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PERFORMANCE EVALUATION OF AF AND DF MIMO INCREMENTAL RELAYING SCHEMES FOR WIRELESS COMMUNICATION SYSTEMS

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Abstract—The evaluation of AF (Amplify and Forward) MIMO (Multiple Input Multiple Output) incremental relay wireless system is carried out and compared against the performance of a DF (Decode and Forward) MIMO relay wireless system. The encoding scheme used in MIMO relay is Alamouti coding and decoding is done by a modified Maximum Likelihood (ML) decoder. The plots of bit error rate (BER) versus signal to noise ratio (SNR) are simulated by incorporating Rayleigh fading condition in the presence of additive white Gaussian noise (AWGN). The performances of the two incremental relaying schemes is evaluated and better spectral efficiency is achieved.

Keywords—AF and DF MIMO incremental relays, Alamouti coding, modified Maximum Likelihood decoder, Rayleigh fading, additive white Gaussian noise.

I. INTRODUCTION

The increasing demand of wireless over wired communication systems wherein high data rates are sought can be met with the 5G generation systems such as the massive MIMO wireless system. MIMO offers high throughput and reliability without any expenditure on additional bandwidth or transmit power by using spatial multiplexing and spatial diversity. Space-time coding is used to exploit spatial diversity gain in point-to-point MIMO channels[1]. Since most receivers are mobile users, transmit diversity is preferred to receive diversity due to constraints on antenna separation on the mobile. However, there are applications where a higher order of diversity is needed and multiple receive antennas are feasible at the remote units which may be either stationary or mobile. Keeping these applications in mind, this paper incorporates multiple antennas both at the transmitter as well as at the receiver. The MIMO concept is extended to relays to increase the capacity and reliability further where the relay is also equipped with multiple antennas both at the receiving and transmitting ends of the relay. This paper evaluates the performances of two incremental relaying schemes and achieves a substantial saving of bandwidth (BW) at the cost of receiver diversity.

In the relay-based communication system, a source communicates with a destination with the help of other nodes or relays. The use of relays (fixed) increase coverage and link capacity in regions where there is significant shadowing without requiring large transmit powers. Because of the ease of implementation, fixed relays are a low cost and low complexity solution to meet the requirement of high data rate communication far from the base station. The benefits of relaying combined with the advantages of multiple antennas make the MIMO relaying technique powerful to achieve high sum capacity with the reliability. All nodes operate in half-duplex mode in MIMO relaying[2].

The paper is organized as follows. Section II deals with the MIMO concept. The modified ML decoder is proposed in Section III . Section IV discusses the SISO and MIMO Relay Concept along with the AF MIMO relay methodology. Section V provides details about the simulation methodology followed. The concept of Incremental Relaying is covered in Section VI. In section VII, the bit-error performance of AF and DF SISO and MIMO relaying methods with binary phase-shift keying (BPSK) is presented. Section VIII draws the conclusions for this paper.

II. MIMO CONCEPT

Alamouti[3] introduced the MIMO scheme allowing to transmit at two antennas with the same data rate as on a single antenna but increasing the diversity at the receiver from one to two in a flat fading channel.

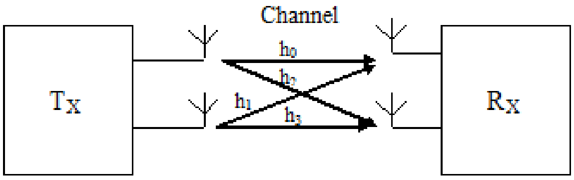

Figure 1. 2x2 MIMO

Figure 1 shows a 2x2 MIMO wireless system having two transmit antennas and two receive antennas where h_0,h_1,h_2 and h_3 are the channels between the transmit and receive antennas. The signal to be transmitted is modulated, encoded and sent over the channel. It is assumed that the channel experienced by each transmit antenna is independent of the channel experienced by the other transmit antennas. The channel is known at the receiver[4]. AWGN is added to the transmitted signals in the Rayleigh channel.

