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Bit Loading of OFDM with High Spectral Efficiency for MIMO

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***Abstract*— The demand for high speed data services have been increasing day by day, a very promising approach is to use Multiple-Input Multiple-Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM). In this paper adaptive bit loading is applied to MIMO-OFDM, to obtain a bit and power allocation for each subcarrier assuming instantaneous channel knowledge. Relying on the available partial CSI at the transmitter, considerably improved communication is possible. Adaptive Bit Loading in MIMO-OFDM is used to maximize the transmission rate, along with desired Bit Error Rate (BER) performance in wireless systems under the constraint of fixed transmit power.**

Index terms: Bit loading, BER, MIMO, OFDM, Power allocation.

INTRODUCTION

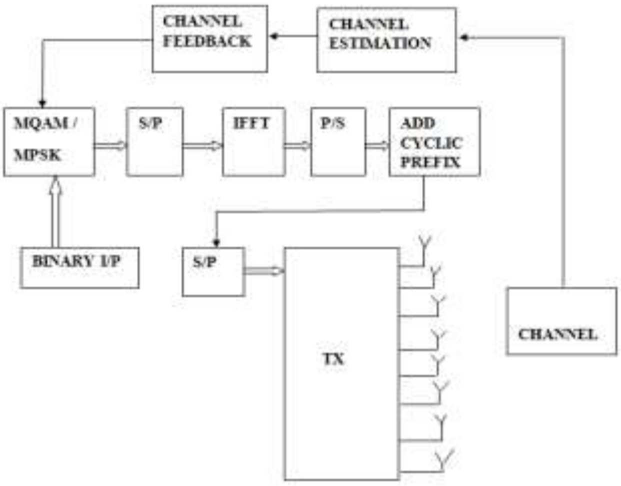
Multiple antennas can be used at the transmitter and receiver, an arrangement called a Multiple-Input Multiple-Output (MIMO) system. It has been recognized in recent years that the use of multiple transmitting and receiving antennas can potentially provide large spectral efficiency for wireless communications in the presence of multipath fading environments [1], [2].

A MIMO system takes advantage of the spatial diversity that is obtained by spatially separated antennas in a dense multipath scattering environment. To achieve higher data rates, data transmission over wireless channels needs to overcome channel fadings. It has been shown that the capacity of the MIMO system increases linearly with the number of transmit antennas by providing multiple independent parallel channels [1].Multiple-Input Multiple-Output channels exhibit strong frequency-selectivity. Orthogonal Frequency Division Multiplexing (OFDM) is a special form of multi-carrier transmission technique in which a single high rate data stream is divided into multiple low rate data streams. These data streams are then modulated using subcarriers which are orthogonal to each other.

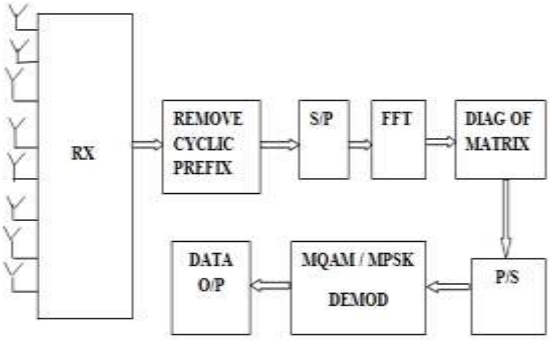
In this way the symbol rate on each subchannel is greatly reduced, and hence the effect of intersymbol interference (ISI) due to channel dispersion in time caused by multipath delay spread is reduced. OFDM is a well-established technique for high-rate communications in frequency-selective fading channels due to its easy per-subcarrier equalization in the frequency domain [1].By making all subchannels narrowband which converts frequency selective fading into flat fading. These MIMO systems can be analyzed in two different perspectives: one concerns the analysis of capacity distribution for MIMO systems, the other concerns performance evaluation in terms of error probability. All of these analyses showed in uncorrelated, as well as correlated Rayleigh-fading environments. Channel capacity is defined as the highest rate at which information can be sent with arbitrarily low probability of error. The MIMO capacity in a narrow-band Rayleigh-fading channel was analyzed.

