Performance Enhancement of Multi-Input Multi-Output (MIMO) System with Diversity

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Abstract– **MIMO is one of the techniques proposed to 3G and 4G LTE-A systems for its added benefits of higher data rates and low bit error rates. The gist of MIMO working is its ability to increase number of channels; thus increasing diversity gain. Correspondingly, more users are accommodated in one communication system. In this work, different MIMO schemes more specifically receive and transmit diversity are analyzed using MATLAB Simulations and the performance criteria are bit error rates (BER), Cumulative Distribution Function (CDF) and channel capacity. MIMO has perfect results but it increases system complexity and this particular constraint limits its implementation to 2×2. More advanced system now days are a bit advanced 4×4 system but this is the limit till now. It's an open field and requires much attention for great explorations.**

Keywords– MIMO, LTE-A, MATLAB and Diversity Gain

I. INTRODUCTION

There is an exponentially increase in the number of users of second-generation mobile network and internet subscribers by the end of second millennium. Hence, there were more expectations in achieving high data rate, capacity and best services among the users of both the systems. To resolve the problems of capacity and high data rate in the challenging radio environment, a novel idea was proposed to use the Multiple Element Array (MEA) at both ends of the wireless communication systems. These wireless systems were referred as Multiple Input Multiple Output (MIMO) systems having multiple transmit and multiple receive antennas in literature in contrast with Single Input Single Output (SISO) antenna systems [1].

A system having only one transmit antenna and multiple receive antennas is referred to Single Input Multiple Output (SIMO) system while the system of multiple transmit antennas and single receive antenna is known as Multiple Input Single Output (MISO) system. A MIMO system having transmit or receive antenna elements in different devices is known as Multiple Transmitters Multiple Receivers (MTMR) [1] To achieve an array or diversity gain, MIMO systems spread the total transmit power over the antennas which gives us more spectral efficiency and link reliability which reduced fading. Hence, without increasing transmits power or bandwidth, we can achieve high data throughput and link range. MIMO technology plays an important role in modern wireless communication standards such as 3GPP Long Term Evolution, 4G, WiMax, HSPA+ and IEEE 802.11n (WiFi) due to having these properties [2].

The techniques used achieving diversity in MIMO systems can also be divided in three main categories: Pre-Coding, Spatial Multiplexing (SM) and Diversity Coding. MIMO receivers are very complex due to spatial multiplexing techniques and multipath channels, therefore we use MIMO with orthogonal frequency division multiplexing (OFDM) or with orthogonal frequency division multiple access (OFDMA) modulation to get rid-off from these problems efficiently. In October 2009, MIMO-OFDM was recommended by IEEE 802.11n while IEEE 802.16e standard integrates MIMO-OFDMA.

In 3GPP and 3GPP2, in mobile radio telephone standards, MIMO is also planned to be used. High Speed Packet Access plus (HSPA+) and Long Term Evolution (LTE) standards also take MIMO into account. Hence; MIMO research groups along with IST-MASCOT planed to develop the advance MIMO techniques e.g., multi-user MIMO (MU-MIMO) to support the cellular environment fully.

Now days, MIMO technologies are also being used in wired communication systems as like home networking standard ITU-T G.9963 e.g., in power line communication systems, to transmit multiple signals over multiple AC wires (Phase, neutral and ground) MIMO techniques can also be used.

The paper is organized as: System Model is given in Section 2 and simulation results are discussed in Section 3 along with discussion in last section.

II. SYSTEM MODEL

MIMO systems are available with N transmit antennas and M receive antennas for the purpose of transmission. Channel matrix H is responsible for the characteristics of the propagation channel. The main purpose of this matrix is to make a relationship between complex inputs to the complex output at the receiver. In this process the Additive White Gaussian Noise (AWGN) is added. We can write in general [3].

$$Y = HX + \psi$$

Where ψ denotes the amount of AWGN noise added to the system, H shows the channel matrix and X is the transmitter and Y is output of the system. A complete MIMO data transmitting system is shown in Fig. 1. Source of information is the random

