Relay-Assisted Distributed Hybrid MIMO Transceiver with Information Exchange Errors for Cooperative Networks

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Abstract: -For non-relaying cooperative networks, the previous work proposed a distributed space-time block code (STBC) scheme considering information exchange errors in two-user cooperative networks. We propose a distributed Hybrid multiple-input multiple-output (MIMO) Transceiver scheme (HMT) considering information exchange errors in three-user cooperative networks. For relaying cooperative networks, the previous work also proposed an un-coded demodulation and forward relay and considering demodulation errors in the relay in two-user cooperative networks. We propose the relay-assisted distributed HMT scheme considering information exchange errors in 3-user cooperative networks, the differences are that our scheme has 3x2 HMT with transmit antenna selection in source-to-relay, source-to-destination, and relay-to-destination links, but the previous scheme has the 2x2 un-coded schemes in these three links. For both non-relaying and relaying scenarios, the simulation results show the proposed schemes have lower bit error rate (BER) than the previous schemes at the same 4 bits/sec/Hz transmission rate.

Key-Words: Hybrid STBC, cooperative networks, distributed coding, demodulation and forward relay

1. INTRODUCTION

In recent research, multiple-input multiple-output (MIMO) technique [1] [2] has been used widely to get higher data rate and/or spatial diversity, and applied to orthogonal frequency division multiplexing (OFDM) [3] and code-division multiple access (CDMA) systems [4]. Due to size, cost, or hardware limitations, a wireless agent may not be able to support multiple transmit antennas. The cooperative system has been proposed to allow single-antenna mobile users cooperate to reap some of the benefits of MIMO systems.

In [5], the cooperative system was proposed to gain spatial diversity. To improve performances further in such cooperative system, the distributed coding is introduced. In distributed coding, different parts of the codeword are transmitted by different nodes through independent wireless channels [6]. The distributed coding includes distributed rate compatible punctured convolutional codes [7], distributed space-time trellis code [8], distributed low density parity check code [9], distributed space time block code (DSTBC) [10][11], etc. In this paper, we consider DSTBC scheme. In this scheme, each user exchanges their information (to be transmitted by distributed STBC) mutually to construct a virtual multiple-transmit-antenna structure. However, there may have some information exchanging errors in such structure to degrade the benefits of the distributed coding. This problem is not addressed in almost all papers. Only [12] proposed a compensatory way to decrease errors caused by information exchange errors in DSTBC.

There are two kinds of cooperative communication in [12], non-relaying scheme and relaying scheme. In non-relaying scheme, the previous method used two-antenna (two-user) cooperative structure. Motivated by getting better bit error rate (BER) performance at the same transmission rate, we propose three-antenna (three-user) cooperative method using distributed Hybrid MIMO Transceiver schemes (HMT) [13], or called hybrid STBC in [14]. The distributed HMT scheme has coded and un-coded part. We also propose to use the partial feedback Channel State Information (CSI) to pick the strongest channel for the uncooperative user to transmit un-coded part (antenna selection). To consider possible information exchange errors, we design multiple cases of HMT matrices. If the cyclic redundancy check (CRC) exists, we use all cases of HMT matrices. If not, we use the worst case- all information exchange errors are wrong.

On the other hand, an un-coded demodulated and forward relay and considering information exchange errors in 2-user cooperative networks is also proposed in [12]**.** Motivated by getting better BER performance at the same transmission rate, we also propose the relay-assisted distributed HMT scheme considering information exchange errors in three-user (three antennas) cooperative networks. The differences are that our scheme has 3x2 HMT with transmit antenna selection in source-to-relay, source-to-destination, and relay-to-destination links, but the previous scheme has the 2x2 un-coded schemes in these three links.

The rest of this paper is organized as follow. Sec. 2 is the proposed distributed HMT scheme considering information exchange error without relay. Sec. 3 is the proposed relay-assisted distributed HMT scheme considering information exchange error. Sec. 4 is the simulation results. Sec. 5 is the conclusion.