This paper, evaluates the characteristic function (c.f.) of the capacity for MIMO Rayleigh fading channels in concise closed form with arbitrary correlation among the transmitting elements or among the receiving elements. This enables the analytical evaluation of the capacity in terms of cumulative distribution function (CDF).Bit loading technique is an effective method to achieve the high spectral efficiency. The use of bit loading technique allows a wireless system to choose the modulation level, dynamically depending on the channel state information (CSI) [3].

This paper is organized in the following manner. An overview of MIMO – OFDM system model is presented in section II; Bit loading strategy on MIMO-OFDM is discussed in section III; simulation results are reported in section IV; finally, the conclusions are given in section V.



(a) Transmitter



(b) Receiver

Fig. 1 System model for Bit Loading of MIMO - OFDM

I. MIMO – OFDM SYSTEM MODEL

The system under consideration is equipped with Nt transmit and Nr receive antennas and $Nt \leq Nr$.The block diagram of the OFDM system with MIMO signal processing and bit loading is shown in Figure1.

A.MIMO System Model

Consider a link for which the transmitting ends as well as the receiving end is equipped with multiple antenna elements. Such a setup illustrated in fig.2.The idea behind MIMO is that the signals on transmit (TX) antennas at one end and receive (RX) antennas at the other end are combined in such a way that the quality (bit-error rate or BER) and the data rate (bits/sec) of the communication for each MIMO user will be improved [4], [7].

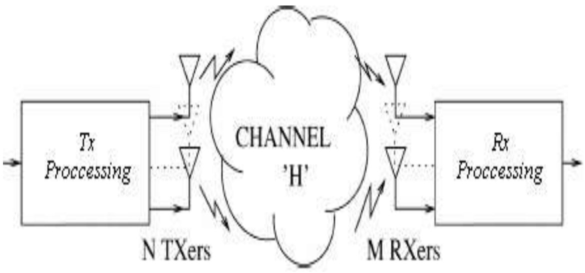


Fig. 2 Diagram of a MIMO wireless transmission system

The Nr dimensional signal y at the output of the receiving antennas in flat fading can be written as [4],

$$y = Hs + n \tag{1}$$

Where S is the N_t dimensional transmitted vector with complex components, and n is an N_r dimensional vector with zero-mean independent and identically distributed (i.i.d.) complex Gaussian entries with independent real and imaginary parts having equal variance as depicted in fig. 2. The channel matrix H, defined by

$$H = \begin{bmatrix} h_{1,1} & \cdots & h_{1,nT} \\ \vdots & \ddots & \vdots \\ h_{nR,1} & \cdots & h_{nR,nT} \end{bmatrix} \tag{2}$$

H is an (NrxNt) random matrix with complex elements $h_{i,j}$ describing the gain of the radio channel between the jth transmitting antenna and the ith receiving antenna. The jth column of H denoted by h_j, i.e., the Nr dimensional propagation vector corresponding to the jth transmitted signal.

The relation (1), denoting a transmission only over one symbol interval, is easily adapted to the case that several consecutive vectors $\{S_1\, S_2\, \ldots .S_L\}$ are transmitted (L denotes the total number of symbol intervals used for transmission) over the channel. Therefore, we arrange the transmitted, the received and the noise vectors in the matrices respectively.

$$S = [s_1 s_2 \ldots, s_L];\ Y = [y_1\, y_{2\ldots,}\, y_L\,]\,;\ N = [n_1\, n_2\ldots,\, n_L] \tag{3}$$

For uncorrelated MIMO Rayleigh-fading channels, the entries of H are identically and independently distributed (i.i.d). Gaussian R.V.'s with zero-mean, independent real and imaginary parts with equal variance. When the correlation among the receiving antennas exists, the columns H of are independent random vectors, but the elements of each column are correlated with the same mean and covariance matrix. The capacity of MIMO channels when the transmitter has N_t is given by

$$C = \log_2 det\,(I + C_x H^{'} C_w^{-1} H)\text{bps/Hz} \tag{4}$$

There are at least two strong reasons for making the Gaussian assumption of the noise. First, Gaussian distributions tend to yield mathematical expressions that are relatively easy to deal with. Second, a Gaussian distribution of a disturbance term can often be motivated via the central limit theorem.