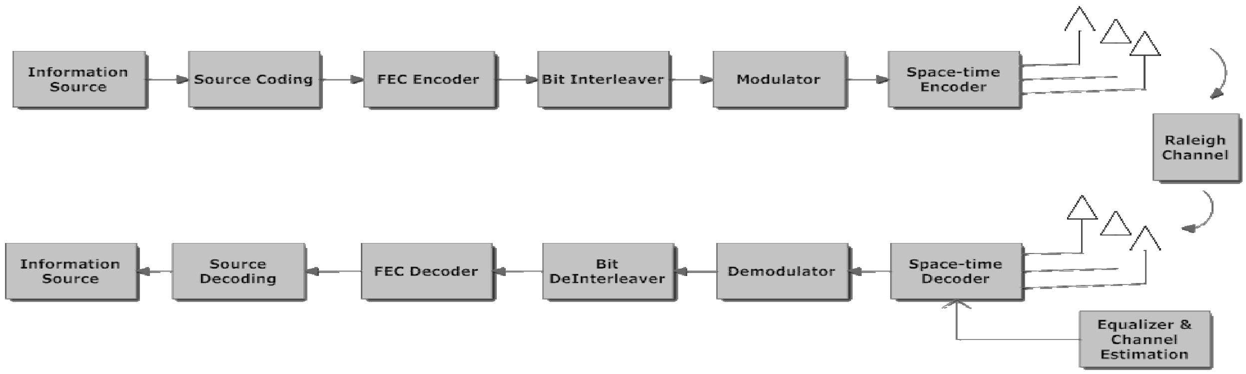

Fig. 1: MIMO System Model

binary data and will be used for transmission purpose. This information is fed to the source coding block which is basically a conversion from a sequence of symbols to a sequence of bits, such that message symbols can be recovered from the mapping bits. Source coding determines the possible data compression which reduces the data redundancy. Shannon capacity or channel capacity bounds the maximum information that can be transmitted over a channel. It is given by [1]:

$$C = B\ log\ (1 + SNR)$$

Where C is channel capacity, B is bandwidth of the channel, SNR is signal to noise ratio. An effective source coding can result in achieving this maximum limit of data transfer [4].

Source coded message is the input to error correcting block. The error correcting block at the transmitter side is Forward Error Correction (FEC) encoding. The data is encoded in a redundant way to minimize the chance of error at the receiver end. For example if we have N bits after the source coding then different FEC coding algorithms can be applied like Hamming Codes etc. In hamming code for any integer $k > 2$ the output block length will be $b = 2^k - 1$ and the input block length at a time will be of $m = 2^k - k - 1$ with a rate of $R = {}^{m}/_{b}$. The total number of bits at the output of this block will be $bits = N * {}^{b}/_{m}$ [1].

The incoming binary stream is interleaved to increase the efficiency of the system. During interleaving process the data is arranged in a non-contiguous way to use with the error correction codes. The aim is to distribute the error among all the blocks ensuring maximum number of errors in a block stays within the correcting limit. The output will be equal to input bits to the interleaver. The process of FEC and bit-interleaving as a whole is called the channel coding.

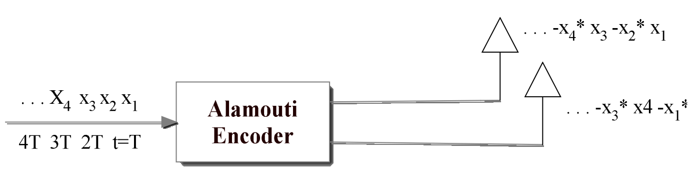

Fig. 2. Alamouti Scheme

The signal after the channel coding is the input to modulator for the purpose of transmission in the medium. Modulation is the technique which facilitates the transfer of information over a medium. It is done by varying the different parameters of the high frequency carrier signal with the information signal. The periodic carrier signal is usually sinusoidal signal used for modulation. By varying the different parameters of the carrier signal give birth to different modulation schemes. We can vary Amplitude, Phase, and Frequency to have Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK) respectively. There are also different modulation schemes in which we can vary two parameters simultaneously i.e., Quadrature Amplitude Modulation (QAM) in which we are varying amplitude and phase at a time.

In the scenario of multiple transmitting antennas, Space-time codes (STC) are utilized to improve the reliability of the communication channel. The STC works on the principle of transmitting redundant bits from multiple antennas to ensure that few of them will be received at the receiver end. Diversity gain at the transmitter end can be improved by using the STC so that at the receiver end it is easy to decode the message. Space-time Trellis & Block codes are available, and here we used Space-time Block Codes (STBC) because of their less complexity and feasible implementation as compared to Trellis Codes. Alamouti code is the example of STBC and can be applied in case of multiple transmit antennas. The general block diagram of Alamouti encoder is shown in Fig. 2. At the first instant t=T, we transmit x_1 from the first antenna and x_2 from the second antenna. During second instant t=2T, we transmit $-x_2^*$ from the first antenna and x_1^* from the second antenna. We can generalize the encoding matrix for the case of more than two antennas. Alamouti encoder encodes the incoming bit stream from the modulator and hand over to transmitting antennas. In this way we achieve the diversity gain at the transmitter side. The code rate of Alamouti is 1 for the case of two transmitting antennas and it decreases with the increasing antennas on transmitter side.

