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Wireless Multiple Input Multiple Output System with Relaying

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Abstract—The Multiple Input Multiple Output (MIMO) system offers high transmission rate without the use of extra bandwidth and power. The principal goal of MIMO technology is to improve the quality, i.e. bit error rate (BER) by means of adequate signal processing techniques. This paper gives an overview of MIMO systems. Multiple antennas have been used to increase diversity to combat channel fading. Receive diversity techniques and transmit diversity techniques are studied and analysed. Inter Symbol interference (lSI) is a major problem even in MIMO systems. To mitigate lSI, equalization techniques are employed on the receiver side. Wireless relaying networks had recently been given considerable benefits over traditional communication system. The relaying terminals forward the information from the source to the destination mainly using the Amplify-Forward method. In this project achievable sum rate of multi way relaying with non re-generative relay (Amplify and forward) method is analyzed.

Index Terms—MIMO system, capacity, spatial multiplexing

I. INTRODUCTION

Upcoming wireless mobile communication systems require the reliable transmission of high data rate under various types of channels and scenarios. Current wireless communication systems like mobile is converging into a data oriented wireless networks. High spectral efficiency is a feature of these networks. The system should be robust to the influence of fading, interference, and hardware imperfections. Next generation wireless communication systems should be adaptive to various scenarios and Quality-of-Service (QoS) requirements. The very high data rates needed for future wireless systems in reasonably large areas is not possible with the conventional techniques and architectures. Frequency bands that are envisioned for future wireless communication systems are well above 2GHz. The design of efficient wireless systems will require the use of multiple antennas, advanced adaptive modulation and coding schemes, relaying nodes and cooperative networks. The goal of reaching high data rates is particularly challenging. The uses of multiple transmit and receive antennas exploit significant increase in channel capacity. MIMO system provides an improved channel capacity without increasing the transmission bandwidth and power resources. MIMO has been developed to fulfil the demand of higher data rates in wireless communications [1].

Digital communication using MIMO, is known as one of the most significant technology. This technology figures prominently in the list of recent technical advances with a chance of resolving the problem of traffic capacity. In future internet oriented wireless network capacity is very important parameter [2].

In this paper SNR improvement analysis using various receive diversity techniques, is done. Also bit error rate is analysed using different diversity techniques and spatial multiplexing receivers (Equalizers). The study of MIMO system is further extended by use of relay in MIMO system.

II. ORGANIZATION OF PAPER

The remainder of this paper is organized as follows. Section 3 gives the brief review of literature papers. In section 4 capacity analysis and simulation of Multiple Input Multiple Output (MIMO) System is done. Cumulative distribution function is also found. In section 5 MIMO characteristics, diversity and spatial multiplexing are studied. The system parameter bit error rate is found for diversity techniques. Spatial multiplexing receivers i.e. equalizers are also studied. Section 6 gives the designing of multi-way relaying. Achievable sum rate of asymmetric traffic for non-regenerative relay is found. Section 7 provides a conclusion and gives recommendations for future study.

III. LITERATURE SURVEY

A brief overview of MIMO wireless technology covering channel models, capacity, coding, receiver design, performance limits has been presented by A. J. Paulraj et al [1]. In 1996 G.H.Foschini examined the advantages of a multi-element array (MEA) technology, which is, processing the spatial dimension to improve wireless capacities in certain applications. In his paper he presented some basic information theory results that promise great advantages of using MEAs in wireless LANs. The capacity offered by MEA technology is expressed by fixing all transmitted power and it is seen that capacity increases with increasing SNR for a large but practical number, 'n', of antenna elements at both transmitter and receiver.

Simultaneous use of transmit and receive diversity greatly increases the capacity over what is possible with just receive diversity [6].

Automatic selection of the strongest among various receivers was discussed as early as 1930. This naturally led to the suggestion of receiver antenna selection combining, initially for microwave links. MRC (Maximum Ratio Combining) first proposed in 1954 [7]. Pioneered in [8], transmit diversity techniques flourished into OSTBC (orthogonal space-time block codes) and, subsequently, onto space-time codes at large. Albeit first proposed for single-antenna receivers, OSTBCs can also be used in MIMO. The idea behind spatial multiplexing is to transmit different symbols from each antenna and have the receiver discriminate these symbols by taking advantage of the fact that, due to spatial selectivity, each transmit antenna has a different spatial signature at the receiver. This does allow for an increased number of information symbols per MIMO symbol [9].