B. OFDM Model.

An OFDM system equipped with K subcarriers, Nt transmit-, and Nr receive-antennas, signaling over a MIMO frequency selective fading channel. An OFDM system equipped with K subcarriers, N_t transmit, and N_r receive-antennas, signaling over a MIMO frequency selective fading channel. OFDM converts a frequency-selective channel into a parallel collection of frequency flat subchannels [1], [9].

The subcarriers have the minimum frequency separation required to maintain orthogonality of their corresponding time domain waveforms, yet the signal spectra corresponding to the different subcarriers overlap in frequency. Hence, the available bandwidth is used very efficiently. If knowledge of the channel is available at the transmitter, then the OFDM transmitter can adapt its signaling strategy to match the channel as shown in fig. 3.

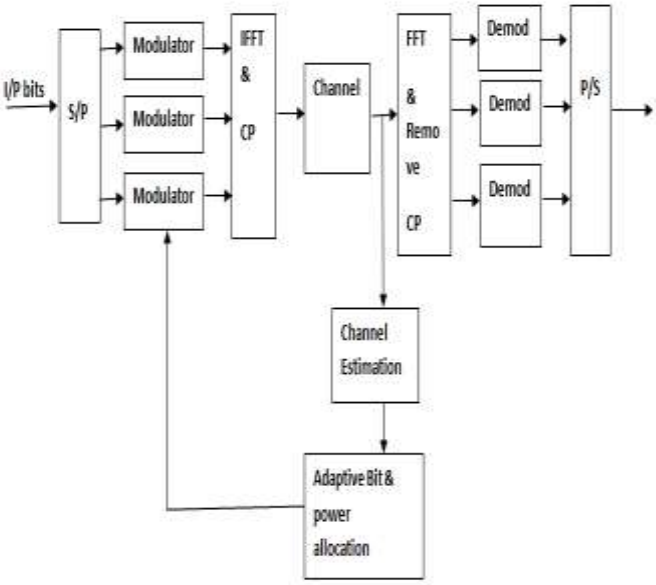


Fig. 3 OFDM System block Diagram

The variation in fading statistics among different subcarriers in some OFDM channels suggests that some good subcarriers with high channel power gain can be made to carry more bits and/or be allocated with less transmission power, and vice versa for the weak subcarriers. This Adaptive modulation is an important technique that yields increased data rates over non-adaptive modulation schemes [6]. For flat-fading multi-antenna channels, the notion of mean feedback has been introduced into account for channel uncertainty at the transmitter, given this channel knowledge, at the transmitter improves the performance.

The number of bits assigned to each subcarrier is variable based on the variability of signal to noise ratio across the frequency range. The OFDM modulation can be efficiently implemented in discrete time using an inverse FFT (IFFT) to act as a modulator and an FFT to act as a demodulator.

The cyclic prefix is added to an OFDM symbol in order to combat the effect of multipath. Intersymbol interference is avoided between adjacent OFDM symbols by introducing a guard period in which the multipath components of the desired signal are allowed to die out, after which the next OFDM symbol is transmitted.

A useful technique to help reduce the complexity of the receiver is to introduce a guard symbol during the guard period. Specifically, this guard symbol is chosen to be a prefix extension to each block. The reason for this is to convert the linear convolution of the signal and channel to a circular convolution and thereby causing the FFT of the circularly convolved signal and channel to simply be the product of their respective FFT's. However, in order for this technique to work, the guard interval should be greater than the channel delay spread.

