Achievable Rate Maximization in the Decode and Forward MIMO Multi Relay Communication

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***Abstract*—Partial information relaying is implemented in a decode and forward based MIMO relay system using the available CSI at the relay. For the broadcast of information between a source and destination with a relay, two transmission phases are considered. During the 1st transmission phase both the forwarding and the non-forwarding streams are broadcasted from the sender to both the relay and the destination and in the 2nd transmission phase the relay forwards only the forwarding streams to the destination. Achievable rate of the system is determined by using the available CSI at the relay. For an indoor wireless communication system with constant distance between the source and the relay the achievable rate in the MIMO relay system is determined.**

***Keywords*—Multiple Input Multiple Output (MIMO), Channel Side Information (CSI), Decode and forward MIMO relay**

I. INTRODUCTION

Relay communication focuses on either reliable communication or coverage extension with low cost and low transmit power. Relays are used to increase data rate. Due to the capacity enhancements in the MIMO communication it has been used extensively in relay communication to achieve high data rate.Several bounds on achievable rate have been derived for MIMO relay communication.

Relays are classified as full duplex and half duplex relays. Full duplex relays transmit and receive data at the same time in a single frequency band and the isolation between transmission and reception on same antenna is difficult to implement. Hence half duplex relays are used.

II.RELATED WORKS

Partial information relaying is introduced as a solution to the spectral efficiency loss caused by half duplex relaying in which the relay forward only a part of the decoded information to SYSTEM MODEL The destination[1],[2]. The variable slot length with the superposition coding is used in decode and forward based relay system with single antenna nodes [3]. Partial information relaying for single antenna system is first proposed by taking into account interstream interference and power allocation between basic and superposed data [4].Partial DF relaying protocol with multiple antennas is used, where forwarding information is constructed by stream control. Specifically, a source node broadcasts multiple data streams over multiple antennas in the first phase and a relay node forwards only a subset of the received streams in the second phase. A destination node decodes non-forwarded data streams after subtracting the forwarded data streams from the received data streams in the first phase using successive interference cancellation, a simple linear precoding scheme for partial DF relaying using CSI.Consider a system with multiple transmit receive and relay nodes. All nodes are equipped with multiple antennas, and the numbers of antennas at the source, relay, and destination are assumed as M, K, and N. The system adopts the half-duplex DF relaying protocol, as shown in Fig.1. In the first transmission phase, the source broadcasts L data streams, L = min{M,K,N}, over M transmit antennas. The MIMO channels from the source to the relay and from the source to the destination are denoted by $H_{SR} \sim CN(0,\sigma^2_{SR}I)$ and $H_{SD} \sim CN(0,\sigma^2_{SD}I)$ where $CN(0, \sigma^2 I)$ represent the matrix follows an independent complex Gaussian distribution with mean 0 and covariance $\sigma^2 I$. The total L data streams are composed of L – J non forwarding streams not to be forwarded by the relay and J forwarding stream.

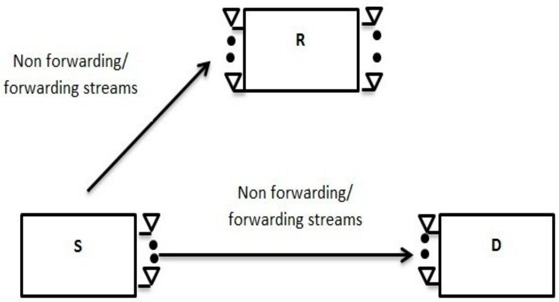

Fig 1 System model for 1st transmission phase

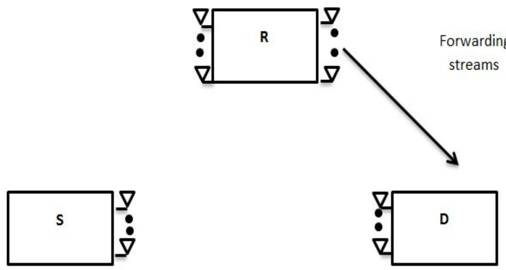

Fig 2 System model for 2nd transmission phase

The channel from the relay to the destination is denoted by H_{RD}~CN (0, σ^2_{RD}I), and the additive white Gaussian noise (AWGN) vectors at the S–R, S–D, and R-D links are represented by n_{SR}, n_{SD}, and n_{RD}, respectively. All AWGN vectors are assumed to follow i.i.d. circularly symmetric complex Gaussian distribution with zero mean and covariance I.

A.MIMO Channel

When the CSI is not available at the source, the source broadcasts data vector x for L streams over randomly selected L transmit antennas with uniform power allocation. Without loss assume that the source broadcasts the data streams x over the first L antennas, i.e., 1st, . . . ,Lth transmit antennas. On the other hand, relay and destination nodes are assumed to perfectly estimate the channel states from other nodes by the received signal. That is, the CSI at the receiver is assumed to be available at all nodes.