The channel effect of the wireless communication system is worthy and actually responsible for the output at the receiver end. Channel Modeling is a prerequisite for the MIMO system design, deployment and the simulations. Different channels models exist like Rayleigh fading and

Rician fading etc. We have used the Rayleigh fading channel for our simulations and it can be described as [5]

$$g(t,\tau) = \sum_{i=0}^{L-1} \alpha_i \delta(t - \tau_i)$$

Where α_i is the time-varying gain having complex Rayleigh Distribution τ_i is time-delay for the i^{th} multipath and L is total number of multipaths.

This model assumes that signal which is passing through the channel will vary randomly under the Rayleigh distribution. Rayleigh distribution is useful when there is absence of line of sight (LOS) between the transmitter and receiver and the path is varying. The channel matrix can be defined as [6]

$$\boldsymbol{H} = \begin{bmatrix} h_{11} & h_{12} & \dots & h_{1M} \\ h_{21} & h_{22} & \dots & h_{2M} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ h_{N1} & h_{N2} & \dots & h_{NM} \end{bmatrix}$$

The incoming data from the STBC will be convolved with this channel matrix and is then propagated.

At the receiver, receiving antennas will receive the incoming data stream and convey to the space-time block decoder for further processing. ISI and frequency selectivity can occur due to the multipath effect. It is required to mitigate the problem by the process of channel equalization. Equalizer's output is the delayed form of the transmitted signal and it compensates for the frequency selectivity in case of time-invariant channel. Time varying channel can be compensated by the use of Adaptive equalizer. We can also use different channel estimation techniques in addition to the equalizer like LMSSE, RLS, and Kalman Filtering etc. to judge the behavior of the channel.

After this process, the data is demodulated and handover to the channel decoding block. In channel decoding we have bit de-interleaver and a Forward error correction decoding block which decodes the incoming message signal. After applying the source decoding we can have information at the receiver end.

III. SIMULATION RESULTS

Fig. 3 shows the BER performance of SISO and MIMO using two transmit antennas and two receive antennas and QPSK modulation scheme. As SISO has single transmit antenna and single receive antenna so there is no diversity on any end while MIMO having two transmit antenna and two receive antenna has diversity at both end of the wireless communication so the BER performance of MIMO system is better than SISO over same SNR.

Fig. 4 shows the comparison of no diversity, transmit diversity, receive diversity and MIMO systems. Fig. 4 shows that BER decreases slowly with no diversity and rapid decrease in MIMO but same diversity order in receive and transmit diversity system because both SIMO and MISO systems have same computation complexity. We also observe that receive diversity has a 3 dB advantage as compared to Alamouti transmit diversity. This is due to same transmitting power in both cases. In receive diversity we transmit all the power from one antenna while in transmit diversity we send half power from one antenna and other half power from second antenna. We try to reduce the computational burden on receiver end to save the power consumption of communication device like mobile. In that case, we prefer transmit diversity because receive diversity is a critical drawback due to more computational burden on receiver end. Differential space-time codes can be used to reduce the computational complexity in mobile unit because CSI estimation is not requiring at receiver end.