The relative length of the cyclic prefix depends on the ratio of the channel delay spread to the OFDM symbol duration [5]. Throughout this work, the channel is assumed to be a Rayleigh fading channel, corresponding to a rich scattering environment with time variation characterized by the fade time. In the MIMO case, the channel is a matrix channel with equation

$$Y_k = H_k x_k + n_k \qquad 0 \le k \le N \tag{5}$$

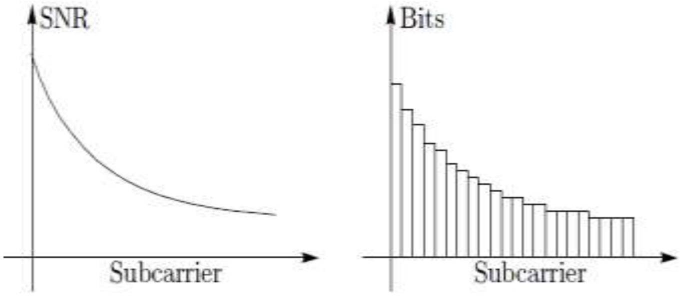
The x_k represents sub-channel N_T dimensional vector transmitted over N_T antennas. H_k is the NRxNT channel matrix for the sub-channel k and n_k is the spatial and spectral Additive White Gaussian Noise (AWGN).The sample streams are then converted from parallel-to serial for final transmission. The SVD technique can be directly applied to the MIMO channel decomposition when partial CSI knowledge at the transmit side is available.

Applying a unitary pre-filtering and post-filtering (shaping) matrix to the transmitted and received signal on the n-th subcarrier, respectively, the MIMO channel can be turned into a couple of conventional SISO channels[8], [10].

III. BIT LOADING STRATEGY ON MIMO-OFDM.

The advantage of OFDM is that each subchannel is relatively narrowband and is assumed to have at-fading. However, it is entirely possible that a given subchannel has a low gain, resulting in a large BER. Channel gain varies over different subcarriers of OFDM. If the channel variations are known at the transmitter, the number of bits and/or transmit power in each subcarrier can be chosen to maximize the total bit rate, to minimize the total transmit power, or to minimize the bit error rate (BER) of the system. These schemes are known as bit loading and power loading. An OFDM system can apply bit loading, power loading or both.

The problem of maximizing the total rate through bit and power loading has long been known and the optimal solution to power loading is called water-filling [7]. This solution is not suitable for practical systems, it is difficult to compute, and it tacitly assumes infinite granularity in the constellation size, which is not practically realizable.



(a) Channel characteristic (b) Bit allocation

Fig. 4 Illustration of Bit loading scheme

A subchannel with high SNR transmits more bits than a subchannel with low SNR, figure 4 shows a schematic picture of SNR and how the number of bits on each subchannel varies accordingly.

The adaptive loading technique employed in this paper is an efficient technique to achieve power and rate optimization based on knowledge of the subchannel gains. Only MPSK/ MQAM signal constellations are used. The adaptive loading technique employed in this paper is to optimize the power and error rate based on knowledge of the subchannel gains. Only MPSK/ MQAM signal constellations are used. Assume that every symbol carry 0, 2, 4, 6, or 8 bits, namely MPSK/MQAM are available in adaptive modulator.