The transmit vector x $\in C^{L\times 1}$ is divided into L -J non-forwarding streams and J forwarding streams, which are denoted by x_N and x_F, respectively.The K×M MIMO channel matrix from the source to the relay as H_{SR} and is decomposed into data streams as given in (1)[1]

$$H_{SR}=[h_{SR,1},\ldots h_{SR,L-J},h_{SR,L-J+1},\ldots, h_{SR,L},\ldots h_{SR,M}] \quad (1)$$

Considering the channel matrix for non-forwarding L-J streams as $H_{SR}^{(1)}$ and the forwarding J streams as $H_{SR}^{(2)}$ and the remaining as $H_{SR}^{(0)}$.The matrix $\widetilde{H}_{SR}$ [1] is a composite matrix of $H_{SR}^{(1)}$ and $H_{SR}^{(2)}$

$$H_{SR}=[\widetilde{H}_{SR}\; H_{SR}^{(0)}] \quad (2)$$

where $H_{SR}^{(1)}=[h_{SR,1},..h_{SR,L-J}]$ and $H_{SR}^{(1)}=[h_{SR,L-J+1},.., h_{SR,L}]$.

B. Mutual Information

The relay node first decodes x_N by treating x_F as noise. Then, the achievable rate for x_N at the relay in terms of the mutual information between x_N and y_{SR} is obtained by [1]

$$I(x_N:y_{SR}) = \log\frac{|I+\rho_S H_{SR}^{(1)}(H_{SR}^{(1)})^H+\rho_S H_{SR}^{(2)}(H_{SR}^{(1)})^H|}{|I+\rho_S H_{SR}^{(2)}(H_{SR}^{(1)})^H|} \quad (3)$$

The matrix $\widetilde{H}_{SR}$ denotes a composite channel of $H_{SR}^{(1)}$ and $H_{SR}^{(2)}$ [1]

$$I(x_N:y_{SR}) = \log\frac{|I+\rho_S \widetilde{H_{SR}}\,\widetilde{H_{SR}}^H|}{|I+\rho_S H_{SR}^{(2)}(H_{SR}^{(1)})^H|} \quad (4)$$

where the transmit signal-to-noise ratio (SNR) at the source is $\rho_S= (P_S/L)$. After decoding x_N at the relay node, the mutual information between x_F and y_{SR} conditioned on x_N is given by [1]

$$I(x_F:y_{SR}|x_N)=\log|I + \rho_S H_{SR}^{(2)}(H_{SR}^{(2)})^H| \quad (5)$$

In the second transmission phase, the relay node forwards $\mathbf{x}_F$ after appropriate precoding according to the available CSI. Then, the mutual information at the destination is given by [1]

$$I(x_F:y_{RD})=\log|I+\widetilde{H_{SR}}\,\widetilde{H_{SR}}^H| \quad (6)$$

Finally, the destination node decodes nonforwarding streams x_N by subtracting x_F from the received signal y_{SD} received in the first transmission phase. Therefore, the achievable rate for x_N at the destination is given by [1]

$$I(x_F:y_{SD}|x_F)=\log|I + \rho_S H_{SR}^{(1)}(H_{SR}^{(1)})^H| \quad (7)$$

C.Achievable Rate

When the CSI is not available at the source, the relay determines the number of forwarding data streams based on the amount of available CSI at the relay to maximize the overall data rate. Because the overall achievable rate of the partial stream relaying is bounded by the minimum data rate of non-forwarding streams $\mathbf{x}_N$ at the relay and the destination, the overall achievable rate is given by [1]

ISSN: 2278-0181

$$R_{PDF}=\min\{R_{1,PDF},R_{2,PDF}\} \quad (9)$$

In the second transmission phase, the relay node forwards only J forwarding data streams $\mathbf{x}_F$ to the destination node. To maximize the achievable data rate of the proposed partial stream relaying, the relay node determines the number of forwarding streams and forwards only the determined number of data streams. Considering the following three different cases according to the available CSI at the relay.

- Case 1: perfect CSI of R–D (H_{RD}) and S–D (H_{SD}) links at the relay
- Case 2: perfect CSI of the R–D link (H_{RD}) and the covariance matrix of the S–D link ($\sigma^2_{SD}I$) at the relay
- Case 3: the covariance matrices of the R–D ($\sigma^2_{RD}I$) and S–D ($\sigma^2_{SD}I$) links at the relay.

