Performance Analysis of MIMO OFDM System using Higher Modulation Techniques and Subcarrier Index modulation

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***Abstract*— There is the demand of speed over 100Mbps downlink and 50Mbps uplink to mobile users, data beyond 6,300,000 terabytes per month for accessing multimedia services like video, VoIP. Similarly there are requirements such as: high throughput, robustness, efficient bit error rate (BER), high spectral efficiency, minimum delays, low computational complexity, low Peak to average power ratio (PAPR), low error probability etc. Typical constraints faced during transmission are; bit error rate, detoriates over wireless transmission, the reduction of a data channel, the corresponding bit error rate (BER) is noise and changes to the propagation path. Clipping and filtering on the performance of OFDM, including the power spectral density, BER.**

In OFDM transmissions system a term called peak-to-average power ratio, arises which result in corresponding distortion when signal gets transmitted through a nonlinear nature device, such as a power amplifier use at transmitter stage. Despite many advantages of OFDM, OFDM signals are very susceptible to the time-varying channel, which breaks the orthogonality between sub-carriers, resulting in inter-channel interference (ICI). The ICI increases in proportion to the normalized Doppler frequency. In a fading radio channel, it is likely that a transmitted signal will suffer deep fades that can lead a complete loss of the signal or outage of the signal. The outage probability is defined as the probability that is measured for signal to interference ratio of received signal considering the certain threshold level. Outage is said to occur when the received signal power goes below a certain threshold level. [1] The multiple antenna system provides better BER, better diversity performance with less computational complexity compared to single antenna system. A MIMO system uses spatial diversity that is obtained by the STBC technique. In a reported paper of 2X2 MIMO system using BPSK, 16-QAM, at BER=10^{-4}, SNR=32dB for BPSK, SNR=37dB for QPSK SNR=40dB for 16-QAM modulation over OFDM transmission. [2] The paper deals with measurement/analysis of parameters such as BER, SNR, outage capacity, for NXN (2, 4, 8, 16, 32) MIMO transceiver system using (QPSK, 16-QAM), ½ rate convolutional encoding to improve BER below 40dB.

***Index Terms*— BER, ICI , MIMO, , OFDM, OFDM-IM ,PAPR, QAM, QPSK , SIM, SNR.**

I. INTRODUCTION

MIMO is abbreviated to multiple input multiple output system, uses multiple T_x and R_x antennas to multiply the capacity of a radio link. The power efficiency of MIMO system can be increased by maximizing spatial diversity. Such techniques are STBC and STTC. Another technique is V-BLAST use to increase the capacity.

There are huge demands of wireless application now days, with better quality of services. Due to restricted bandwidth, high BER, low SNR, wireless systems like SISO, SIMO and MISO fail to meet the growing demands of users. Therefore a new technique MIMO system is used. The MIMO system is used to improve spectral efficiency, data rate, and transmission coverage, to minimize error, to optimize speed, without wasting the additional frequency spectrum. [2]

Consider a transmitter with N transmits antennas, and a receiver with M receives antennas. The channel can be modeled by the NXM matrix H, where H is the channel matrix, the NX1 received signal y is given by Eq. 1

$$y=H_s+n, \tag{1}$$

Where s is the transmitted symbol (s1, s2, s3… SNT), and the covariance matrix for this transmitted signal is given by Eq. 2

$$Rss=\frac{Es}{Nt}INT \tag{2}$$

Where $\frac{Es}{Nt}$ is equal to the power of each antenna. In the Eq.1, the H-channel matrix can be defined by Eq.3

Transmitter Propagation Environment Receiver

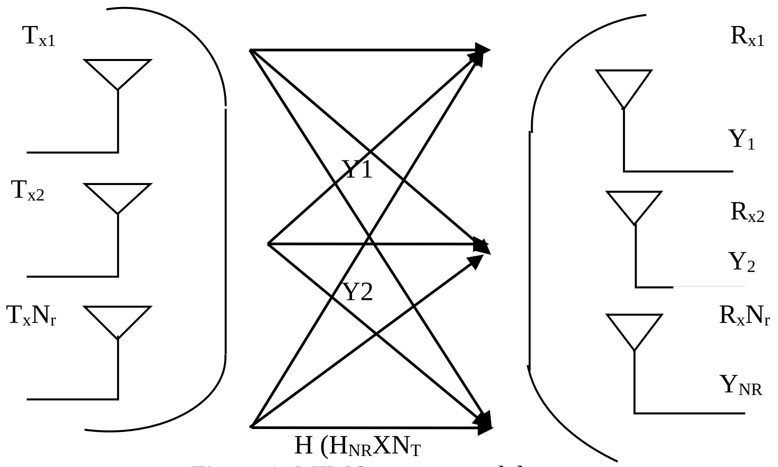

Figure 1: MIMO system model

$$H=\begin{bmatrix} h_{11} & h_{12}\ldots\ldots\ldots h_{1M} \\ h_{21} & h_{22}\ldots\ldots\ldots h_{2M} \\ & \cdot \\ & \cdot \\ hN1 & hN2 \qquad hNM \end{bmatrix},$$
(3)

Where h_{ij} is a complex gaussian, random variable that models fading gain between the j_{th} transmit antenna and i_{th} receive antenna in MIMO system.

The generalize model of MIMO as shown in fig.1 At first, the incoming data streams travels through serial to parallel converter and then all the streams are modulated by using BPSK, QPSK, 16-QAM etc.At receiver end, the modulated data stream is collected, then demodulated and detected by the V-BLAST detection technique. MIMO the only efficient way to increase bandwidth, range & will become a core technology in wireless systems. The MIMO channel is constructed with multiple antennas at both ends of the wireless link. [3]

The layout of the paper is as follows. section 1 deals with introduction, section 2 depicts about OFDM system, section 3 explains MIMO OFDM block diagram, section 4 describes about the modulation techniques, section 5 explains principle of index modulation and operation of MIMO OFDM–IM system, section 6 describe the proposed system and simulation results, section 7 states the conclusion of the paper.

II. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

OFDM stands for orthogonal frequency division multiplexing, that divides a high data rate stream into lower data rate stream, place them onto narrowband close-spaced subcarriers and then transmitted in parallel fashion. OFDM signal consists of a number of closely spaced modulated carriers. When modulation of any form - voice, data, video etc. is applied to a carrier, then sidebands spread out either side of the spectrum. OFDM has high data rate transmission capability with high bandwidth efficiency and robustness to multi-path fading delay. fig.2 shows the comparison between conventional OFDM and OFDM.[3]

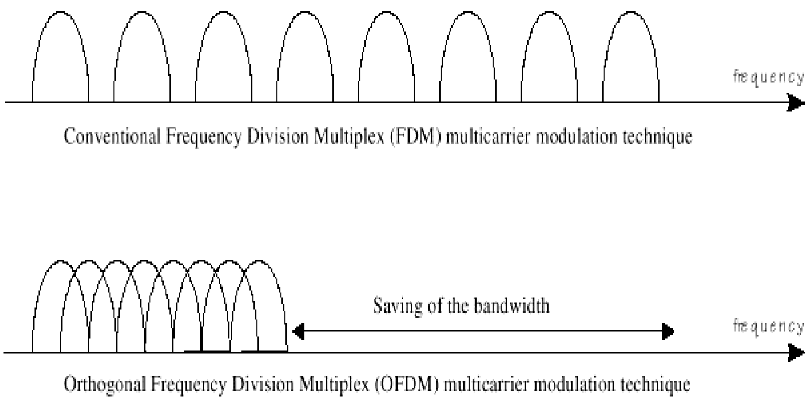

Figure 2: Comparision between conventional FDM and OFDM

When signals are transmitted from the channel and if they are close to each other so that this signal must be spaced apart so that the receiver can separate them using a demodulator, filter so that there must be a guard band between these samples. This is not the case with OFDM. When the sideband from received envelope carrier overlap at receiver side, so that they can still be receive without the interference at receiver provided they should be orthogonal to each another. The carrier spacing between the subcarrier must be equal to the reciprocal of the symbol period.fig.2 shows the traditional view of receiving signal carrying modulation.

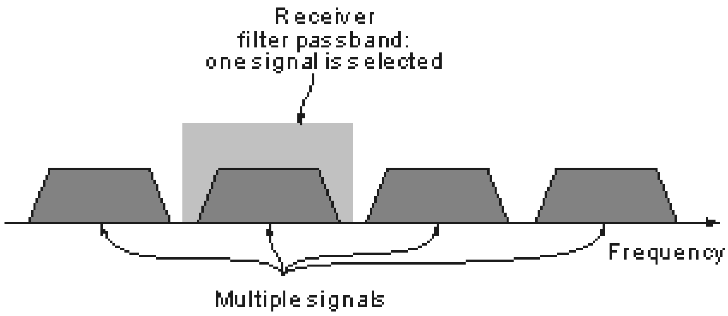

Figure 3: Traditional view of receiving signals carrying modulation

To understand the mechanism of OFDM, let us look at the receiver operation with respect to the OFDM spectrum shown in fig.4.The receiver comprises of bank of demodulators, which translates each carrier down to DC. The resultant signal is integrated over the one symbol period to regenerate the data from that carrier. The same demodulator also demodulates the other carriers. As the carrier spacing between the subcarrier is equal to the reciprocal of the symbol period in OFDM, which means that they will have a whole number of cycles in the symbol period and their contribution will sum to zero - in other words there is no interference contribution to the OFDM signal. The OFDM transmitting and receiving systems must be linear. Any non-linearity will cause interferencence between the carriers as a result of inter-modulation distortion. This will introduce unwanted signals that would cause interference and impair the orthogonality of the transmission.[3]

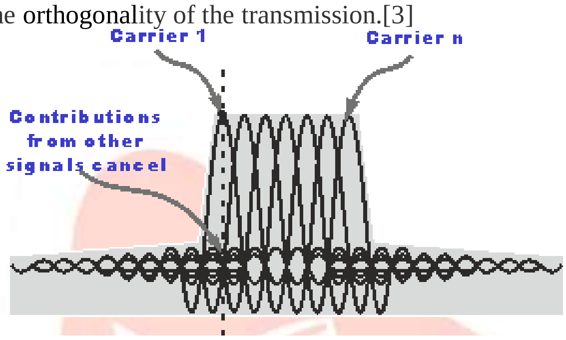

Figure 4: OFDM spectrum

To obtain the less BER, hence data rate the peak to average power ratio (PAPR) of the OFDM system must be very less so an RF power amplifier must be incorporated at the output of the transmitter in order to handle the peaks otherwise the average power is much lower and this leads to inefficiency.

III. MIMO OFDM BLOCK DIAGRAM

The multiple transmit antennas can be used for beam forming, and multiple receive antennas can be used for diversity, operation. The word "MIMO" refers to the simultaneous transmission of multiple signals called spatial multiplexing to multiply spectral efficiency, hence system capacity. MIMO multiples the channel capacity of radio channel as it transmit the multiple number of signals over a communication channel.