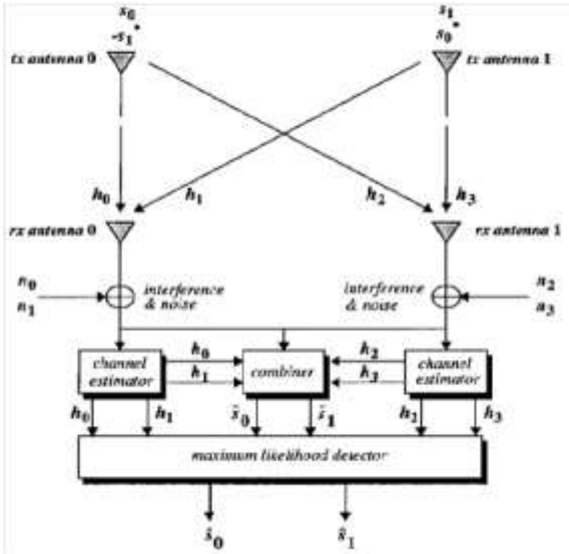

Figure 2. Two-branch transmit diversity scheme with two receivers

The MIMO model which is to be realized at the receiver is of the form

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

where y is the matrix at the receiver, h is the Rayleigh channel coefficient matrix, x is the matrix of transmitted signals and n is the matrix of random, complex, zero mean, unit variance noise signals. The transmitted signal is encoded using the Alamouti Space-Time Code[3] in which the information bits are first modulated using an *M*-ary modulation scheme. The Space-Time Code matrix is,

$$s=\begin{bmatrix} s_0 & -s_1^* \\ s_1 & s_0^* \end{bmatrix} \tag{2}$$

The received signal at the two receive antennas (rx_0 and rx_1) are r_0, r_1, r_2 and r_3 where r_0 and r_2 are the received signals at time t at rx_0 and rx_1, respectively, while r_1 and r_3 are the received signals at time (t+T) at rx_0 and rx_1, respectively. n_0, n_1, n_2 and n_3 are complex random variables representing receiver thermal noise and interference[3] .

$$\begin{aligned} r_0 &= h_0 s_0 + h_1 s_1 + n_0 \\ r_1 &= -h_0 s_1^* + h_1 s_0^* + n_1 \\ r_2 &= h_2 s_0 + h_3 s_1 + n_2 \\ r_3 &= -h_2 s_1^* + h_3 s_0^* + n_3 \end{aligned} \tag{3}$$

The combiner[3] in figure 2 builds the following two signals that are sent to the ML detector:

$$\begin{aligned} \tilde{s}_0 &= h_0^* r_0 + h_1 r_1^* + h_2^* r_2 + h_3 r_3^* \\ \tilde{s}_1 &= h_1^* r_0 - h_0 r_1^* + h_3^* r_2 - h_2 r_3^* \end{aligned} \tag{4}$$

III.MODIFIED MAXIMUM LIKELIHOOD DECODER

The modified ML detector is used to determine at the receiver the probabilities of what the transmitter sent and select the most likely transmission. For signal $\boldsymbol{s_0}$,it uses the following decision criteria for PSK signals[3].

Choose $\boldsymbol{s_i}$ iff

$$d^2(\tilde{\boldsymbol{s}}_\mathbf{0}, \boldsymbol{s_i}) \le d^2(\tilde{\boldsymbol{s}}_\mathbf{0}, \boldsymbol{s_k}) = \delta(delta), \forall \boldsymbol{i} \ne \boldsymbol{k} \tag{5}$$

where $d^2(\tilde{\boldsymbol{s}}_\mathbf{0}, \boldsymbol{s_i})$ is the squared Euclidean distance between signals $\tilde{\boldsymbol{s}}_\mathbf{0}$ and $\boldsymbol{s_i}$ and $\boldsymbol{s_i}$ is any one of the four symbols transmitted by the source in the two time intervals t and t+T. $\boldsymbol{s_k}$ is estimated by the pilot transmissions incorporating sufficient noise margin that gives a conservative value of BER. Similarly, for signal $\boldsymbol{s_1}$, it uses the following decision rule for PSK signals.