The use of multiple antennas at both ends of a wireless link has recently been shown to have the potential of achieving extraordinary bit rates. The corresponding technology is known as spatial multiplexing In the presence of rich multipath leading to antenna de-correlation and full channel rank, MIMO links offer capacity gains that are proportional to the minimum of the number of transmit and receive antennas. These gains can be achieved using spatial multiplexing algorithms [10][11][12].

Spatial multiplexing receivers are equalizers. An in-depth analysis of the zero forcing (ZF) and minimum mean squared error (MMSE) equalizers applied to wireless MIMO systems receive antennas is given in [13].

The study of MIMO system can be advanced by using MIMO system with relay. Wireless relay network has recently attracted lots of attention due to its capability of improving the transmission spectrum efficiency and enhancing the detection reliability. So far, two types of relay networks have been extensively studied: one way relay networks (OWRN) [13], where data streams flow unidirectionally from one terminal to the other, and twoway relay network (TWRN) [14], where data streams flow in a bidirectional manner. A natural generalization to OWRN and TWRN is to consider multiple source terminals that communicate with one another with the assist once of the relay node. The system derived like this is named as N-way relay networks, where N stands for the number of the source terminals. A typical scenario is the peer-to-peer (P2P) computer communications through wireless links, where each source terminal has the packets that are required by all other terminals. The structure of the beamforming matrix used at relay which can be used for capacity, MSE, BER, outage, etc. is presented [1].

IV. CAPACITY ANALYSIS OF MIMO SYSTEM

The use of antenna arrays at both sides of the wireless communication link can result in high channel capacity [6].

A. Single Input Single Output (SISO)

Wireless transmissions traditionally use one antenna at the transmitter and one antenna at the receiver. It has been used from many years since the birth of radio technology. It is used in radio, TV broadcast and our personal wireless technologies for example Wi-fi, Bluetooth, etc. The main problem with this type of system is fading. Capacity of SISO system is defined as given in equation 1.

$$C_{SISO} = \log_2(1 + SNR_{SISO})\text{bits/sec/Hz}\ldots\ldots(1)$$

In this type of system 3dB extra power is needed for the transmission of every extra bit.

B. Multiple Input Single Output(MISO)

Capacity of MISO is given in equation 2.

$$C_{MISO} = \log_2(1 + \frac{P||H^2||}{NN_0})\text{bits/sec/Hz}\ldots\ldots(2)$$

H is MISO channel with 'n' transmit antennas and single receive antenna (m=1). P is the average energy per bit. The technique is known as transmitter diversity. MISO technology has widespread applications in digital television (DTV), wireless local area networks (WLANs), metropolitan area networks (MANs) and mobile communications.

C. Single Input Multiple Output (SIMO)

The receiver can either choose the best antenna to receive a stronger signal to combine signals from all antennas in such a way that maximizes SNR. This technique is known as selection diversity or receiver diversity. Capacity of SIMO is given by equation 3.

$$C_{SIMO} = \log_2(1 + \frac{P||H^2||}{N_0})\text{bits/sec/Hz}\ldots\ldots..(3)$$

H is SIMO channel with 'm' receive antennas and single transmit antenna (n=1). P is the average energy per bit.

Multiple receive antennas increase the effective SNR and provide a power gain. Dual receive antennas provide 3dB power gain over a single system.

D. Multiple Input Multiple Output(MIMO)

Capacity of MIMO system is given by equation 4.

$$C_{MIMO} = \log_2[\det\left(I_N + \frac{PHH^+}{N_0}\right)]\text{bits/sec/Hz}\ldots \qquad (4)$$

H is MIMO channel with 'n' transmit antennas and 'm' single receive antenna. P is the average energy per bit.

Capacity is proportional to minimum number of transmitter and receiver antennas min (n,m)[6].