This is accomplished without the need for additional transmit power or bandwidth. OFDM distributes user data across a number of closely spaced, narrowband sub channels. This helps to remove the intersymbol interference (ISI). ISI is usually caused by multipath propagation and non-linear frequency response of a channel causing successive symbols to overlap over each other. This overlap duration is large compared to the symbols duration. Normally, high data rates signal require shorter duration symbols cause to increase the ICI. By dividing a high-rate data symbols into numerous low-rate data symbols, OFDM enables longer duration symbols. [3]

A cyclic prefix (CP) may be inserted to create a (time) guard interval that prevents the occurrence of ISI. If the guard interval obtained after CP insertion is longer than the delay spread so there would be the difference in delay experienced by the transmitted symbols over wireless channel, then there will be no symbols overlap between adjacent symbols and consequently no intersymbol interference. With the addition of CP the spectral capacity slightly gets reduces by consuming a small percentage of the available bandwidth, the elimination of ISI makes it an exceedingly worthwhile tradeoff. The fast fourier transforms (FFTs) operation is used to simplify implementation. Fast fourier transforms are numerical algorithms used by computers to perform DFT calculations. OFDM system makes efficient use of bandwidth.

Here the all sub channels must be spaced apart in frequency representation just enough to ensure that their time-domain waveforms will be orthogonal to each other. In practice, this means that the sub channels can be partially overlapped in frequency domain. When MIMO combine with the OFDM provides various advantages such as OFDM do not require signal equalization. MIMO-OFDM can achieve very high spectral efficiency even when the transmitter does not suffer from channel state information (CSI). Even when the transmitter possess the channel state information (which can be obtained through the use of training sequences), it is possible to obtain the theoretical channel capacity. [3]

Fig.5 shows the MIMO communication system's basic blocks. The information bits to be transmitted are encoded and interleaved. The spatial data streams are mapped to the transmit antennas by the space-time coding block with linear precoding block thus spreading the various parallel streams across the various antennas with the aid of appropriate weighting factors. The receiver then collects the received signals at the output of each receive antenna and reverses the transmitter operations in order to decode the data.

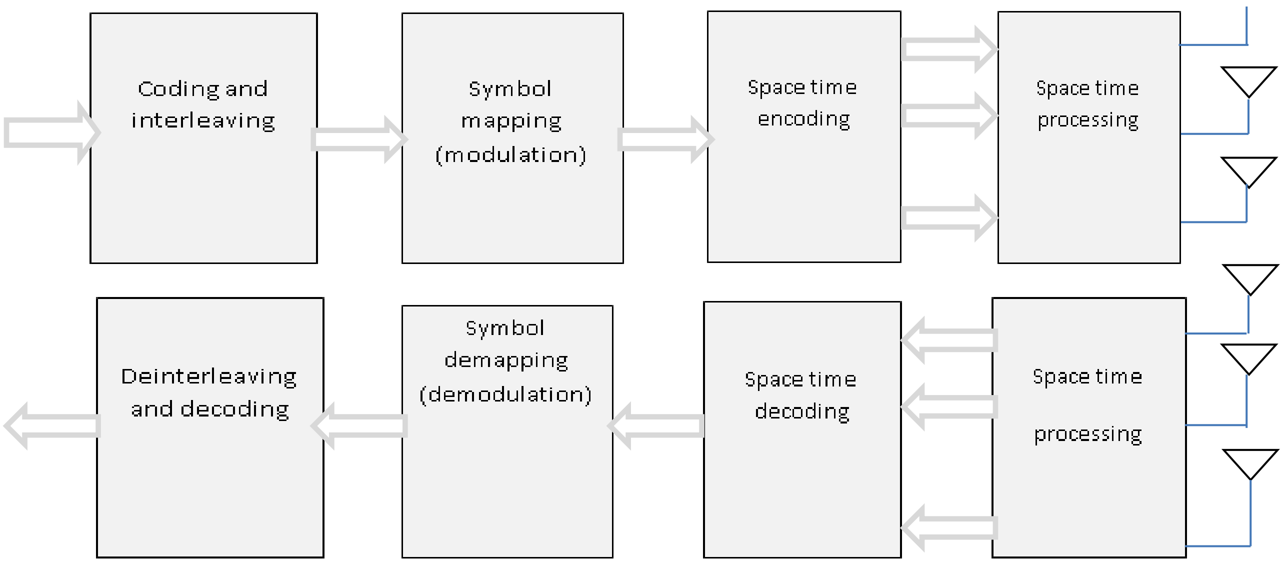

Figure 5: MIMO Transmit and Receive System Block Diagram

IV. MODULATION TECHNIQUES

The process of varying property of carrier signal, with a modulating signal that typically contains information to be transmitted. This alteration is termed modulation, and it's the modulated signal that's transmitted. The receiver then recovers the initial signal through a method known as demodulation. Modulation is the way in which the information is superimposed on the radio carrier. Modulation techniques are expected to have three positive properties.[4]

- **Good Bit Error Rate Performance:** BER is the percentage of bits with errors divided by the total number of bits that have been transmitted, received or processed over a given time period. The rate is typically expressed as 10 to the negative power. Low bit error rate is required in the presence of fading, Doppler spread effect in wireless system.
- **Power Efficiency:** Power limitation is one of the critical design challenges in mobile applications. Nonlinear amplifiers are usually used to increase power efficiency. However, nonlinearity present at the amplifier output cause degradation to the BER performance of modulation.
- **Spectral Efficiency:** It refers to the information rate that can be transmitted over a given bandwidth in a specific communication system. Spectral efficiency density should have a narrow main lobe and fast roll-off of side lobes. It is defined as η =bitspersec/channel B.W [4]