Choose $\boldsymbol{s_i}$ iff

$$d^2(\tilde{\boldsymbol{s}}_\mathbf{1}, \boldsymbol{s_i}) \le d^2(\tilde{\boldsymbol{s}}_\mathbf{1}, \boldsymbol{s_k}) = \delta(delta), \forall \boldsymbol{i} \ne \boldsymbol{k} \tag{6}$$

The decoded signal is then compared to the original input data stream and the BER is calculated.

IV. SISO AND MIMO RELAY CONCEPT

Adding relays in a cell reduces the signal transmission distances, resulting in lower propagation loss and higher average SINR to the mobile users. This guarantees stronger and more stable receiving signals, especially for the mobile users near the edge of the cell and improves the overall system capacity. A SISO relay cooperative communication system is shown in figure 3. It consists of the source (S), the relay (R) and the destination (D) where h_{SD}, h_{SR} and h_{RD} are complex valued channel coefficients between source and destination terminals, source and relay terminals, and relay and destination terminals, respectively. The relay receives and transmits the signal to enhance the communication between the source and destination.

The source terminal communicates with the relay and destination terminals during the first time slot. In the second time slot, both the relay and source terminals communicate with the destination terminal. In the AF SISO relay, the amplification factor is given by

$$\beta = \sqrt{\frac{x_i}{x_i * |h|^2 + \mathrm{N}_0}} \tag{7}$$

where $x_i = |s|^2$, s is the modulated input signal, h represents the Rayleigh channel and N_0 is the noise variance.

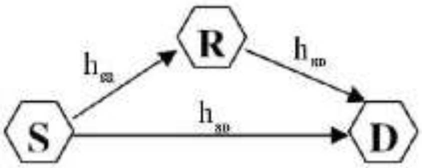

Figure 3. SISO relay

Figure 4 shows a MIMO wireless single relay which provides significant improvements in data rate and reliability compared with single-antenna systems. The transmission schemes used at the relay node are AF or DF. In AF, the relay amplifies the Alamouti encoded signal and performs simple operation of *unitary* linear transformation and then

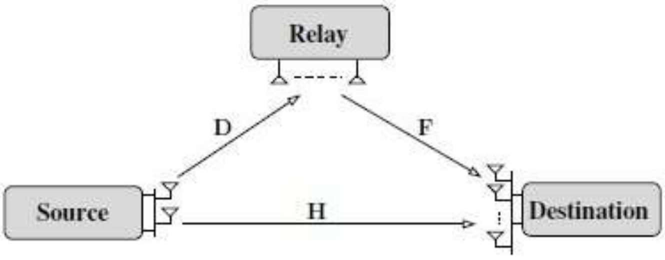

Figure 4. MIMO relay

forwards the received signal without performing any decoding or demodulation, and accordingly the phase of signals from all the relay nodes are randomly combined at a destination node. This has the big advantage[5] that the relay needs no or only partly knowledge about the structure and coding scheme of the signal. This allows for easy upgrade of a mobile communication network regarding, for example, new coding schemes, without also having to upgrade the relay station. In the DF case, the relay decodes and demodulates the signal prior to re-encoding and retransmission. This has the main advantage that the transmission can be optimized for both links, separately[5]. If a relay node correctly decodes, it will forward the source data in the second phase of the cooperation protocol; otherwise, it remains idle. This can be achieved by setting an SNR threshold at the relay node, and the relay will only forward the source data if the received SNR is larger than that threshold [6].