C1. Case 1

Because the perfect CSI of the S–D and R–D links is available at the relay, the relay node can exactly calculate both $R_{1,PDF}$ and $R_{2,PDF}$. Hence the total achievable rate is same as that of the general achievable rate from [1]

$$R_{1,PDF}=\frac{\log\left|I+\widetilde{H_{RD}}\,\widetilde{H_{RD}}^{H}\right| * \log\left|I+\widetilde{H_{SR}}\,\widetilde{H_{SR}}^{H}\right|}{\log\left|I+\widetilde{H_{RD}}\,\widetilde{H_{RD}}^{H}\right| + \log\left|I+\rho_S H_{SR}^{(2)}(H_{SR}^{(2)})^{H}\right|} \quad (10)$$

For the determined precoding matrix at the relay, the effective channel of the R–D link is given by [1]

$$\widetilde{H_{RD}}=H_{RD}F^*_R \quad (12)$$

where F^*_R is the effective precoding matrix and is given as [1]

$$F^*_R=V_{RD}(1:J)\Sigma_R^{1/2} \quad (13)$$

where $H_{RD}=U_{RD}S_{RD}^{1/2}V_{RD}^{H}$ and $V_{RD}(1:J)$ denotes a matrix of right singular vectors that corresponds to the largest J eigen values. P_R is the average power at the relay. Power allocation is obtained by water filling algorithm and is given by [1]

$$\Sigma_R=\mathrm{disg}[p_{r,1}\ldots.p_{r,J}] \quad (14)$$

and $p_{R,i}(i=1\ldots.J)$ is obtained by

$$p_{R,i}=\left(\frac{1}{\nu}-\frac{1}{\lambda_{RD,i}}\right)^{+} \quad (15)$$

where ν is determined by $\sum p_{R,i}=P_R$ and $(x)^{+}:=\max\{x,0\}$.

C2.Case 2

When the relay node has the perfect CSI of the R–D link (H_{RD}) and knows the channel covariance matrix of the S–D link (i.e., $\sigma^2_{SD}I$), the effective channel of the R–D link after precoding at the relay is the same given by [1]

$$\widetilde{H_{RD}}=H_{RD}F^*_R \quad (16)$$

As the relay node knows the perfect CSI of the R–D link, the relay can calculate $R_{1,PDF}$ with the available CSI but cannot calculate $R_{2,PDF}$ due to the absence of the CSI of H_{SD}[1].

C3.Case 3

When the relay node knows only the channel covariance matrices of the R–D and S–D links (i.e., $\sigma^2_{RD}I$ and $\sigma^2_{SD}I$), the effective channel of the R–D link after precoding is determined by [1]

$$R_{PDF}=\frac{T_1}{T_1+T_2}\min\{\, I(x_N:y_{SR})+I(x_F:y_{SR}|x_N)\ \ I(x_N:y_{SD}|x_F)+I(x_F:y_{SR}|x_N)\} \quad (8)$$

$$R_{2,PDF}=\log\left|I+\widetilde{H_{RD}}\widetilde{H_{RD}}^{H}\right| * \left(\frac{\log\left|I+\rho_S H_{SR}^{(1)}(H_{SR}^{(1)})^{H}\right|+\log\left|I+\rho_S H_{SR}^{(2)}(H_{SR}^{(2)})^{H}\right|}{\log\left|I+\widetilde{H_{RD}}\widetilde{H_{RD}}^{H}\right|+\log\left|I+\rho_S H_{SR}^{(2)}(H_{SR}^{(2)})^{H}\right|}\right) \quad (11)$$

$$E_{H_{SD}}[R_{2,PDF}]=\log\left|I+\widetilde{H_{RD}}\widetilde{H_{RD}}^{H}\right|\left(\frac{E_{H_{SD}}\left[\log\left|I+\rho_S H_{SR}^{(1)}(H_{SR}^{(1)})^{H}\right|\right]+\log\left|I+\rho_S H_{SR}^{(2)}(H_{SR}^{(2)})^{H}\right|}{\log\left|I+\widetilde{H_{RD}}\widetilde{H_{RD}}^{H}\right|+\log\left|I+\rho_S H_{SR}^{(2)}(H_{SR}^{(2)})^{H}\right|}\right) \quad (17)$$

$$E_{HRD,HSD}[R_{2,PDF}] \le J\times\Gamma_{SD}\left(\frac{(L-J)\Gamma_{SD}+\log\left|I+\rho_S H_{SR}^{(2)}(H_{SR}^{(2)})^{H}\right|}{J\Gamma_{SD}+\log\left|I+\rho_S H_{SR}^{(2)}(H_{SR}^{(2)})^{H}\right|}\right) \quad (19)$$

$$\widetilde{H_{RD}}=H_{RD}\widetilde{F_R} \quad (18)$$

where $\widetilde{F_R}=\sqrt{\frac{P_R}{J}}\,[I_{J\times J}0_{J\times(K-J)}]^{T}$ is the effective precoding matrix [1]