A. Quadrature Phase shift Keying

Here, the phase of the carrier signal is divided which is designed by allotting four equally spaced values for the phase angle. QPSK sent twice data that can be sent in the same bandwidth compared to BPSK.QPSK provides twice the spectral efficiency with same energy efficiency. QPSK has four constellation points in the constellation diagram as shown in fig.6. But the exact phase retrieval is a challenge in the receiver design considerations, failing which can give rise to erroneous detection of the signal. This factor increases the receiver design complexities. To overcome these problems, and to shape up the carrier modulated signal, the root raise cosine pulse shaping is used, which in turn provides demerits that the constant envelope property of the signal is lost.[4] The implementation of QPSK is more general than that of BPSK as given by Eq.4

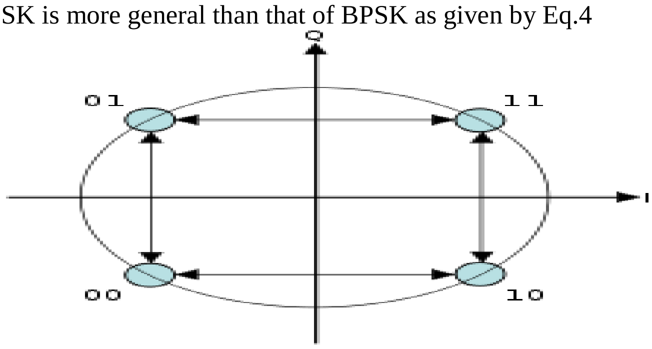

Figure 6: Constellation diagram for QPSK

$$S_n(t)=\sqrt{\frac{2Eb}{Tb}}\,\mathrm{Cos}(2\pi fct) + \pi(2n-1), \text{where } n = 1,2,3,4$$

(4)

This yields the four phase's $\pi/4$, $3\pi/4$, $5\pi/4$ and $7\pi/4$ as needed. This results in a two-dimensional signal space with unit basis function. The first basis function is used as the in-phase component of the signal, is given by Eq.5

$$\Phi_1(t)=\sqrt{\frac{2}{Ts}}\,\mathrm{Cos}(2\pi fct),$$

(5)

And second basis function is used as the quadrature component of the signal, is given by Eq.6

$\Phi_2 (t) = \sqrt{\frac{2}{Ts}}\, \text{Sin}(2\pi fct),$

(6)

B. Quadrature amplitude modulation

Quadrature amplitude modulation (QAM) requires changing the phase and amplitude of a carrier sine wave. 16-QAM is also called 16-state quadrature amplitude modulation. Here four I phase values and four Q phase values are used, which generates four bits per symbol. It has got 16 states because 2^4 = 16-states.Its theoretically calculated bandwidth efficiency is four bits/second/Hz. Data is split into two channels,(i.e.) I channel and Q channel. To achieve a $1X10^{-6}$ bit error rate (BER), 16-QAM requires 20.92 dB C/N assuming AWGN channel. The constellation diagrams show the different positions constellation points for the states within different forms of QAM. As the order of the modulation (M=4, 8, 16) increases, so does the number of points on the QAM constellation simultaneously increases as shown in constellation diagram of fig. 7.

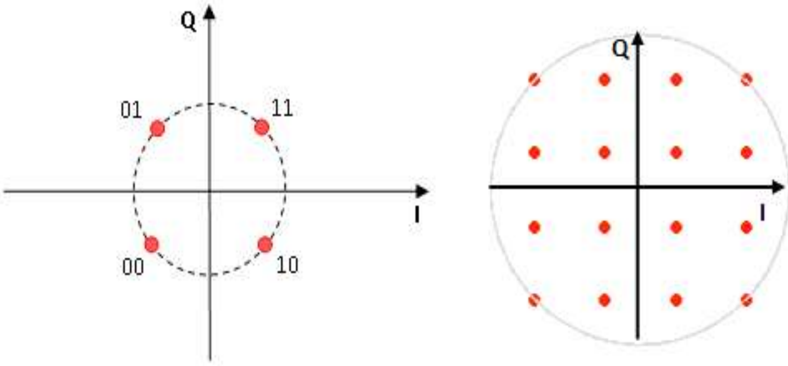

Figure 7: Constellation diagram for QPSK

Let's look at the time-domain representation of QAM signals. Taking 4-QAM, supposed to transmit the bit stream 100111.Map the 4-QAM symbols representing 10, 01, 11. The time-domain waveform for this bit stream is shown in fig. 7. One period of the sine wave and has a unique phase shift. In this respect, 4-QAM might be considered a special case of QAM where the amplitude is the same for all symbols. [4]

- **Bit Error Rate (BER):** The Bit error rate is a ratio of number of bits received in error divided by the number of transmitted bits, measure in dB, as given by Eq.7

BER= (Bits in Error) / (Total bits received) (7)

In wireless transmission, when the number of data bits are received, and if these data bits have modified compare to transmitted data bits, so this happens due quantization, and synchronization error. BER is often expressed as normalized carrier-to-noise ratio denoted by E_b/N_0 that is energy per bit to noise power spectral density ratio. [4]

- **Signal to noise to ratio**

The SNR is the ratio of the received signal power over the noise power in the frequency range of the process, and measured in decibel (dB). SNR is inversely related to bit error rate (BER). High BER causes an increase in packet loss, enhance in delay and decrease throughput, and is given by Eq.8. [4]

SNR = 10 $\log_{10}$ (Signal power/Noise power) dB (8)

- **Outage capacity**

The probability that the capacity of the system is less than a capacity threshold level, where the SNR of the channel is a random variable that can take realizations close to zero. In this case the capacity is zero and we need an alternative capacity metric. The outage probability is defined as given by Eq.9

$P_{out}(R) = P_r(C(H) < R),$ (9)