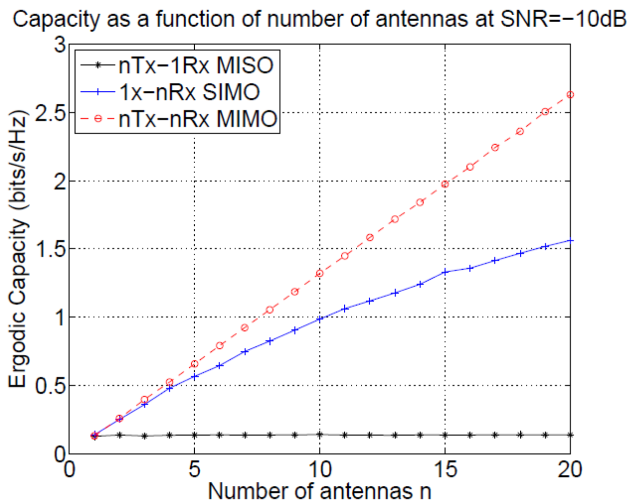

Fig.1 Comparison of capacities of MIMO systems with varying number of antennas at SNR of -10 dB.

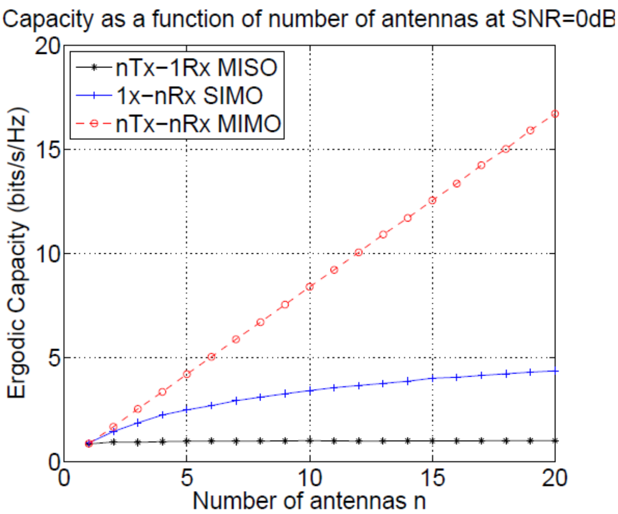

Fig.2 Comparison of capacities of MIMO systems with varying number of antennas at SNR of 0 dB.

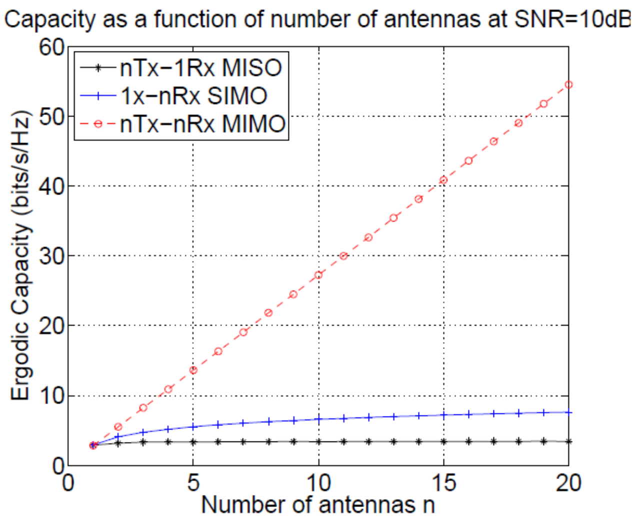

Fig.3 Comparison of capacities of MIMO systems with varying number of antennas at SNR of 10 dB.

From the result as shown in fig.1, 2 and fig.3 it is found that capacity range increases as we increase SNR value. Because maximum capacity for MIMO at -10 dB SNR is 2.5 bits/sec/Hz, at 0dB SNR maximum capacity is 14 bits/sec/Hz and at 10 dB SNR maximum capacity is 45 bits/sec/Hz.