2. Proposed Distributed HMT Scheme Considering Information Exchange Error

The previous distributed STBC scheme considering information exchange error [12] in two-user cooperative networks is shown in Fig. 1 for comparison. The proposed distributed HMT scheme considering information exchange error in three-user cooperative networks is shown in Fig. 2. We assume two receive antennas in both figures. From Figs 1-2, the proposed distributed HMT matrix has four information symbols, using QPSK modulation, while the previous distributed STBC matrix has two information symbols, using 16-QAM modulation. Thus the transmission rate is 4 bits/s/Hz for both schemes.

In the proposed scheme, we assume perfect CSI feedback, so we select the strongest channel for the un-coded part to transmit. In Fig. 2, we assume user 3 has the strongest channel, without loss of generality.

$$R_1(t) = h_{2-1}X_2(t) + Z_1 \qquad (1)$$

$$R_2(t+1) = h_{1-2}X_1(t+1) + Z_2 \qquad (2)$$

In our proposed scheme, at first the users exchange their information mutually. And the received signals at users M1 and M2 are given as follows:

Where X_i is the information symbol of the user i, R_i is the received signal at the user i, $h_{i\text{-}j}$ is the channel gain from the user i to user j, Z_i is additive white Gaussian noise (AWGN) with zero mean and N_0 variance.

The user 1 and 2 exchange information may be correct or in errors (four cases in total), so we are motivated to design the novel distributed HMT matrix for these four cases, If cycle redundancy check (CRC) is present and we use the corresponding matrix (one of four matrices) according to the CRC results. If CRC is not present, we always use the worst case (case 4). The novel four matrices for these four cases are designed as follows:

Case 1: X_1, X_2 are correct

$$\Rightarrow C = \begin{bmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \\ X_3 & X_4 \end{bmatrix},$$

Case 2: X_2 is correct, X_1 is wrong

$$\Rightarrow C = \begin{bmatrix} X_1 & -X_2^* \\ X_2 & \beta_2 R_2^* \\ X_3 & X_4 \end{bmatrix},$$

Case 3: X_2 is wrong, X_1 is correct

$$\Rightarrow C = \begin{bmatrix} X_1 & -\beta_1 R_1^* \\ X_2 & X_1^* \\ X_3 & X_4 \end{bmatrix},$$

Case 4: X_1, X_2 are wrong

$$\Rightarrow C = \begin{bmatrix} X_1 & -\beta_1 R_1^* \\ X_2 & \beta_2 R_2^* \\ X_3 & X_4 \end{bmatrix} \qquad (3)$$

Where the rows of the code matrix C represent the users, and columns of the matrix represent time slots. The power normalization factor β_i is:

$$[\mathbf{y}_1\,\mathbf{y}_2] = \begin{bmatrix} h_{1,1} & h_{1,2} & h_{1,3} \\ h_{2,1} & h_{2,2} & h_{2,3} \end{bmatrix} \begin{bmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \\ X_3 & X_4 \end{bmatrix} + [\mathbf{n}_1\,\mathbf{n}_2], \qquad (4)$$

where P is the users' power constraint.

For case 1 (all information exchanges are correct), we can write the system equation over two time slots as:

$$\beta_1 = \sqrt{\frac{P}{P|h_{2-1}|^2 + N_0}}, \beta_2 = \sqrt{\frac{P}{P|h_{1-2}|^2 + N_0}} \qquad (5)$$

where $\mathbf{y}_k$ is the 2x1 receive vector at time slot k, $h_{i,j}$ represent the channel gain of the ith time slot and the jth transmit antenna, X_i are the transmitted information symbols of the user i, $\mathbf{n}_k$ is the 2x1 AWGN vector.