In figure 4[7], the modulated Alamouti encoded input signal from the Source reaches the Relay by passing through the channel **D**. After addition of noise at the receiver, the received signals at the Relay are amplified by a gain **G** defined as

$$\mathbf{G} = \sqrt{\frac{\alpha_{rd}}{\alpha_{sr}E_s\|\mathbf{D}\|_F^2+\mathbf{N}_0}}\,\mathbf{I}_{2N_r} \tag{8}$$

where α_{rd} and $\alpha_{sr}$are the path loss factors related to the relay destination and source relay links respectively, assumed to be equal to one,$E_s$is the average power of each symbol which is equal to $E\{x_n\} = P_s/N_t$, where $P_s$is the total transmit power per symbol,N_t and $N_r$are the source and relay node antennas, respectively. $\|\mathbf{D}\|_F^2$ is the Frobenius norm of the matrix **D** defined as $\|\mathbf{D}\|_F^2 = \sqrt{\mathbf{Tr}(\mathbf{DD^H})}$and $\mathbf{I}_{2Nr}$is the $2_{Nr}\times 2_{Nr}$ identity matrix.In order to simplify the analysis, we assume a fixed gain[8],

$$\mathbf{G} = \sqrt{\frac{\alpha_{rd}}{\alpha_{sr}E_s+\mathbf{N}_0}}\,\mathbf{I}_{2N_r} \tag{9}$$

The elements of $\mathbf{N}_0$ are all assumed to be identical and are given by $\mathbf{N}_0$. The amplified signals are transmitted through channel **F** and AWGN is added at the Destination[7].

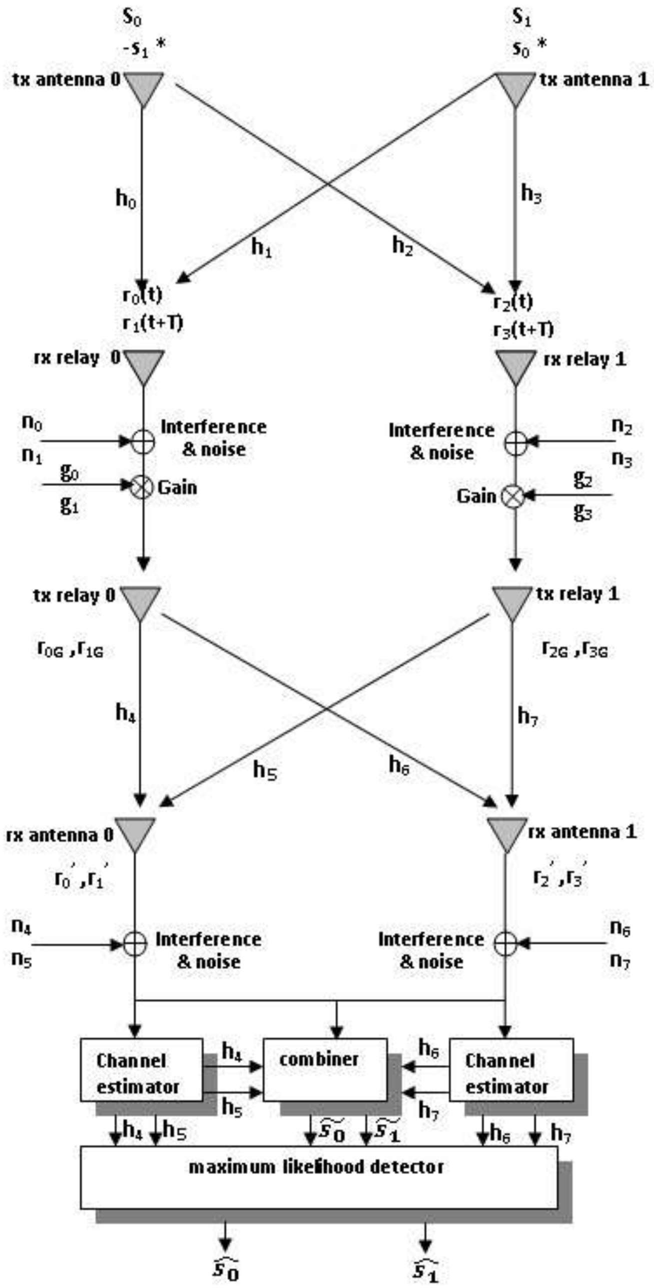

Figure 5. AF MIMO relay methodology

The methodology for the AF relay simulation is as shown in figure 5. The received signals at the relay are amplified by gain **G**, where r_{0G} and r_{2G} are amplified signals at relay transmitter antennas in first time slot and r_{1G} and r_{3G} are amplified signals at relay transmitter antennas in second time slot. The amplified signals at the relay are transmitted to the destination through channel **F**. h_4, h_5, h_6 and h_7 are the channels between relay and receive antennas. n_4, n_5, n_6, n_7 are AWGN added at the Destination. The received signals at the Destination are of the form