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From the result as in fig. 4 it is found that if we increase the number of transmitter and receiver antennas the Shanon capacity increases. This can be practically proved by taking capacity values at 30dB SNR. Capacity for MIMO (8x8) is 69.23bits/sec/Hz, for MIMO (4x4) is 34.91bits/sec/Hz and for MIMO (2x2) is 19.08bits/sec/Hz.

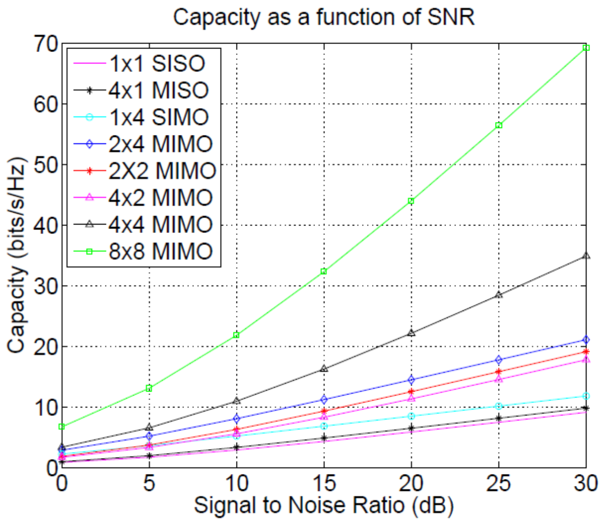

Fig.4 Capacity comparison of MIMO system as a function of SNR

From these findings, we can conclude that capacity C grows linearly with min(n,m). Capacity for MIMO(2x4) is 21.07bits/sec/Hz, and MIMO (4x2) is 17.73bits/sec/Hz. For MIMO (1x4) is 11.78bits/sec/Hz, for MIMO(4x1) is 9.778bits/sec/Hz and for SISO it is 9.129bits/sec/Hz. The capacity of SIMO greater than MISO. From result as shown in fig. 5 it is found that Cumulative Distribution Function(CDF) of MIMO system increases if we increase the number of transmitter and receiver antennas.

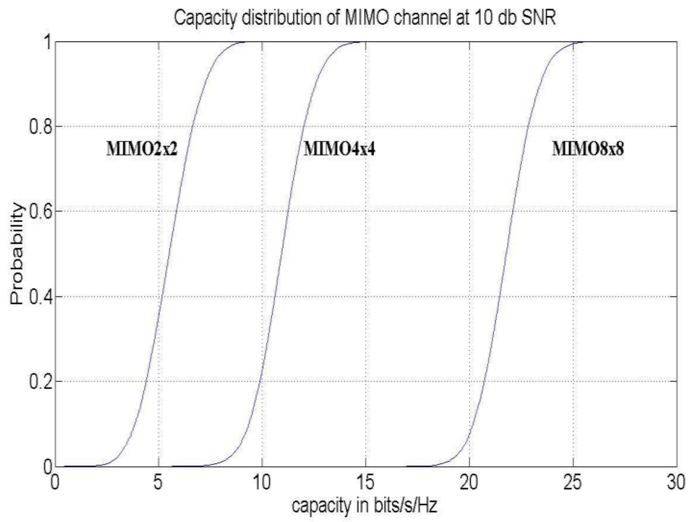

Fig.5 Distribution of channel capacity

V. DIVERSITY AND SPATIAL MULTIPLEXING

It is observed that if two or more radio channels are sufficiently separated in space, frequency, or time and sometimes in polarization then the fading on the various channels is more or less independent. The standard techniques for reducing the effect of fading known as diversity techniques make use of this fact. The key idea in MIMO diversity techniques is that the same data stream is transmitted from multiple antennas or received at more than one antenna. Diversity can be

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implemented at the transmit end (transmit diversity), at the receive end (receive diversity) or at both ends of the wireless link. Generally, MIMO diversity techniques can provide higher SNR and improve transmission reliability [8].

5.1 Receive Diversity Techniques

Receive diversity techniques are widely used in wireless communication systems; it can be achieved by receiving redundant copies of the same signal. There are several classical methods for combining the different diversity branches at the receiver, the most important of which and most widely used are Selection Combining (SC), Maximal Ratio Combining (MRC) and Equal Gain Combining (EGC) [9][10].