After the matrix operation, (5) can be arranged as:

$$\begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2^* \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} & h_{1,3} & 0 \\ h_{2,1} & h_{2,2} & h_{2,3} & 0 \\ h_{1,2}^* & -h_{1,1}^* & 0 & h_{1,3}^* \\ h_{2,2}^* & -h_{2,1}^* & 0 & h_{2,3}^* \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ X_2 \\ X_2 \\ X_4^* \end{bmatrix} + \begin{bmatrix} \mathbf{n}_1 \\ \mathbf{n}_2^* \end{bmatrix}, \qquad (6)$$

Similarly for case 4 (all information exchanges are wrong, (worst case) in (3), the received vector can be rewritten as:

$$\begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2^* \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} & h_{1,3} & 0 \\ h_{2,1} & h_{2,2} & h_{2,3} & 0 \\ \beta_2 h_{2-3} h_{1,2}^* & -\beta_1 h_{3-2} h_{1,1}^* & 0 & h_{1,3}^* \\ \beta_2 h_{2-3} h_{2,2}^* & -\beta_1 h_{3-2} h_{2,1}^* & 0 & h_{2,3}^* \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ X_2 \\ X_3^* \\ X_4^* \end{bmatrix} + \begin{bmatrix} \mathbf{n}_1 \\ \mathbf{n}_2^* \end{bmatrix}, \quad (7)$$

3. Proposed Relay-Assisted Distributed HMT Scheme Considering Information Exchange Error

The proposed relay-assisted distributed HMT scheme considering information exchange error in three-user cooperative networks is shown in Fig. 3, while the previous relaying scheme considering demodulation error in the relay in two-user cooperative networks [12] is shown in Fig. 4 for comparison. We assume two receive antennas in both figures. From Figs 3-4, the proposed distributed HMT matrix has four information symbols, using QPSK modulation, while the previous relaying scheme has two information symbols from two users, using 16-QAM modulation. Thus the transmission rate is 4 bit/s/Hz.

For illustration, we first consider the worst case (Case 4), the received vector at the relay is given by:

$$[\mathbf{w}\ \ \mathbf{w}_2] = \begin{bmatrix} h_{1,1} & h_{1,2} & h_{1,3} \\ h_{2,1} & h_{2,2} & h_{2,3} \end{bmatrix} \begin{bmatrix} X_1 & -\beta_1 R_1^* \\ X_2 & \beta_2 R_2^* \\ X_3 & X_4 \end{bmatrix} + [\mathbf{m}_1\, \mathbf{m}_2], \quad (8)$$

where $\mathbf{w}_k$ is the 2x1 receive vector at time slot k, $\mathbf{m}_k$ is the 2x1 AWGN vector.

After some matrix operations, (8) can be re-arranged as:

$$\begin{bmatrix} \mathbf{w}_1 \\ \mathbf{w}_2^* \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} & h_{1,3} & 0 \\ h_{2,1} & h_{2,2} & h_{2,3} & 0 \\ \beta_2 h_{2-3} h_{1,2}^* & -\beta_1 h_{3-2} h_{1,1}^* & 0 & h_{1,3}^* \\ \beta_2 h_{2-3} h_{2,2}^* & -\beta_1 h_{3-2} h_{2,1}^* & 0 & h_{2,3}^* \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ X_2 \\ X_3^* \\ X_4^* \end{bmatrix} + \begin{bmatrix} \mathbf{m}_1 \\ \mathbf{m}_2^* \end{bmatrix} \quad (9)$$

Then the relay decodes the signal by ML detector, and then re-encoded data and forward to the destination (a decode and forward relay). The received vector at the destination from the relay is given by:

$$[\mathbf{v}_1 \mathbf{v}_2] = \begin{bmatrix} g_{1,1} & g_{1,2} & g_{1,3} \\ g_{2,1} & g_{2,2} & g_{2,3} \end{bmatrix} \begin{bmatrix} X_1' & -X_2'^* \\ X_2' & X_1'^* \\ X_3' & X_4' \end{bmatrix} + [\mathbf{z}_1 \mathbf{z}_2], \quad (10)$$

Where X_1', X_2', X_3', X_4' are the decoded data from relay, $\mathbf{v}_k$ is the 2x1 receive vector received by destination at time slot k, $g_{i,j}$ represent the channel gain for the ith time slot and jth transmitting antenna, $\mathbf{z}_k$ is the 2x1 AWGN vector.