In other words, the system is said to be in outage state if the decoding error probability cannot be made arbitrarily small in value with the transmission rate of R bps/Hz. Then, the outage capacity of channel is defined as the largest possible data rate such that the outage probability in Eq.9, is less than ε. In other words, it is corresponding to Cε, such that P(C (H) ≤ ε), the capacity for the random MIMO channel can be performed by cumulative distribution function (CDF) when CSI is not available at the transmitter side. Fig. 8 and 9 shows the CDFs of the random MIMO channel capacities when SNR is 10dB, in which 2X6, 2X4 MIMO channel capacities when SNR is 10dB, in which ε=0.1, outage capacity is indicated. It is clear for the fig.8 the outage capacity is same for any value of CDF. [1]

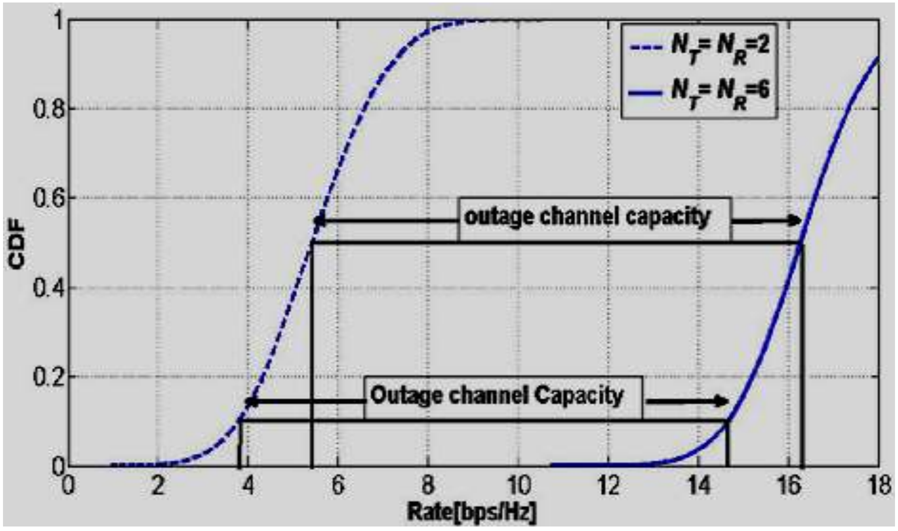

Figure8: Distribution of MIMO channel capacity (SNR =10dB; CSI is not available at the transmitter side for N_T=N_R=2 and N_T=N_R=6)

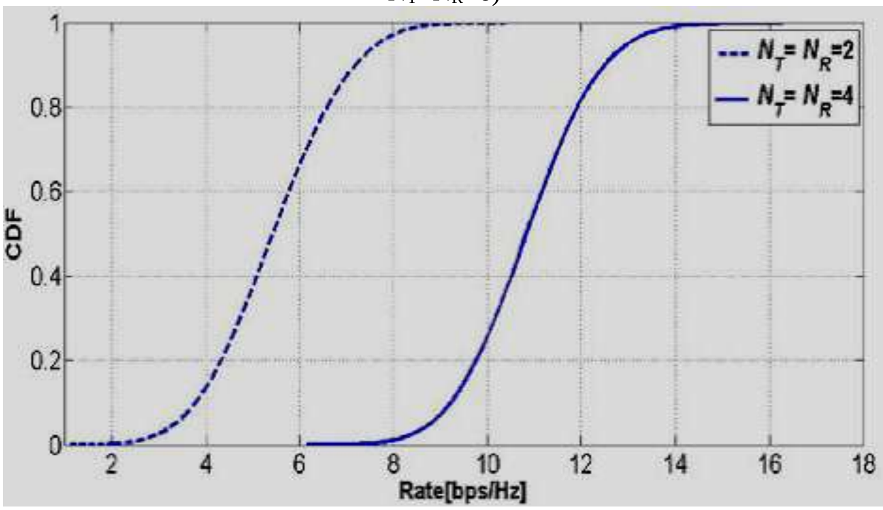

Figure 9: Distribution of MIMO channel capacity (SNR =10dB; CSI is not available at the transmitter side) for N_T=N_R=2 and N_T=N_R=4

On comparing the fig. 8 and 9 it can be deduced that as the number of N_T and N_R increases the bit rate as well as the outage capacity increases.

V. Proposed work

In order to improve the data rate beyond the $10^{-6,}$ then a new technique called MIMO-OFDM with index modulation can be adopted.

A: Principle of index modulation

The index modulation is multicarrier transmission technique, which is based on OFDM to reduce the amount of required transmitted power. It provides better BER performance, flexible system design with variable number of active OFDM subcarriers,

In addition to the robustness against multipath fading, OFDM-IM has better energy efficiency and BER performance than OFDM. OFDM-IM has got an error that means uses a subset of the all possible subcarrier activation patterns (SAPs). A latest modification is in Index modulation is the OFDM-IMA, which uses a modified data loading method and overcomes this problem by employing all of the possible SAP_s in data transmission. In the reported paper, it is proposed to use OFDM-IMA with subcarrier-level interleaving to improve the system performance under multipath Rayleigh fading channel. The results of reported paper shows that the OFDM-IMA achieves significant BER improvement compare to OFDM-IM. [5], [6]

B: Orthogonal frequency division multiplexing with index modulation

The block diagram of an OFDM-IM transmitter is presented in fig.10.Basically; OFDM-IM divides an OFDM block of subcarriers into sub blocks. For each sub block, only out of subcarriers are employed to carry M-QAM constellation symbols. There are a total of C (n, k)(=n!/((n-k)!k!, Possible SAP_s.

The data stream 0 1 1 1 1 0 1 0 0 is segmented into groups of m-bits, each group of m bits is mapped to a sub block by splitting a group of bits into two parts, one part is used to select the activation pattern of the subcarriers and the other part of information is modulated on the active subcarriers. These sub blocks are then combined into one block and forwarded to the inverse fast fourier transform (IFFT) block and thereafter transmitted.

