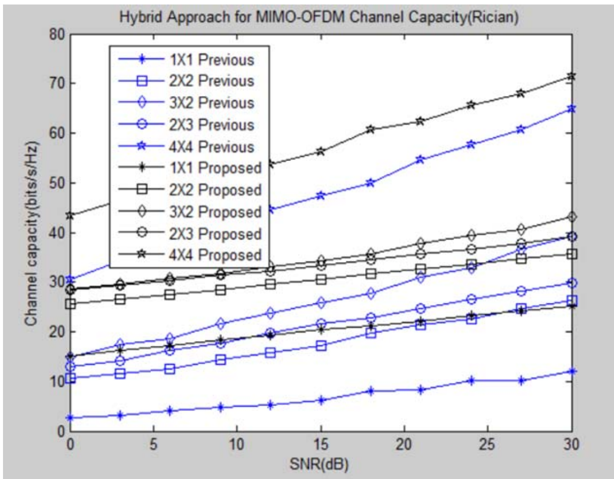

Fig.6 comparison of previous and proposed algorithm for Rician fading channel

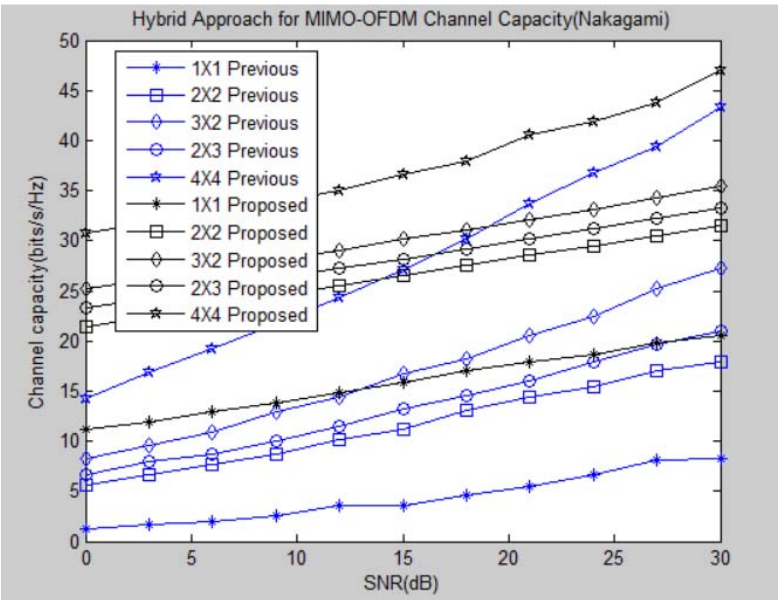

Fig.7 Comparison of previous and proposed algorithm for Nakagami fading channel

Simulation results show that proposed algorithm (hybrid algorithm combination of SVD, IWFA and EVD) has better results than previously used algorithm WFA (Water Filling Algorithm) and EVD). The results of comparison are concluded in table below for 4×4 antenna arrangement.

Algorithm used	Capacity achieved at SNR 30 dB by 4×4 antenna arrangement
Previous used algorithm(EVD and WFA)	Rayleigh fading-36.69 b/s/Hz Rician fading- 65.02 b/s/Hz Nakagami fading- 43.36 b/s/Hz
Proposed algorithm(SVD ,IWFA and EVD)	Rayleigh fading- 38.17 b/s/Hz Rician fading- 71.5 b/s/Hz Nakagami fading-47.3 b/s/Hz

Table1 Comparison of Previous and Proposed Algorithm

For next generation wireless communication the BER of the system should be negligible.

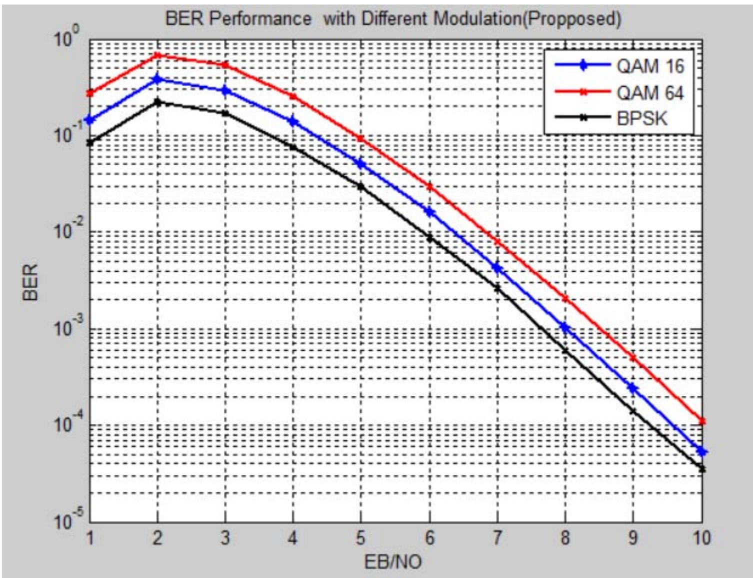

Fig.8 BER vs EB/NO for different modulation scheme

BER performance for different modulation techniques has been studied. From figure it is clear that BPSK modulation scheme has low BER i.e. achieved improved BER. Figure shows the graph between BER and EB/NO (SNR) as SNR is indirectly proportional to BER which indicates that with the increase in SNR there is decrease in the value of BER.

VI. Conclusion

MIMO OFDM system have gain popularity due to its robustness to multipath fading environment and increased capacity of the system to support high data rate multimedia services. In this paper, a hybrid algorithm is applied on the system i.e. firstly SVD is applied on the system which decompose MIMO channels into parallel sub SISO channels. IWFA is applied to allocate power to sub channels then EVD is applied which introduce λ value to get the optimal results. From the graphs it is clear that with the increase in SNR the channel capacity of the system also increases i.e. capacity of the system increases with the increase in the number of antennas at the transmitter and receiver. This paper depicts the capacity and SNR performance of MIMO-OFDM system through Rayleigh, Rician and Nakagami fading channel. The simulation result shows that Rician fading channel have enhanced results for proposed algorithm. BER performance of the system has also been studied for different modulation techniques are QAM-16, QAM-64 and BPSK. Simulation result shows that BPSK has better BER performance than other modulation techniques.

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