The destination also received signals directly from the users 1-3. For case 4, the received vector at the destination directly from the source is given by:

$$[\mathbf{r}_1\, \mathbf{r}_2] = \begin{bmatrix} q_{1,1} & q_{1,2} & q_{1,3} \\ q_{2,1} & q_{2,2} & q_{2,3} \end{bmatrix} \begin{bmatrix} X_1 & -\beta_1 R_1^* \\ X_2 & \beta_2 R_2^* \\ X_3 & X_4 \end{bmatrix} + [\mathbf{b}_1\, \mathbf{b}_2] \quad (11)$$

Where $\mathbf{r}_k$ is the 2x1 receive vector received by destination directly from the users at time interval k, $q_{i,j}$ represent the channel gain of the ith time slot and jth transmit antenna, $\mathbf{b}_k$ is the 2x1 noise vector with zero mean and uni-variance Gaussian distributed white noise.

After combining (10) and (11), and some matrix operations, we get

$$\begin{bmatrix} \mathbf{v}_1 \\ \mathbf{v}_2 \\ \mathbf{r}_1 \\ \mathbf{r}_2 \end{bmatrix} = \begin{bmatrix} g_{1,1} & g_{1,2} & g_{1,3} & 0 \\ g_{2,1} & g_{2,2} & g_{2,3} & 0 \\ g_{1,2}^* & g_{1,1}^* & 0 & g_{1,3}^* \\ g_{2,2}^* & g_{2,1}^* & 0 & g_{2,3}^* \\ q_{1,1} & q_{1,2} & q_{1,3} & 0 \\ q_{2,1} & q_{2,2} & q_{2,3} & 0 \\ \beta_2 h_{2-3} q_{1,2}^* & -\beta_1 h_{3-2} q_{1,1}^* & 0 & q_{1,3}^* \\ \beta_2 h_{2-3} q_{2,2}^* & -\beta_1 h_{3-2} q_{2,1}^* & 0 & q_{2,3}^* \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3^* \\ X_4^* \end{bmatrix} + \begin{bmatrix} \mathbf{z}_1 \\ \mathbf{z}_2 \\ \mathbf{b}_1 \\ \mathbf{b}_2 \end{bmatrix} \quad (12)$$

Finally the destination utilizes $\boldsymbol{v}_1$, $\boldsymbol{v}_2$, $\boldsymbol{r}_1$ and $\boldsymbol{r}_2$ to jointly decode X_1, X_2, X_3 and X_4 by the ML rule.

4. SIMULATION RESULTS

We assume Rayleigh fading channels and 4 bits/sec/Hz transmission rate. We simulate the following schemes:

A. Previous non-relaying scheme [12]: Using 2x2 distributed STBC scheme with 16-QAM modulation

B. Proposed non-relaying scheme: Using 3x2 distributed HMT with QPSK modulation
C. Previous un-coded relaying scheme [12]: Using 2x2 un-coded relaying scheme with 16-QAM modulation
D. Proposed relaying HMT scheme: Using 3x2 HMT scheme with QPSK modulation

In Fig. 5, we compare the BER performances of scheme A and scheme B. Result shows that scheme B obtains about 5.5 dB gains over scheme A at 10^{-4} bit error rate for same transmission rate.

Fig. 6 compares BER performance of scheme C and scheme D. Result shows that scheme D obtains about 1.7 dB gains over previous scheme C at 10^{-4} bit error rate for same transmission rate.

We also plot non-relaying scheme in Fig. 6 for comparison. We add 10 dB path loss to scheme A and scheme B because the direct path between the source and the destination is longer than the path between the source and the relay or the path between the relay and the destination. We can see the relaying scheme has much better BER performance than non-relaying scheme.

5. CONCLUSION

Previous modified DSTBC transmits only two information symbols in two time slots. To transmit four information symbols in two time slots (double data rate), we propose the novel modified distributed HMTs considering possible information exchange errors. To compensate the BER degradation, we select the strongest sub-channel (best transmitting antenna) to transmit the un-coded part. The simulation results show that the proposed scheme's BER performance is not too far away from the previous modified DSTBC scheme (about one order), but has twice the data rate. Therefore, it is more suited to high-data-rate applications such as multimedia communications.