However, for a block of information of m-bits entering the OFDM-IM transmitter, it is split into groups of g-bits of p-bits. where p=p1+p2.Each group of p-bits is mapped to an OFDM sub block of length n subcarriers, the segment of p_1 bits used to select the SAP_s, is given by Eq.10 where $p1=[\log_2(C(n, k)]$, (10) and the [.] is the greatest lowest integer Then, each active subcarrier within a sub block is modulated by an M-QAM symbol leading to the modulation of 2 bits to the k-active subcarriers of a sub-block, is given by Eq.11

Where $p_2=k\log_2(M)$, (11)

Referring to fig. 10, in this case the data segment assigned to a sub-block is m=12 bits. The total number of subcarriers is N=8, with n=4, and k=2, which produce two sub blocks (g=2), with two active subcarriers per sub block. The number of used subcarrier activation patterns is 4 out of 6 available SAP_S. Therefore, p_1=2 bits are mapped to a SAP_s, and p_2=4bits are modulated to a sub block when M=4.

It worth mentioning that the OFDM-IM uses only 2^{P1} out of total no.of possible available SAP^s, C (n, k), there are C (n, k)-2^{P1} wasted SAP_s.This causes unused SAP_s to be detected at the receiver and leads to incorrect sub-block information demapping. However, this error possibility is cancelled by the latest yet development of OFDM-IM called OFDM-IMA scheme where all of the possible SAP_s are used to transmit data. [5], [6]

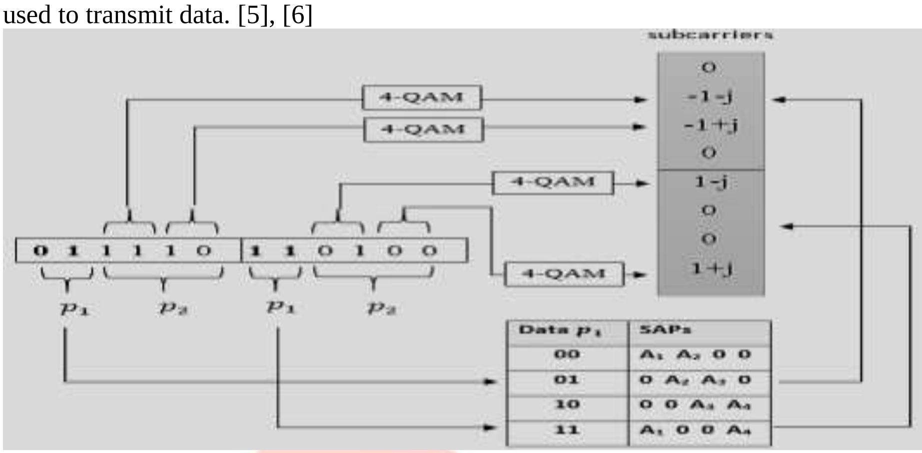

Figure 10: OFDM-IM transmitter diagram with N=8, g=2,n=4,and k=2

VI. Result and Discussion

A. Implemented BER vs. SNR analysis for MIMO system using QPSK and 16-QAM

Case 1: In case1 the following parameters are considered. In this section, coding results for 02X02, 04X04 MIMO configuration employing QPSK and 16-QAM modulations are presented in figure 11. Firstly the classical MIMO-OFDM system is build which is encoded using convolution encoding, ML detection used at receiver. Considering parameters like N=64, No of symbols=64000, M1=4, M2=16-QAM, N_{T1}= (02, 04) N_{R1}= (02, 04), convolution encoding. The BER vs. SNR graph for 02X02, 04X04 MIMO using QPSK, 16-QAM modulation.

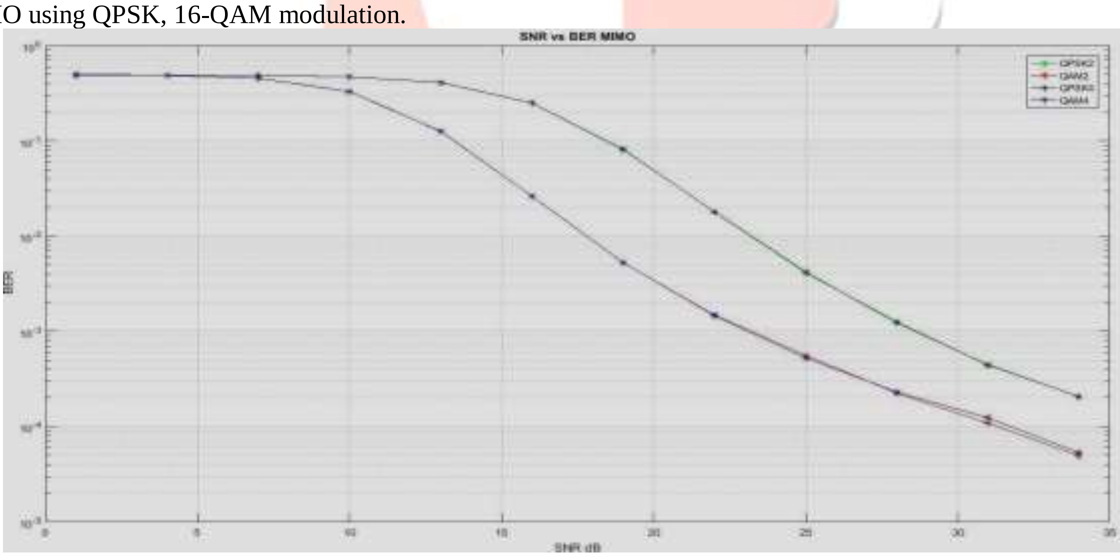

Figure 11: BER vs. SNR graph for 02X02, 04X04 MIMO systems using QPSK, 16-QAM

Considering 2X2 MIMO the BER difference of 4.5dB is obtained between QPSK, 16-QAM modulation. Considering the 4X4 MIMO BER difference of 5.2dB is obtained between QPSK, 16-QAM modulation. [2], [7]