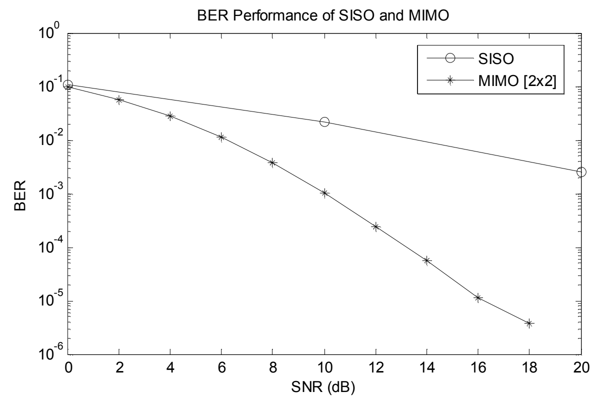

Fig. 3. BER vs SNR for SISO and MIMO

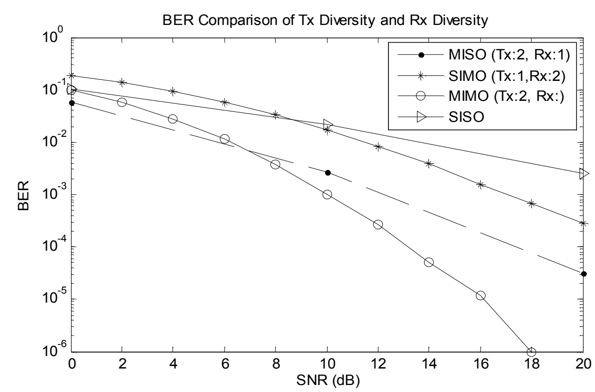

Fig. 4. BER vs SNR for Tx and Rx Diverdity

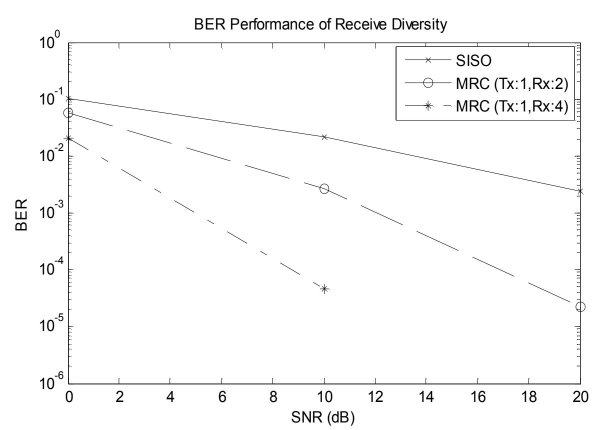

Fig. 5. BER vs SNR for Receive Diversity

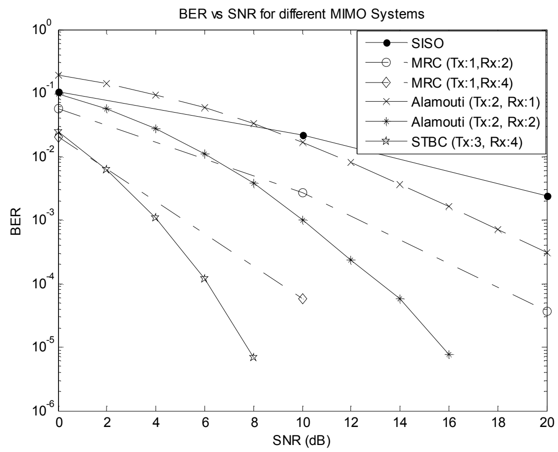

Fig. 6. BER vs SNR for different MIMO Systems

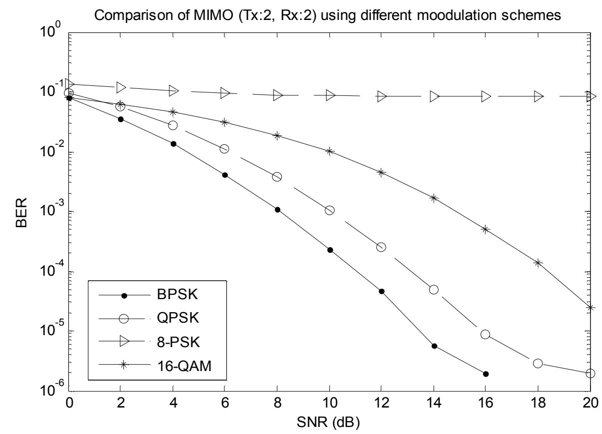

Fig. 7. BER vs SNR for different Modulations

Fig. 5 shows the comparison of only receive diversity. With the increase in receive diversity there is rapid degradation in BER with increase in SNR. As the system having one transmit antenna and two receive antenna has BER about $10^{-4.6}$ at SNR about 18 dB while same BER can be achieve at 10 dB SNR using four receive antennas.

Fig. 6 shows the BER performance of SISO, SIMO, MISO and MIMO system using QPSK modulation scheme. Figure 6 clearly shows that with the increase of SNR, BER decreases gradually. In MIMO system BER decreases more rapidly than SISO, SIMO and MISO systems due to high diversity gain in MIMO system and similarly SIMO and MISO systems give more BER performance than SISO systems. The purpose of our using the diversity techniques is to diminish the degradation in error performance due to unstable fading channels in wireless systems. The complexity of different MIMO systems for different modulation techniques is given in Table 1.

Fig. 7 demonstrates the performance of MIMO system employing different modulation techniques for data transmission. As from the general modulation theory we know the performance is better for less order modulation technique as compared to high order modulation but in high order modulation we have larger data rate. Same behavior is also observed for MIMO system. Performance is same for all kinds of modulation at small value of SNR but as we increase the SNR value the performance gap goes on increasing. So enhance the diversity with improved data rate we prefer high order modulation but at the cost of degraded performance.