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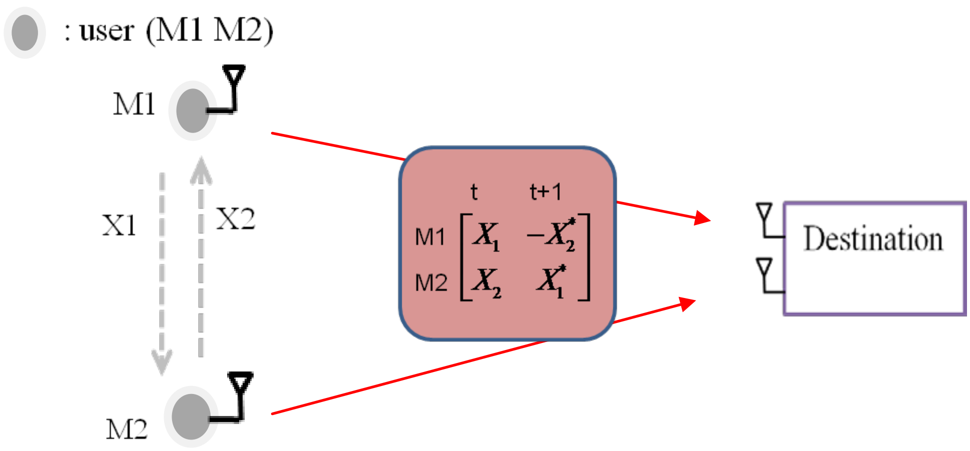

Fig. 1. Previous two-user distributed STBC [12]