Case 2: In case 2, another 08X08, 16X16 MIMO system configuration employing QPSK and 16-QAM modulations is considered. The other measurements parameters would remain the same. The BER vs. SNR graph for the 08X08, 16X16 MIMO system using QPSK, 16-QAM modulation is shown in fig.12. Considering 8X8 MIMO the BER difference of 6.8dB is obtained between QPSK, 16-QAM modulation. Considering the 16X16 MIMO BER difference of 7.8dB is obtained between QPSK, 16-QAM modulation. [4], [8]

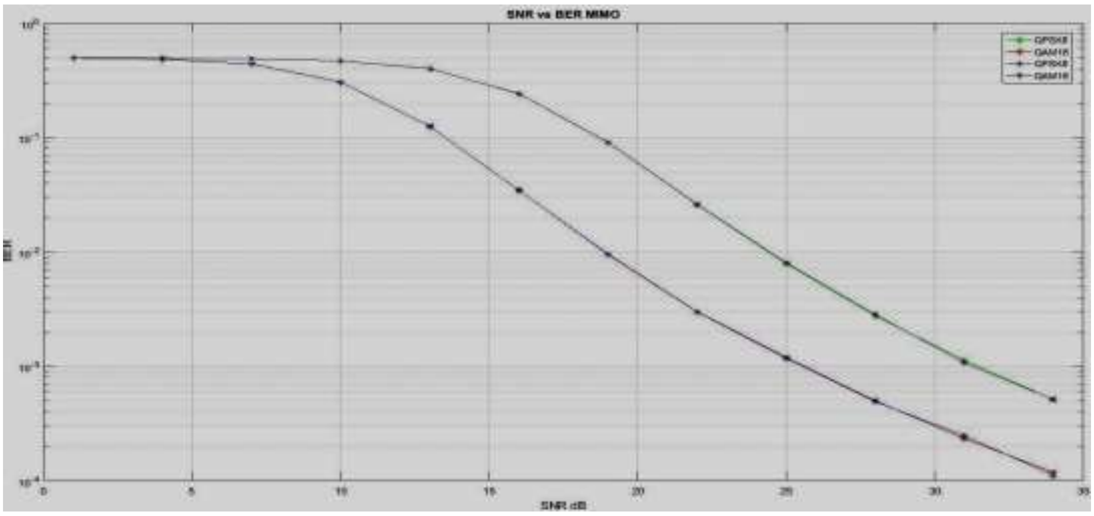

Figure 12 BER vs. SNR graph for 08x08, 16x16 MIMO systems using QPSK, 16-QAM

B. Implemented ergodic capacity vs. SNR analysis various MIMO configurations

Here the outage capacity vs. SNR graph is implemented for the following 2X2,2X4,4X4,4X2, 4X8,8X4,8X8,16X8,8X16,16X16,16X32,32X16,32X32 MIMO configurations. From the implemented graph shown below the higher order MIMO system stabilizes the ergodic capacity vs. average SNR graph. The Fig.13 is the implementation of capacity vs. average SNR graph 2X2,2X4,4X4,4X2,4X8,8X4,8X8,16X8,8X16,16X16,16X32,32X16,32X32 MIMO configurations.

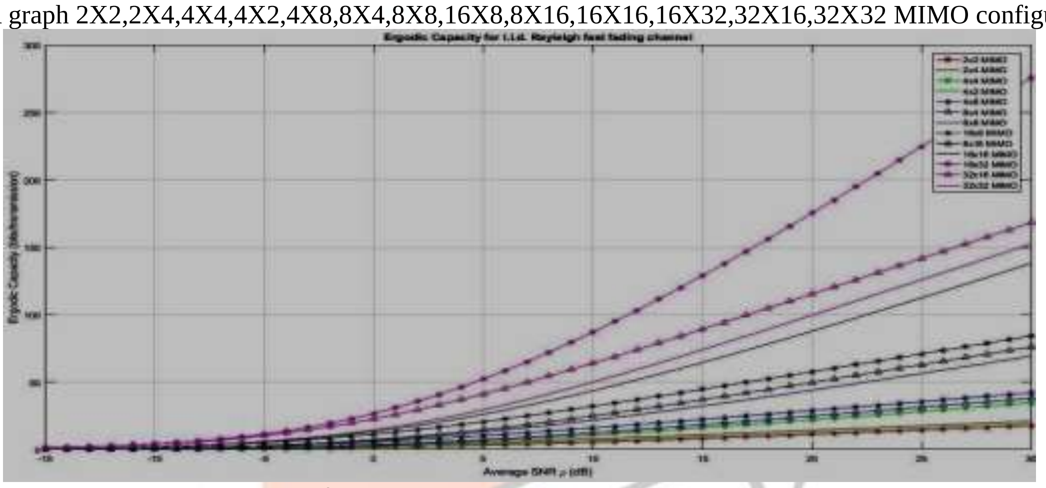

Figure 13:capacity vs. average SNR graph for 2X2,2X4,4X4,4X2,4X8,8X4,8X8,16X8,8X16,16X16,16X32,32X16,32X32 MIMO configurations

C. Outage capacity vs. SNR analysis:

In another case the outage probability vs. SNR graph is plotted for the 16X16, 32X32, etc. MIMO configuration.