A. Selection Diversity

The design criterion here is that, at any given time, the system simply picks out the best of the N noisy signals. Very often, the selection in such systems has been by electronic means. Effective SNR for this diversity is given by equation 5.

$$\mathrm{SNR} = \sum_{k=1}^{k=N} \frac{1}{k} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

B. Maximal Ratio Diversity

The selection combining technique ignores information from all diversity branches except the particular branch that has the highest SNR. This drawback is mitigated by using Maximal Ratio Combining, in which the information from all branches is combined in order to maximize the output SNR. MRC works by weighting each branch with the complex conjugate of their particular channel coefficients and then do summation to produce the received signal [10].

Effective SNR for this diversity is given by equation 6.

$$SNR = N \ldots\ldots\ldots\ldots(6)$$

where N is number of receive antennas.

C. Equal Gain Diversity

This is probably the simplest possible linear diversity technique; it is characterized by the property that all channels have exactly the same gain.
Equal Gain Combining (EGC) is similar to Maximal Ratio Combining without weighting the signals before summation as shown in fig.6

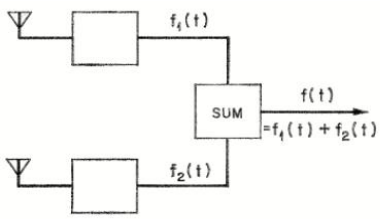

Fig.6 Receive Diversity:Equal Gain Combining

In EGC co-phasing is needed to avoid signal cancellation. The average SNR improvement of EGC is typically about 1 dB worse than with MRC, but still simpler to implement than MRC. The effective SNR for this diversity is given by equation 7.

$$\mathrm{SNR} = 1 + (\mathrm{N}-1)\left(\frac{\mathrm{pi}}{4}\right) \ldots\ldots\ldots\ldots\ldots (7)$$

where N is number of receive antennas.

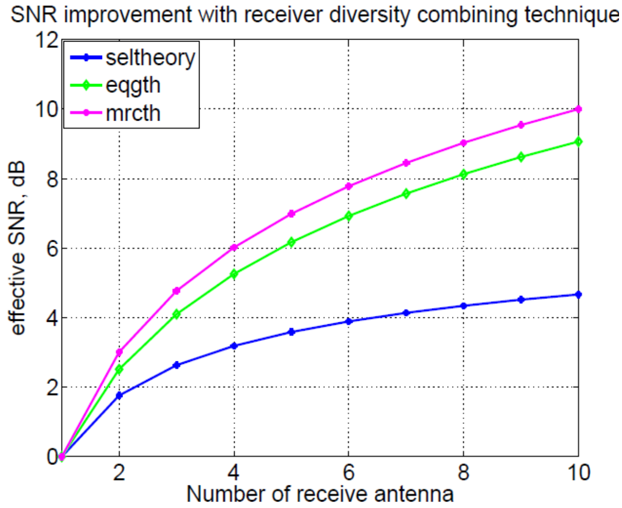

Fig.7 SNR improvement with receiver diversity techniques

From the result shown in fig.7 it is found that MRC outperforms the Selection Combining. Equal gain combining (EGC) performs very close to the MRC.

5.2 Transmit Diversity Techniques

Transmit diversity improves the signal quality and achieves a higher SNR ratio at the receiver side; it involves transmitting data stream through multiple antennas and receiving by single antenna or more. Transmit diversity can effectively mitigate multipath fading effects as multiple antennas give several observations of the same data stream to a receiver. Each antenna will experience a different interference environment. Thus, transmit diversity can help improve the reliability of the data reception and data decoding as well. The most popular examples of these transmit diversity techniques is Alamouti code [9][11]. In following section Almouti's transmit diversity schemes are explained.

Two branch transmit diversity with one receiver

The signal transmitted from antenna zero is denoted by s_0 and from antenna one by s_1. During the next symbol period $(-s_1^*)$ is transmitted from antenna zero and signal (s_0^*) is transmitted from antenna one, where * is the complex conjugate operation. The received signal can be expressed by equations 8 and 9

$$r_0 = h_0 s_0 + h_1 s_1 + n_0 \quad \text{.................}(8)$$

$$r_1 = -h_0 s_1^* + h_1 s_0^* + n_1 \quad \text{.................}(9)$$

where r is the received signal at the receiver, h is channel transfer function.