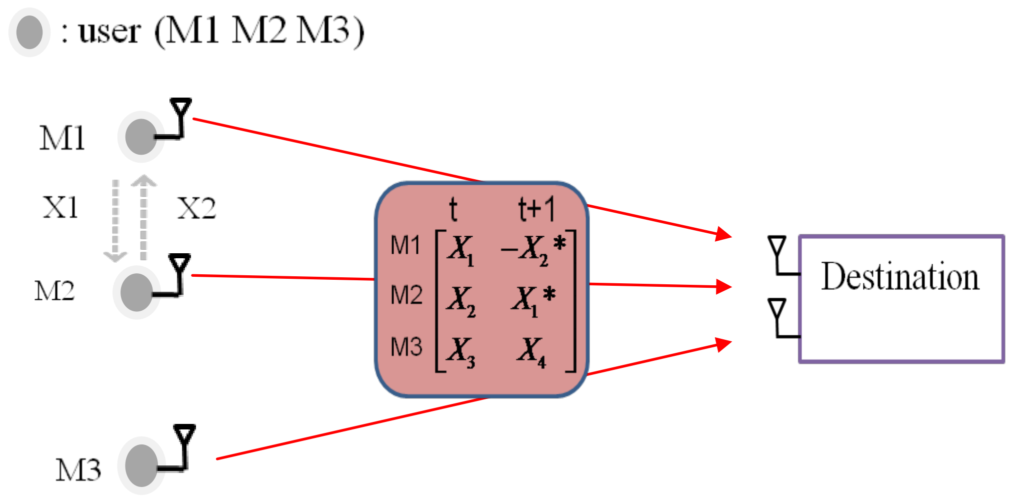

Fig. 2. Proposed three-user distributed HMT

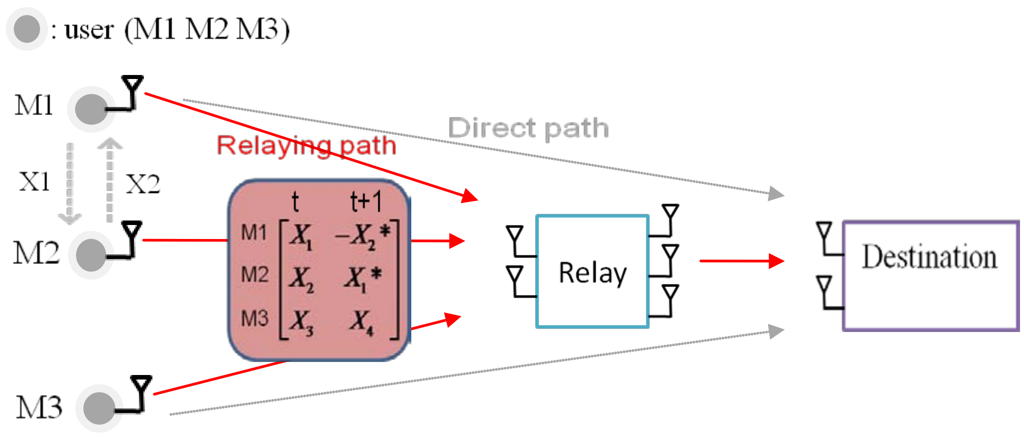

Fig. 3. Proposed multi-antenna HMT coded relaying scheme

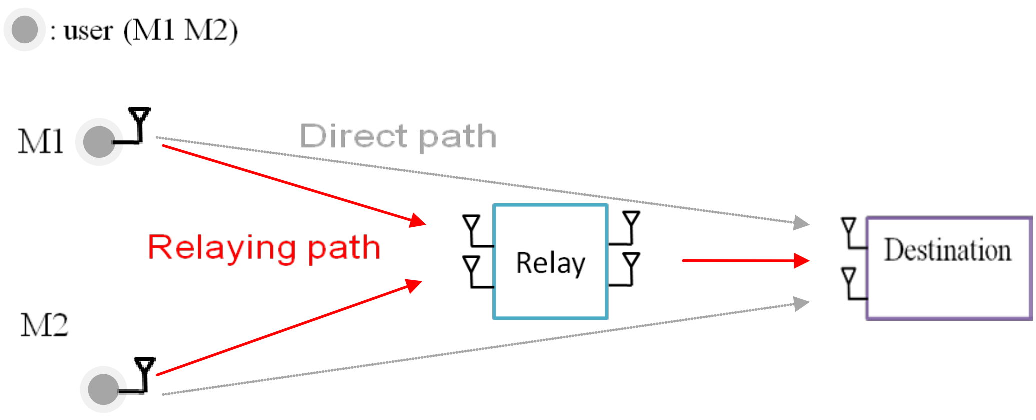

Fig. 4. Previous multi-antenna un-coded relaying scheme [12]