Constellations with $M = 2^i$, $0 \le i \le 8$, and Gray labeling of signal points. The symbol error probability of subcarriers that use MQAM modulation is given by a uniform formula,

$$P_e^i = K_i Q(\sqrt{\frac{d_i^2/4}{N_i/2}}) \quad (6)$$

$$Q(x) = \frac{1}{\sqrt{(2\pi)}} \int_x^{\infty} \exp\left(-\frac{t^2}{2}\right) dt \quad (7)$$

where Q function is complementary Gaussian integral and d_i is the minimum Euclidean distance in the constellation. For conciseness K_i is selected as a constant number.

$$K_i = 4(1 - \frac{1}{\sqrt{M}}) \quad (8)$$

where M is the number of signal constellation and is equal to 2^{R_i}

$$R_T = \sum_{i=1}^{N} R_i = Const \quad (9)$$

where R_T is the total bits to be transmitted, R_i is the allocated number of bits to the i^{th} subcarrier.

$$P_T = \sum_{i=1}^{N} P_i = Const \quad (10)$$

P_T denotes the total power and P_i denotes the transmit power of the i^{th} subcarrier. N is the number of subcarriers.

$$\mathrm{R_i} = \frac{\mathrm{R_T}}{\mathrm{N}} + \frac{1}{\mathrm{N}} Log(\prod_{\mathrm{K}=1}^{\mathrm{N}} \frac{\mathrm{N_K}}{\mathrm{N_i^N}}) \quad (11)$$

If $\mathrm{R_i}<0$, the related channel must be in a terrible condition and not be allowed to serve transmission. Among a smaller number of channels excluding the forbidden one, equation (11) can be applied once again. This is done iteratively until all rates R_i of the remaining channels are positive. The algorithm needs to perform bit round off since the R_i obtained until now is non-integer number; the power then is distributed evenly among the remaining subcarriers.

$$P_i = SNR \frac{N_i}{2} 2^{R_i} \quad (12)$$

The algorithm needs to perform bit round off since the R_i obtained until now is non-integer number; the power then is distributed evenly among the remaining subcarriers.

IV.RESULTS AND DISCUSSION

The performance of the loading algorithms is evaluated by computer simulations. The noise power is characterized by σ^2 which is composed of additive white Gaussian noise (AWGN). The Fig. 5. Illustrate the distribution function (CDF) of the channel capacity of MIMO configuration estimated from 200 random channels. The computed CDF of the channel capacity for eight configuration:1x1,2x2,3x3,4x4,5x5,6x6,7x7,8x8.The result clearly shows that MIMO systems with more transmit and receive antennas will have CDF distribution concentrated at higher capacity or rate. For example, 2x2 MIMO systems will have capacity below 16 bits/sample with a probability of 1. However, for 3x3 MIMO systems the probability drops to only 0.05. When considering 8x8 MIMO systems, the probability falls below 0.0005. This clearly demonstrates the higher capacity achieved by MIMO – OFDM technologies.

The Shannon channel capacity depends heavily on channel bandwidth, frequency assumptions and propagation models. In MIMO channel capacity depends on how antennas should be arranged, array gain, and diversity which is shown in Fig. 6.The following figure shows capacity of MIMO system is greater than Shannon channel capacity. To demonstrate the bit allocation, an instance of the channel was generated and the optimal bit allocation found Fig. 7. shows the channel frequency response, the allocation of bits to each tone, and the Corresponding power on each tone.