Table 1: Complexity of Different MIMO Systems

Simulation Times (sec)				
System	BPSK	QPSK	8-PSK	16-QAM
1 × 1	6.3669	7.47	8.7885	12.3583
1 × 2	7.4268	8.4965	9.8929	13.1939
1 × 4	9.4618	10.4681	11.9176	15.2098
2 × 1	50.9264	60.19	72.8174	103.6118
2 × 2	98.1303	120.8139	161.0485	253.4673
3 × 4	124.214	161.0066	197.3825	278.6012

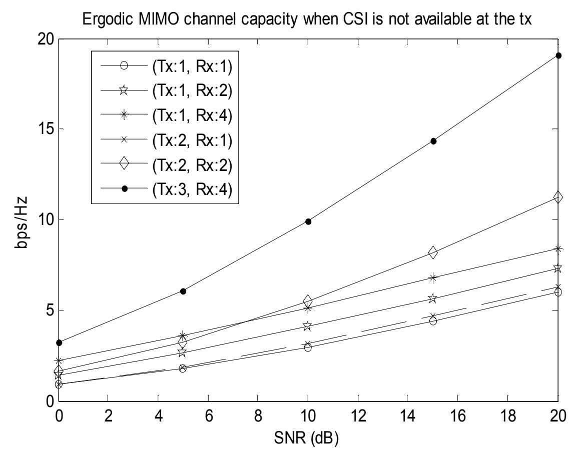

Fig. 8. MIMO Channel Capacity

The MIMO channel capacity for different operating power conditions when channel state information is not available at the transmitter is given in Figure 8. Irrespective of order of system, the capacity is almost same at low SNR values. But as we increase the SNR the capacity increases as we use more transmit and receive antennas. So at high SNR conditions, more capacity can be achieved but at the cost of increased system order which also results in more system complexity.

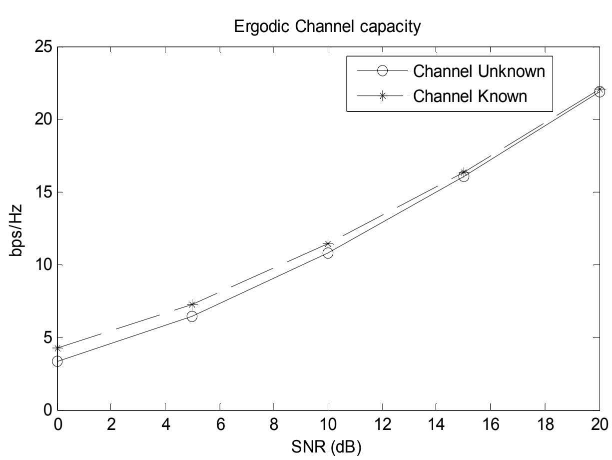

Fig. 9. Channel Capacity with and without CSI

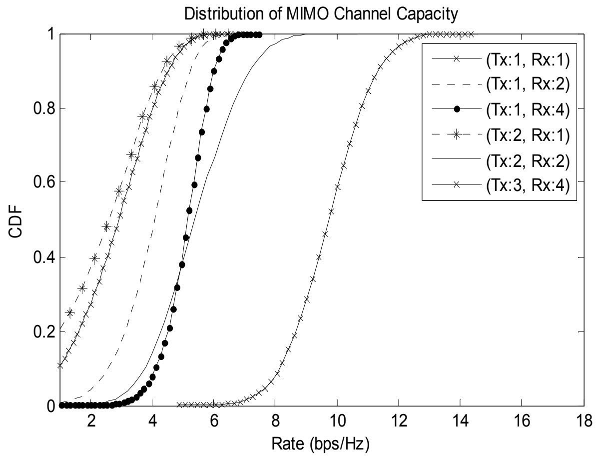

Fig. 10. Capacity vs CDF for different MIMO Systems

Channel Capacity under known Channel State Information (CSI) and unknown CSI conditions is given in Figure 9. At low SNR, the capacity is greater for known CSI case as compared to un-known CSI condition but as we increase SNR this difference goes on diminishing and at high SNR, both have almost same capacity.

Fig. 10 shows the channel capacity vs Cumulative Distribution Function (CDF) for different MIMO systems. It is clear from Figure 10 that system capacity increase with increasing the number of antennas at the transmitter and receiver side.

IV. CONCLUSION

In this paper, performance of different MIMO systems is evaluated for different modulation schemes. It is observed that by increasing the order of the MIMO system the capacity of the system increases but along with this the complexity of the overall transceiver increases. To increase the capacity further we can make use of Channel State Information that can be made available by using any channel estimation technique. For low SNR, both the performance and capacity of all MIMO systems remains almost same but at high SNR values, the differentiation is easier to make.

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