Approximate upper bounds of $E_{HRD}[R_{1,PDF}]$ and $E_{HRD,HSD}[R_{2,PDF}]$ for determining the number of forwarding data streams as

ISSN: 2278-0181

$$E_{HRD}[R_{1,PDF}] \leq \frac{J\Gamma_{SD}\, log\left|I+\widetilde{H_{RD}}\widetilde{H_{RD}}^{H}\right|}{J\Gamma_{SD}+\log\left|I+\rho_S H_{SR}^{(2)}(H_{SR}^{(2)})^{H}\right|} \qquad (20)$$

D.RELAY SELECTION IN MULTIPLE RELAY USING ACHIEVABLE RATE

Consider a set of relay nodes $S=\{s_1, s_2, \dots, s_{|S|}\}$ in the MIMO system the power at the relay node varies accordingly of the distance between the source and the relay and is given by [8]

$$P_r = P_s + K - 10\gamma log_{10}\left(\frac{d}{d_0}\right) \qquad (21)$$

where $K=20\log_{10}(\lambda/4\pi d_0)$, λ is the wavelength of the signal that is being transmitted, P_r is the power atthe relay, P_s the average power at the source , γ is the path loss exponent for free space its value is equal to 2, d_0 is the reference distance and d the distance between the source and the relay. This P_r is used for the estimation of the $\widetilde{H_{RD}}$ which in turn is used in achievable rate estimation.

II. SIMULATED RESULT

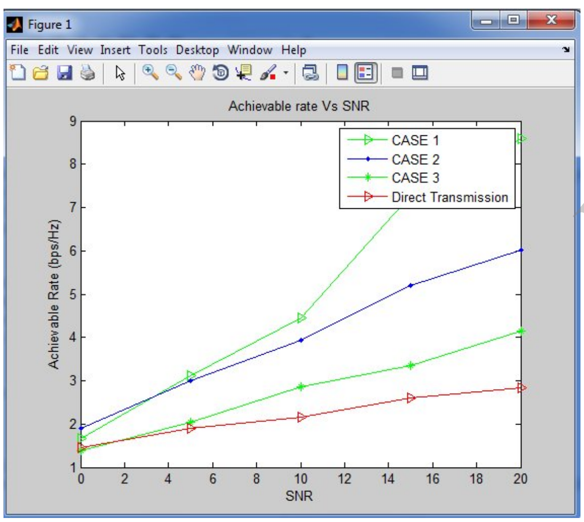

Fig 3 Achievable rate Vs. SNR

The figure3 compares the achievable rate of the 3 cases of the relay system with the CSI unknown at the source. The achievable rate for the direct transmission (ie. without the relay) is compared with the system with relay. From the graph it is interpreted that if both the channel matrix are known the achievable rate is substantially high compared to the other cases where the channel matrix is unknown.

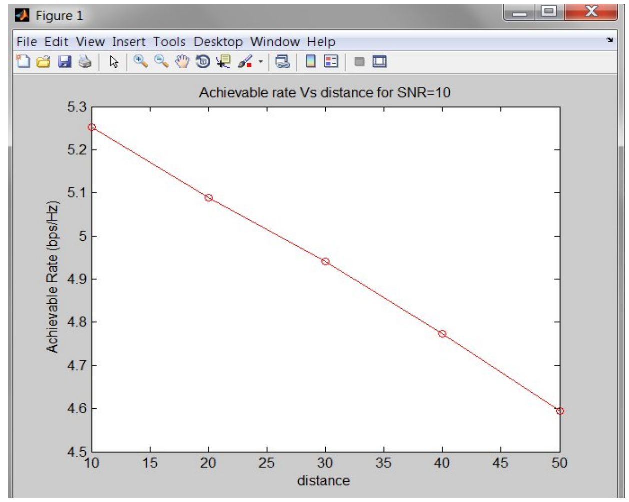

Fig 4 Achievable rate Vs. distance for SNR=10

From the fig.4 for an indoor wireless system the reference distance d_0 is taken ad 10m and distance between the transmitter and relay is taken as 40m with constant SNR as10dB then the achievable rate of the system is 4.784 bps/Hz.

VII .CONCLUSION

The scenario of CSI is not available at the source is considered and the achievable rate of the data transmissions using partial information relaying scheme is estimated. The achievable rate is analyzed for the various ranges of SNR values. Although the CSI is unknown at the source the CSI information and the link covariance information available at the relay is used for evaluating the achievable rate. Achievable rate of all the three cases of the CSI available at the relay is estimated and is plotted against various values of SNR. The optimal relay selection for multiple relay nodes can be analyzed by evaluating the power at the relay for varying distances between source and relay.

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