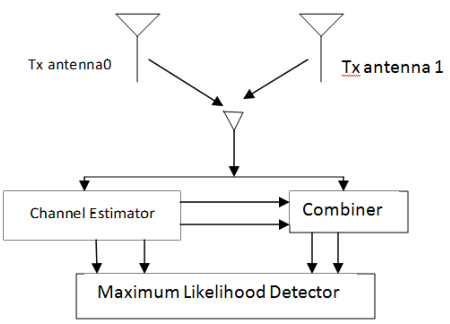

Fig. 8 Transmit diversity with one receiver

Fig.8 shows the baseband representation of the two branch transmit diversity scheme. The scheme uses two transmit antennas and one receive antenna. At a given symbol period two signals are simultaneously transmitted from the two antennas.
Bit error rate metric gives the number of bit discrepancies between the transmitted and received message as a fraction of the total number of bits contained in the message. The ratio given is normally an average with the message size tending to infinity as the number of bit errors for any given message will vary.

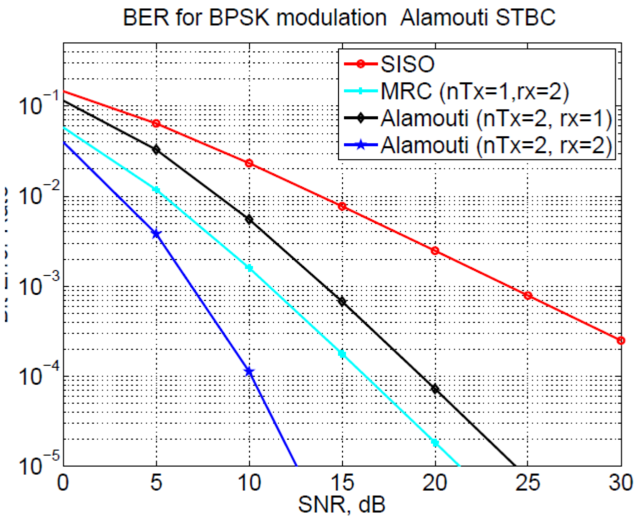

Fig. 9 Bit Error Rate comparison of MIMO using different transmit and receive diversity techniques

It can observed from fig.9 that the BER performance of Almouti's case with two transmit and two receive antenna is much better than MRC(2x1) case. This is because the effective channel concatenating the information from two receive antennas over two symbols results in a diversity order of 4. In general, with m receive antennas, the diversity order for 2 transmit antenna Alamouti STBC is 2m [9].

5.3 Spatial Multiplexing

Spatial Multiplexing (SM) is the process to break the sequence of information bits into a certain set of sub-streams that will be treated differently. In SM, 'n' independent symbols are transmitted from 'n' transmitting antennas. In order to perform SM, the number of receive antennas must be equal to or greater than the number of transmit antennas. The main idea behind SM encoding techniques rely on the use of powerful decoding techniques on the receiver side. To mitigate lSI, equalization techniques are employed on receiver side as shown in fig.10.
In this paper, Bit error rate (BER) performance improvements of MIMO systems using various equalization techniques like Zero-forcing (ZF) and Minimum mean square error (MMSE) are shown and compared.

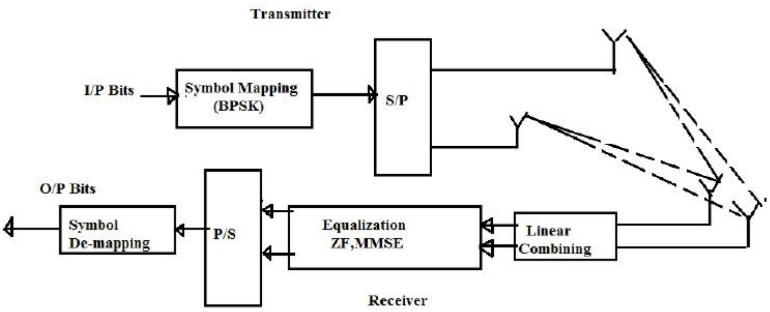

Fig. 10 Equalization Technique

BER analysis is done under Rayleigh frequency flat fading channel[10]. lSI caused by multi-path channels will result into an irreducible errorat the receiver. It severely affects the system performance when modulation symbol time is of the same order as that of channel delay spread. Equalization is a filtering approach which minimizes the error between actual and desired output by continuous updating its filter coefficients [13].