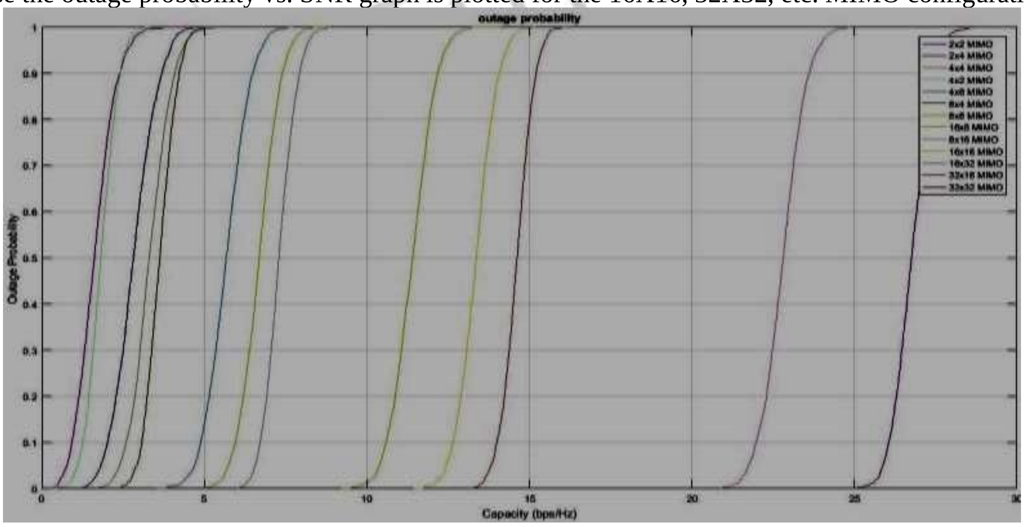

Figure14: Distribution of MIMO channel capacity (SNR =10dB).for N_T=N_R=16 and N_T=N_R=32

The result as shown in fig.14 are improved in terms of outage capacity vs. SNR using the differente MIMO configurations..

D. Implementation of subcarrier index modulation

The concept of subcarrier index modulation is developed for the 4X4, 8X8 MIMO system, here in this study; active subcarrier index selection is performed by the reference look-up tables 1 and 2 at OFDM index modulators of the transmitter.

Table 1: Look-up table for N= 4, K = 2 and P1 = 2

Bits	Indices	OFDM-IM sub blocks $(x_t^g)^T$
[0 0]	{1,3}	[$s_1$0 s_2 0]
[0 1]	{2,4}	[0 s1 0 s2]
[1 0]	{1,4}	[s1 0 0s2]
[1 1]	{2,3}	[0s1 s2 0]

Table 2: Look-Up Table for N= 4, K = 3 and P1 = 2

Bits	Indices	Sub blocks
[0 0]	{1,2,3}	$[s1\ s2\ s3\ 0]^T$
[0 1]	{1,2,4}	$[s1\ s2\ 0\ s3]^T$
[1 0]	{1,3,4}	$[s1\ 0\ s2\ s3\ ]^T$
[1 1]	{2,3,4}	$[0\ s1\ s2\ s3]^T$

The considered reference look-up tables for N = 4;K = 2 and N = 4;K = 3 are given in tables 1 and 2 respectively, where Sk϶S for k = 1; 2; : : :K. As seen from table 1, for N = 4 and K = 2, the incoming p1 = 2 bits can be used to select the indices of the two active subcarriers out of four available subcarriers according to the reference look-up table of size C $=2^{P1}=4$. [5], [6]

As seen from as seen from table 2, for N = 4 and K = 3, the incoming p1 = 2 bits can be used to select the indices of the three active subcarriers out of four available subcarriers according to the reference look-up table of size C $=2^{P1}=4$.The concept of subcarrier index modulation with the help of above different lookup table method is implemented using the matlab codes. [5], [6]

VII. . CONCLUSION

The performance of 2X2, 4X4, 8X8 MIMO OFDM transceiver is analyzed for differente QPSK, M-QAM (16-QAM) using QPSK,16-QAM with convolution channel coding by varying the number of transmit(2,4,8) and receive antennas(2,4,8). Lower order modulation and higher transmit and receive diversity reduces bit error rate (BER) resulting in better/improved performance. In addition to the above, the results show that convolution coding scheme under Rayleigh multipath fading channel improves bit error rate performance with less signal-to-noise ratio (SNR).

This is also true in case of random MIMO channel, and it is concluded that the channel capacity is comparatively better in case of MIMO channel in comparisons to others, and the capacity increases with N_T and N_R. Finally, MIMO channel capacity in the presence of antenna correlation effect is estimated and it has been found that the capacity get reduced due to the correlation effect.

The paper has dealt with measurement/analysis of parameters such as BER, SNR, outage capacity, for NXN (02, 04, 08) MIMO transceiver system using 16-QAM, ½ rate convolutional encoder to improve BER below 40dB.

Here the convolution method has been used to reduce the effect of error in OFDM.ML decoding is used for decoding purposes. Matlab coding have shown that the error between simple OFDM method and convolution method in terms of bit error rate, taking differente values of signal to noise ratio.

Using 2X2 MIMO the BER difference of 4.5dB is obtained between QPSK, 16-QAM modulation. Considering the 4X4 MIMO BER difference of 5.2dB is obtained between QPSK, 16-QAM modulation. Considering 8X8 MIMO the BER difference of 6.8dB is obtained between QPSK, 16-QAM modulation. Considering the 16X16 MIMO BER difference of 7.8dB is obtained between QPSK, 16-QAM modulation. It is proposed to use OFDM-IMA scheme with subcarrier-level interleaving to improve the BER performance compare to OFDM-IM scheme beyond the 10^{-6}.

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