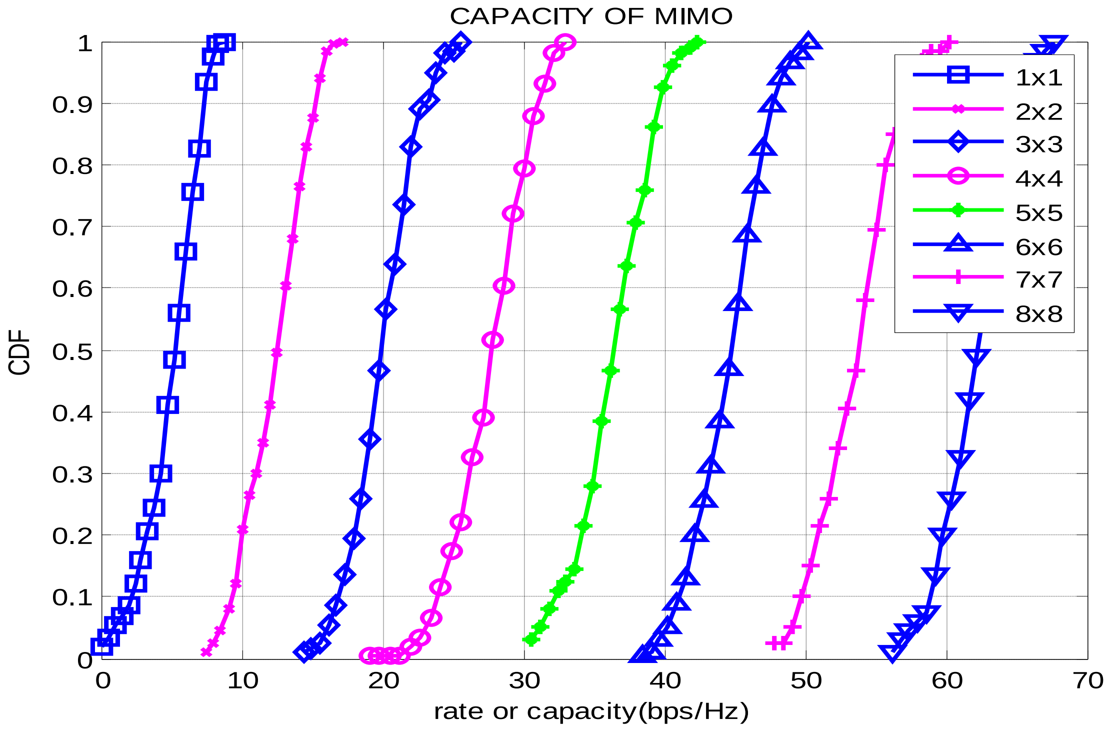


Fig. 5 Capacity of MIMO-OFDM System with partial CSI

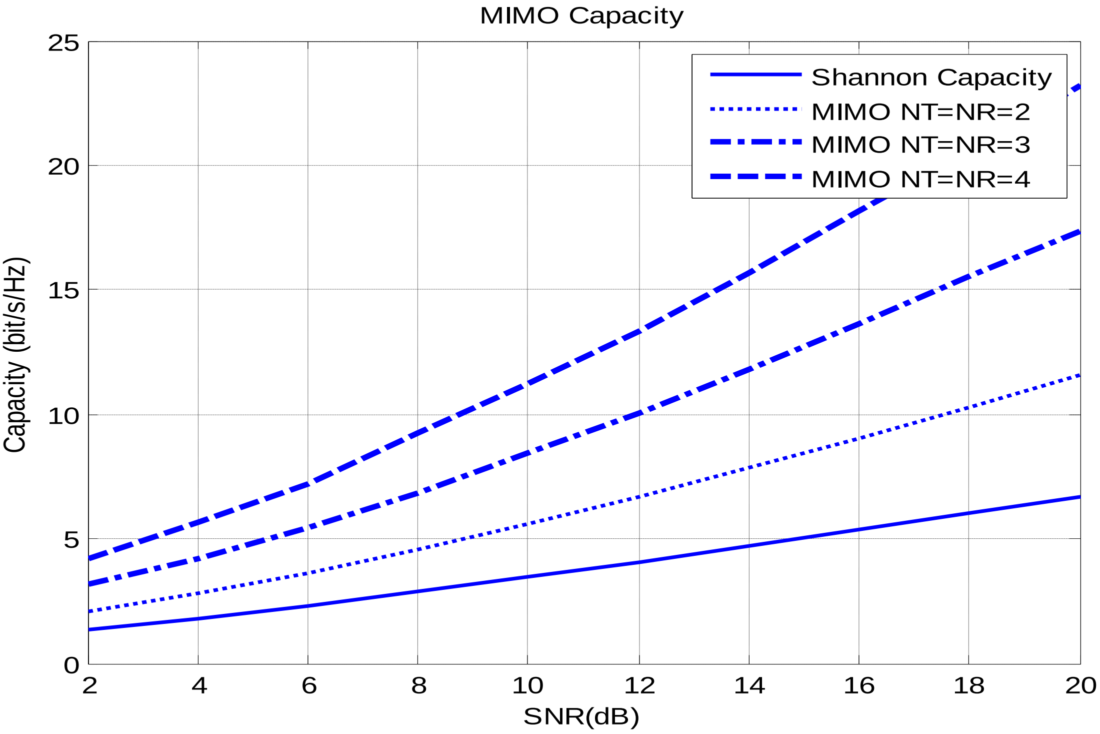


Fig. 6 Comparison graph of capacities of SISO & MIMO

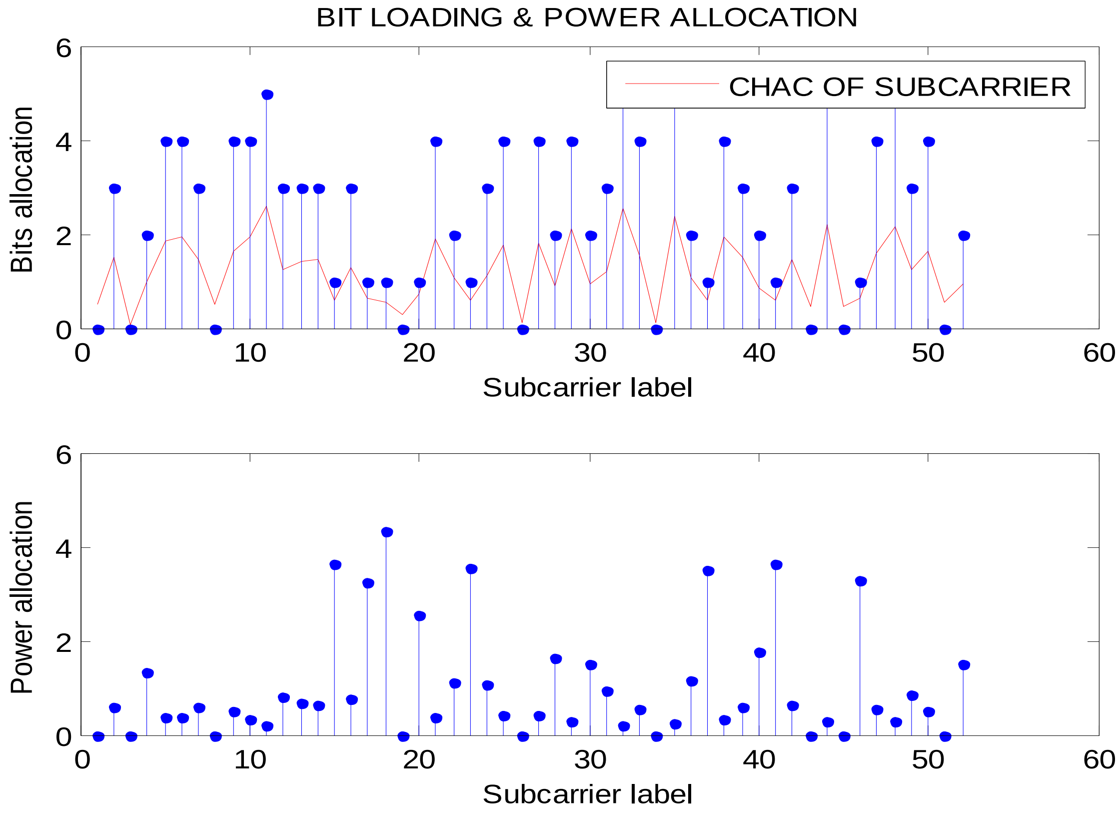


Fig. 7 Bit & Power Allocation of MIMO-OFDM System

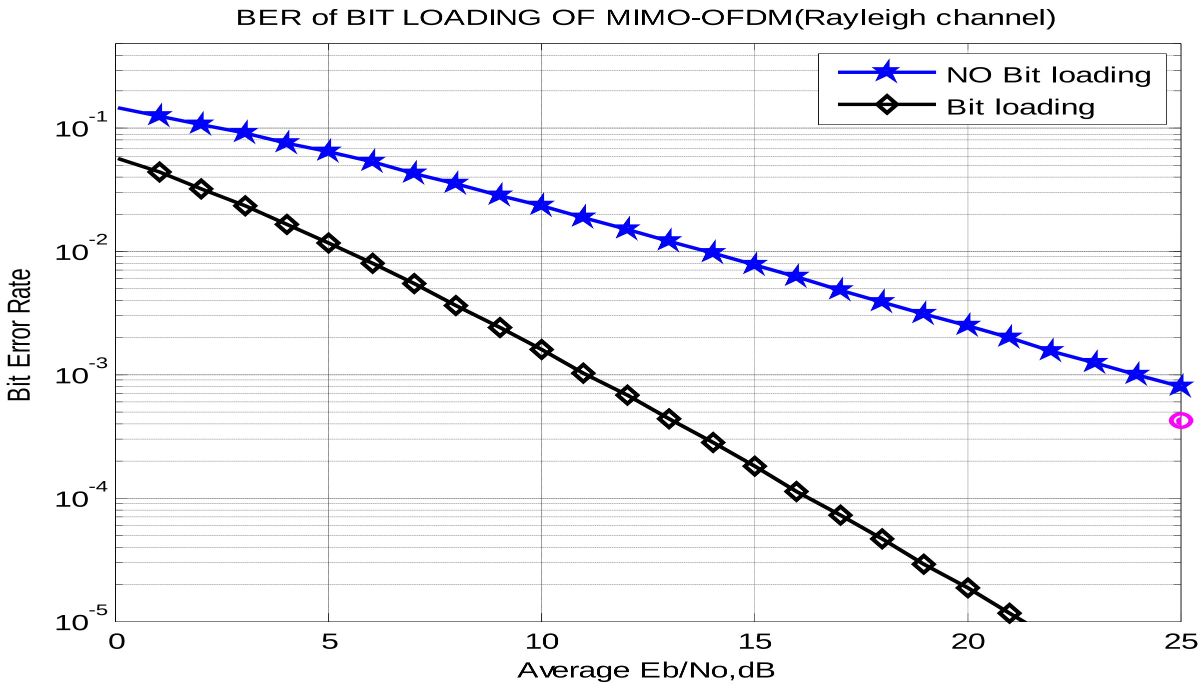


Fig. 8 BER Curves for MIMO-OFDM Scheme with & without Bit Loading

The BER performance of the Bit loading of of MIMO-OFDM is compared with conventional MIMO-OFDM Scheme in Fig. 8.It Clearly shows at any given BER of conventional MIMO-OFDM system outperformed by the Bit loading of MIMO-OFDM system by 4-5dB.

TABLE 1 SIMULATION PARAMETERS

S.No	Type of Parameter	Quantity
1.	Number of FFT Points	64
2.	Number of subcarriers	52
3.	Number of cyclic prefix	16
4.	Type of modulation	M-PSK/M-QAM
5.	Number of antennas(Tx)	08
6.	Number of antennas(Rx)	08
7.	Number of Bits	10^6
8.	Power delay profile	$[1, 1/e, 1/e^2]$

V.CONCLUSION

Bit Loading algorithms in MIMO-OFDM systems are investigated in this paper. The bit loading algorithm excludes the subcarriers with negative *Ri*. This sequence avoids the situation that some subcarriers are turned off but in fact should remain used. Further, Bit loading of MIMO-OFDM leads to better BER performance, as well as outperforming a MIMO-OFDM without Bit Loading. Results on the capacity of MIMO-OFDM systems with partial CSI at the transmitter is relatively straightforward and predicts that capacity grows linearly with the number of antennas.

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