A. Zero Forcing Equalizer

A zero-forcing equalizer uses an inverse filter to compensate for the channel response function. At the output of the equalizer, it has an overall response function equal to one for the symbol that is being detected and an overall zero response for other symbols. Thus, it results in removal of interference from all other symbols. The major advantages of ZF linear equalizer is that it simply eliminates ISI by forcing the overall pulse to make a unit-impulse response. The ZF equalizer is given by the pseudo inverse of H as given in equation 10.

$$W_{ZF} = (H^H H)^{-1} H \dots\dots..(10)$$

where W_{ZF} is equalization matrix and H is a channel matrix. The result of ZF equalization is written as given in equation 11.

$$y_{ZF} = W_{ZF} y \dots\dots\dots\dots(11)$$

B. Minimum Mean Square Error (MMSE)Equalizer

MMSE equalizer is used to minimize the average mean square error (MSE) between the transmitted symbol and its estimated value at the output of equalizer. The MMSE detector is also called an optimal detector because it minimizes interference and noise[10].

Minimum mean square error equalizer minimizes the mean square error between the output of the equalizer and the transmitted symbol. Compared with a ZF equalizer, an MMSE equalizer is much more robust in presence of deepest channel nulls and noise. The MMSE equalization matrix W_{MMSE} is given by equation 12.

$$W_{MMSE} = H^H (HH^H + n_0 I_n)^{-1} \dots\dots(12)$$

where W_{MMSE} is equalization matrix, H is a channel matrix and n is channel noise. The result of MMSE equalization is written as given in equation 13.

$$y_{MMSE} = W_{MMSE} y \dots\dots..(13)$$

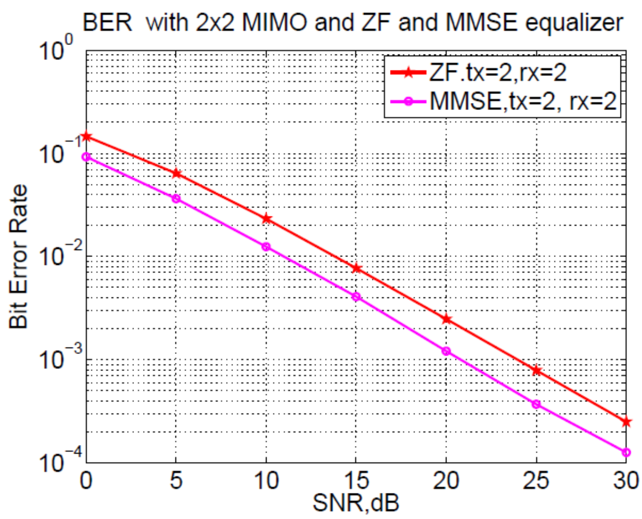

Fig.11 Bit error rate comparison using different equalizer

The simulation results shown on fig.11 demonstrate that for BER values sharply decreases as the SNR increases. From the results shown in fig.4.10 it is found that when MIMO system is integrated for bit error rate with ZF and MMSE equalizers MMSE performs better than ZF. BER of MMSE at 15 dB SNR is 0.004 where as BER of ZF at 15dB SNR is 0.0072.

VI. DESIGNING MULTI-WAY RELAY

Recently relay communication becomes an interesting topic of research. There are two types of relay one way relay and two way relay. Two-way relaying adopts the idea of network coding where the RS uses either analogue network coding or digital network coding. Analogue network coding is non-regenerative relaying. Non-regenerative RS has three advantages: no decoding error propagation, no delay due to decoding and deinterleaving and transparency to the modulation [15].
In this paper performance of non-regenerative multi-way relay is evaluated with achievable sum rate for asymmetric traffic. In asymmetric traffic all nodes communicate with minimum traffic rate. In multi-way communication, if all N nodes are half-duplex and there are direct links between them, the required number of communication phases in order for each node to obtain the information from all other nodes is N[13]14]. The number of nodes decides the number of communication phases.