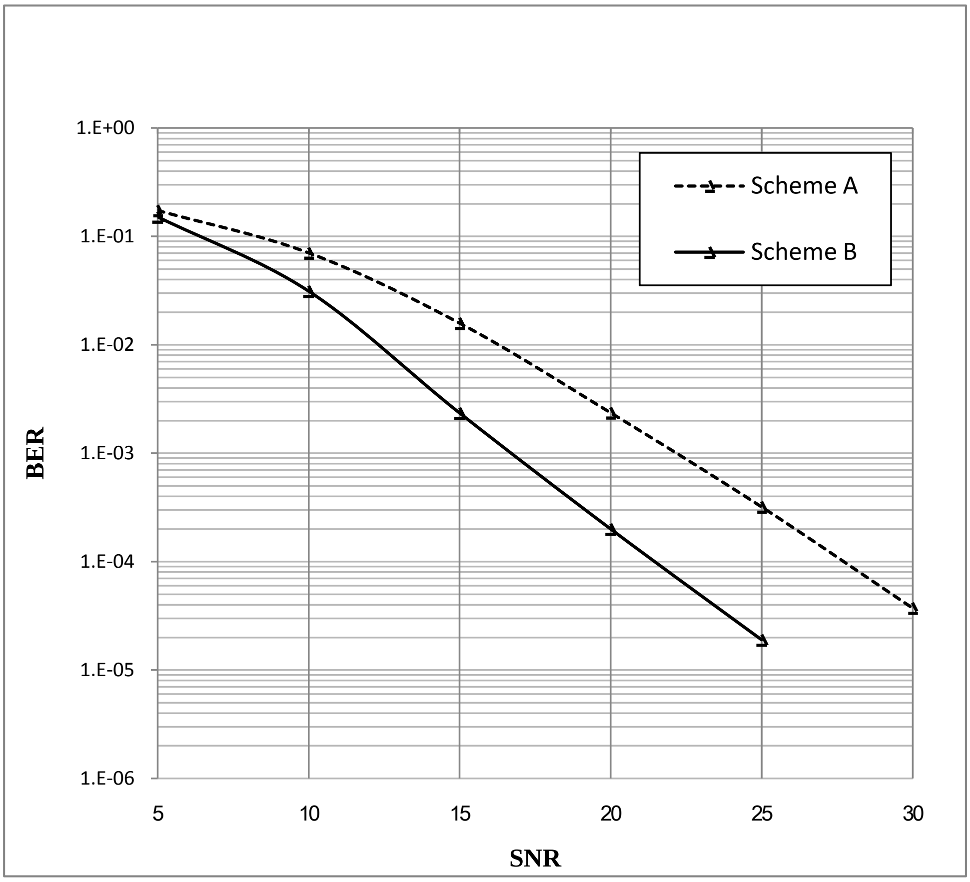

Fig. 5. Bit error rate versus SNR for scheme A and scheme B at 4bits/sec/Hz transmission rate.

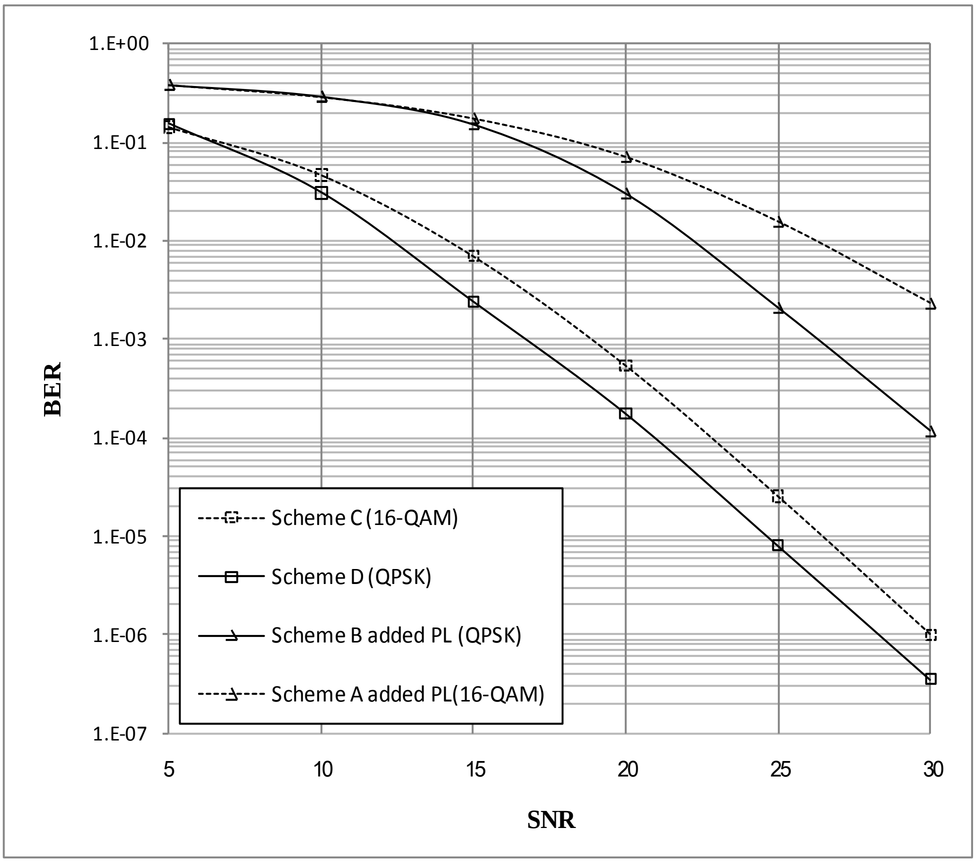

Fig. 6. Bit error rate versus SNR for scheme A added 10 dB PL, scheme B added 10dB PL, scheme C and scheme D at 4bits/sec/Hz transmission rate.