$$r_0' = h_4 r_{0G} + h_5 r_{2G} + n_0'$$
$$r_1' = h_4 r_{1G} + h_5 r_{3G} + n_1'$$
$$r_2' = h_6 r_{0G} + h_7 r_{2G} + n_2'$$
$$r_3' = h_6 r_{1G} + h_7 r_{3G} + n_3' \quad (10)$$

where n'_0, n'_1, n'_2 and n'_3 are the complex random variables. At the amplified relay and receiver, thermal noise and interference are added. The received signals are combined, fed to the modified ML decoder and the signal obtained is compared with original input signal. Thereafter, the BER is calculated.

IV. METHOD OF SIMULATION

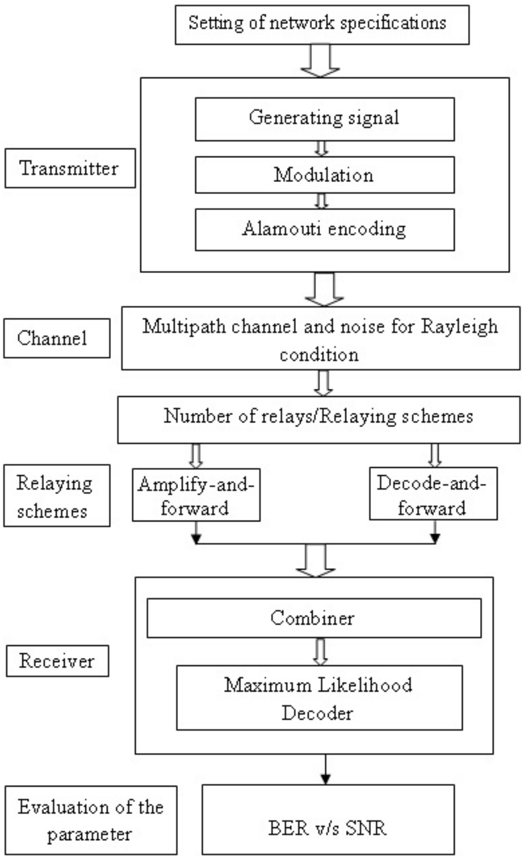

Figure 6. Simulation methodology for MIMO relays

Figure 6 describes the simulation methodology used for MIMO relays. The simulation is done by specifying the various parameters that are used namely the length of the signal, number of iterations, number of bits/symbol, type of modulation implemented, the SNR range for which BER is calculated. The input signal is then split between the two transmit antennas. Each split signal is individually modulated. Data is encoded using Alamouti's 2x2 space-time block code. The transmitted signal is thereafter fed to the channel where it is subjected to AWGN. The received signal at each receive antenna is a linear superposition of the two transmitted signals.

In the case of DF MIMO relaying, the received signal at the relay is first decoded. Without using any error correction code, this signal is again encoded using Alamouti space-time block code and transmitted to the receiver in a manner similar to that of AF MIMO relaying but without any amplification.

V. INCREMENTAL RELAYING

The above protocol as explained in section IV makes an inefficient use of the channels, especially for high rates, because relays forward the source signal to the destination every time regardless of the channel conditions. Incremental relaying protocol is carried out to save the channels by restricting the relaying process to the bad channel conditions only. Incremental-relaying schemes exploit limited feedback from the destination terminal, for example, a single bit indicating the success or failure of the direct transmission. If the destination provides a negative acknowledgment

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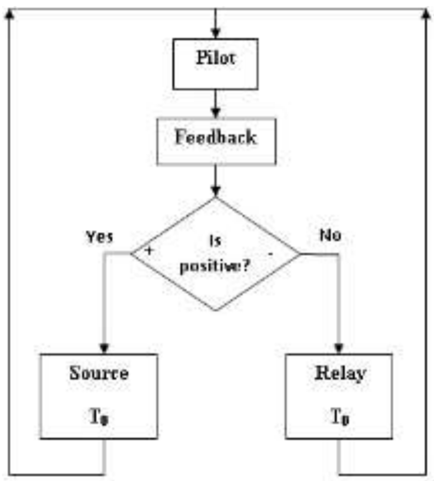
via feedback, in this case only, the relay retransmits the source signal in an attempt to exploit spatial diversity by combining the signals received at the destination from the source and the relay[9].