6.1 Transcieve Beamforming

In this section the design of two transcieve beamforming for N-phase non-regenerative multi-way relaying is explained. Two different criteria are considered, namely Zero Forcing(ZF) and Minimum Mean Square Error(MMSE).

A. Zero Forcing beamforming

Zero-forcing Beamforming (ZF-BF) is a spatial signal processing in multiple antenna wireless devices. For downlink, the ZF-BF algorithm allows a transmitter to send data to desired users together with nulling out the directions to undesired users. If the transmitter knows the downlink channel status information perfectly, ZF-based precoding can achieve close to the optimal capacity especially when the number of users is sufficient.

B. Minimum Mean Square Error Beamforming

The minimum mean squared error (MMSE) algorithm minimizes the error with respect to a reference signal. The MMSE technique minimizes the error with respect to a reference signal. In the multipath fading environment, MMSE beamformer gives the optimum results. Thus, MMSE beamforming is an optimum candidate for non-line of sight (NLOS) urban environment, as it not only reduces the interference, but also multipath fading is mitigated [1].

C. Signal to Interference and Noise Ratio (SINR)

SINR is a quantity used to give theoretical upper bounds on channel capacity in wireless communication systems such as networks. Similar to the SNR used often in wired communications systems, the SINR is defined as the power of a certain signal of interest divided by the sum of the interference power and the power of some background noise.

6.2 Performance analysis

Fig. 12 shows the sum rate performance of multi-way relaying using two linear transceive beamformers for the asymmetric case, with and without interferenccancellation.

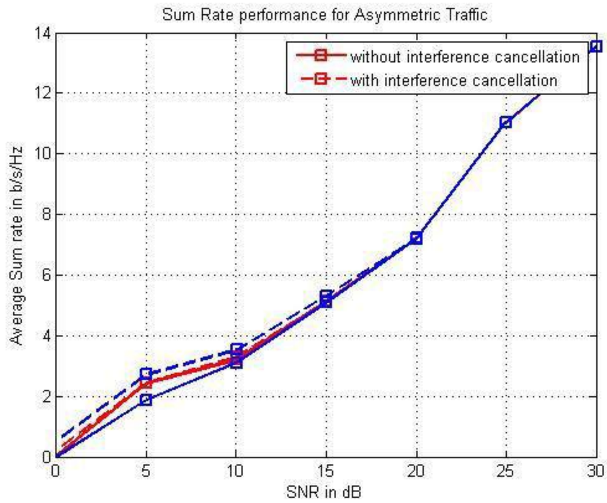

Fig.12 Sum Rate Performance for asymmetric traffic

The MMSE performs the best. As it can be seen, MMSE converges to ZF in the high SNR . When we consider the impact of interference it is found that ZF, which forces the interference to be zero, does not have any performance improvement since there is no appearance of the BC's interfering signals at all nodes. MMSE is able to obtain a performance gain if interference cancellation is applied.

VII. CONCLUSION

In this paper wireless MIMO system is analyzed. For analysis capacity is taken as basic parameter. It is found that capacity grows linearly with minimum number of transmitter or receiver antenna. In MIMO system capacity can be increased without increase in power or bandwidth.

Diversity techniques are used to reduce the effect of fading in wireless communication. In this paper various receive diversity techniques are presented. SNR improvement using these receive diversity techniques is also studied. Transmit diversity techniques was first studied by Almouti. Almouti's scheme is compared with receive diversity techniques with respect to bit error rate.

There are various advantages of MIMO system like capacity enhancement and spatial multiplexing but Inter Symbol Interference (ISI) is major problem even in MIMO system. To lessen the effect of ISI various equalization methods are used. Zero forcig and MMSE equalizers are studied and their bit error rates(BER) are compared.

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