Incremental relaying protocols can be viewed as extensions of incremental redundancy, or hybrid automatic-repeat-request (ARQ), to the relay context. In ARQ, the source retransmits if the destination provides a negative acknowledgment via feedback; in incremental relaying, the relay retransmits in an attempt to exploit spatial diversity. As one example, consider the following protocol utilizing feedback and amplify-and-forward transmission. First, the source transmits its information to the destination. The destination indicates success or failure by broadcasting a single bit of feedback to the source and relay, which we assume is detected reliably by at least the relay. If the source-destination SNR is sufficiently high, the feedback indicates success of the direct transmission, and the relay does nothing. If the source-destination SNR is not sufficiently high for successful direct transmission, the feedback requests that the relay amplify-and-forward what it received from the source. Protocols of this form make more efficient use of the channel, because they repeat only rarely. Incremental decode-and-forward is also possible; however, its performance is slightly worse than the above protocol[10].

In this paper, the protocol is implemented in the following manner. Initially, at the start of the transmission, the source sends a pilot signal consisting of two bits to both the relay and the destination. At the destination, by observing the BER, a decision is made whether the channel is good or bad and accordingly a single bit is fed back to the source and relay, indicating success or failure of the direct transmission. Only if the direct transmission is a failure, does the relay transmit data to the destination. Otherwise, at all other times the source transmits data to the destination successfully.

In the first time slot (t), the source transmits the pilot signal to both the relay and the destination. In the second time slot (t+T), a single bit is fed back to the relay and source. In the third time slot from (t+2T) to (t+kT) where k is an integer, either the source or the relay transmits data to the destination for a continuous period of T_0, where T_0 is equal to (k-2)T since it is not convenient to obtain the feedback for every transmission. Rather, we assume that the channel parameters are constant for a



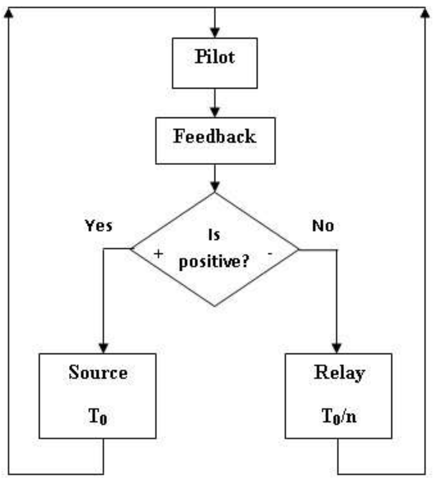


Figure 7. Incremental relay ***Figure 8. Improved incremental relay***

period of T_0 (figure 7). This saves the channel BW. A large k means a change in channel characteristics will not be noticed and the BER will increase. A small k means saving in BW is not appreciable. An improvement in this protocol is shown in figure 8 where relay transmission is reduced by a factor of ‘n’.

VI. SIMULATION RESULTS

The SNR versus BER graph has been plotted for a DF SISO and DF MIMO relaying communication system using BPSK in figure 9. Simulation results show that BER is less for DF

MIMO relaying scheme as compared to DF SISO relaying scheme for a SNR range of 1 to 10 which clearly indicates that MIMO relaying is preferred over SISO relaying on account of its superior BER.

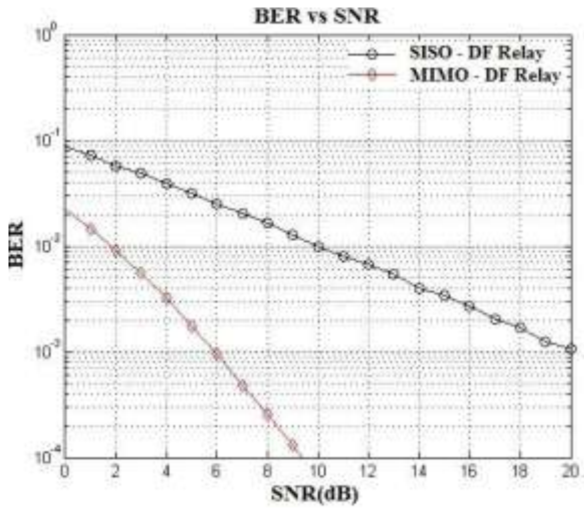


Figure 9. Comparison between DF SISO and DF MIMO relaying schemes

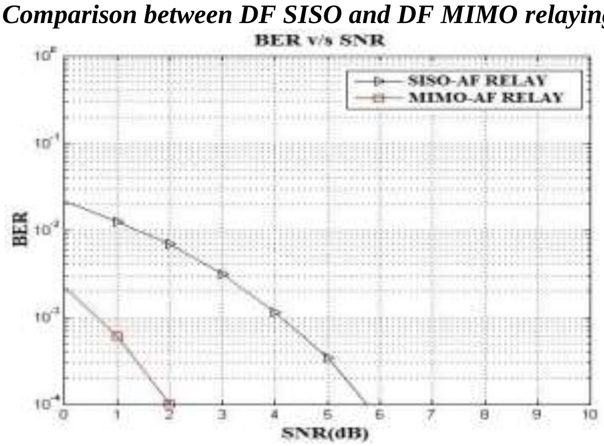


Figure 10. Comparison between SISO and MIMOAF relayingschemes

In figure 10, AF MIMO relaying shows a marked improvement of 89.05% over AF SISO relaying scheme with SNR ranging from 1 to 10.

As seen in figure 11, DF MIMO relay is better than MIMO direct link by 71.43 % and AF MIMO relay shows a marked improvement over MIMO direct link by 92.86 %, due to the relaying effect over the specified SNR range . AF MIMO relay has 75% better BER than DF MIMO relay as thedecoding process is more prone to noise and interference in the absence of error correcting codes.

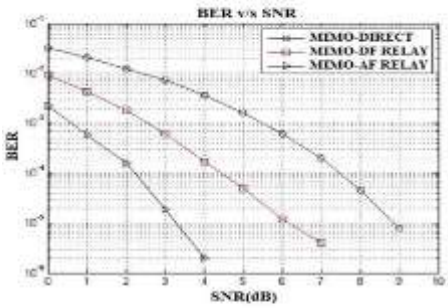


Figure 11. Comparison between MIMO direct and AF and DF MIMO incremental relays

Figure 12 gives the range of delta values for which BER are in an acceptable range.

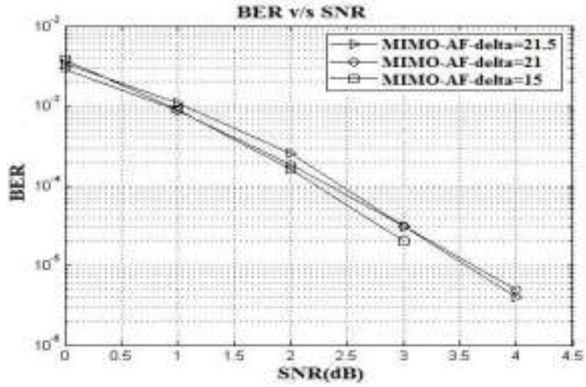


Figure 12. Curves for different values of delta for MIMO AF relay

VII. CONCLUSION

DF and AF MIMO incremental relaying schemes show a BER improvement of 71.43% and 92.86%, respectively, over MIMO. AF MIMO method of incremental relaying is preferred over DF MIMO method of incremental relaying especially at low SNRs since performance is better by 75%.

VIII. ACKNOWLEDGEMENT

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