Performance of Cooperative MIMO Relaying System Using Linear Pre-Coding

Lucas M. Vasconcelos, André L. F. de Almeida and João C. M. Mota

***Resumo*— Neste artigo, consideramos um sistema de comunicação cooperativo MIMO (do inglês, *Multiple-Input Multiple-Output*) com um relay, em que codificação espaço-tempo é utilizada na fonte e no relay, para o provimento de ganhos de diversidade espacial na transmissão. É calculada a performance da taxa de erro de bits média do sistema. O impacto da pré-codificação e do número de antenas na performance do sistema é analisado com o uso de simulações computacionais.**

***Palavras-Chave*— Sistemas MIMO, *relaying*, codificação espaço-tempo, *zero forcing*.**

***Abstract*— In this work, we consider a cooperative MIMO single relay system using linear pre-coding at the source and relay in order to provide transmit spatial diversity gains. For this system, we evaluate the average bit error rate (BER) performance of the system by considering zero-forcing (ZF) equalization at the relay and the destination nodes. The impact of the use of pre-coding and number of antennas on the BER performance analyzed by means of computer simulation results for some system configurations.**

***Keywords*— MIMO systems, relaying, pre-coding, zero forcing.**

I. Introduction

Multi-hop networks are built when it is introduced intermediate nodes (relays) that forward data packets to a destination that is otherwise out of reach of the source. Using relays can bring a number of advantages. Apart from increasing the range [3], cooperative transmission from several relays and the base station, simultaneously, allows for increased diversity [4], [5], [6], which can be further seized by applying distributed space-time coding [7].

In the one hand, relaying techniques have appeared recently as viable options for challenging the trade-off between the transmission range and the end-to-end data rate [3]. The use of relays in a cooperative communication system considerably provides extra spatial diversity gains. On the other hand, pre-coding is a well-known multi-antenna technique employed to improve the reliability of data transmission in MIMO systems by improving spatial diversity and possibly providing coding gains [1],[2]. By combining cooperative relaying with pre-coding allows to improve the link reliability and increase coverage in MIMO systems [1].

The purpose of this work is to study the performance of a cooperative MIMO system employing a relay station to help the communication between source and destination nodes, in addition to the direct link between them. In particular, we assume the use of linear pre-coding at both the source and relays. The bit error rate (BER) performance of the system is evaluated for some system configurations by assuming zero forcing equalization at the destination. Our simulation results corroborate that the use of pre-coding yields remarkable performance improvements in the considered cooperative MIMO system.

The authors are with the Wireless Telecom Research Group (GTEL), Department of Teleinformatics Engineering, Federal University of Ceará, Fortaleza, Brazil (emails: lmv123@hotmail.com, andre@gtel.ufc.br, mota@gtel.ufc.br). This work is partially supported by CNPq and FUNCAP.

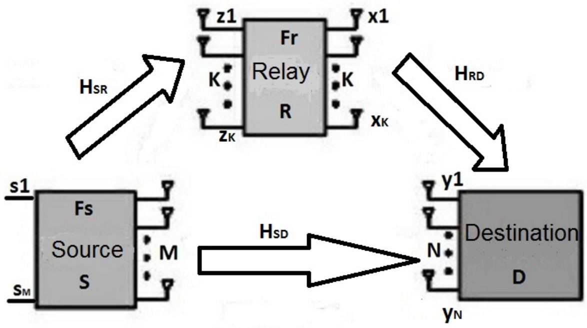

Fig. 1. Illustration of a dual-hop cooperative MIMO system.

II. System Model

We consider a cooperative MIMO communication system where a source communicates with a destination with the help of a relay station, in addition to the direct source-to-destination link. All devices are equipped with antenna arrays. We denote by M, K, and N the number of antennas used at the source, relay and destination, respectively. Moreover, we work under the following assumptions:

A1 The channel is flat fading and constant during a symbol period;

A2 The additive noise at each receive antenna follows a complex-valued Gaussian distribution with prespecified variance;

A3 The channel matrices $\mathbf{H}_{SR}$ and $\mathbf{H}_{RD}$ are perfectly known at the relay and destination, respectively.

Let us denote by $\mathbf{s} \in \mathbb{C}^{M\times 1}$ the vector of symbols to be transmitted. We consider a half-duplex scenario, where transmission from the source to the destination is done in non-overlapping time-slots. The first one is associated with the source-relay (*S-R*) link while the second one is associated with the relay-destination (*R-D*) link. We define $\mathbf{H}_{SR} \in \mathbb{C}^{K\times M}$ and $\mathbf{H}_{RD} \in \mathbb{C}^{N\times K}$ as the MIMO channel matrices associated with *S-R* and *R-D* links, respectively.

In the *S-R* time slot, the source broadcasts a precoded version of the symbol vector $\mathbf{s} \in \mathbb{C}^{M\times 1}$, so that the signals received at the relay and destination nodes can be written as:

$$\mathbf{r} = \mathbf{H}_{SR}\mathbf{x} + \mathbf{n}_R \in \mathbb{C}^{K\times 1}, \quad (1)$$

$$\mathbf{d} = \mathbf{H}_{SD}\mathbf{x} + \mathbf{n}_D \in \mathbb{C}^{N\times 1}, \quad (2)$$

where $\mathbf{x} = \mathbf{F}_S\mathbf{s} \in \mathbb{C}^{M\times 1}$ denotes the precoded signal, while $\mathbf{n}_R$ and $\mathbf{n}_D$ are the additive noise vectors at the relay and destination, respectively, whose entries are modeled as zero-mean complex Gaussian random variables with variance σ^2. The precoder $\mathbf{F}_S \in \mathbb{C}^{M\times M}$ is chosen as a discrete fourier transform (DFT) matrix with typical entry given by $[\mathbf{F}_S]_{m,i} = e^{-j2\pi(m-1)(i-1)/M}$.

After receiving the signal, the relay may or may not demodulate the received signal. If demodulation is used, we assume that a zero forcing filter followed by a decoder is used so that the estimate of the transmitted symbol vector is obtained as

$$\widehat{\mathbf{s}} = \mathbf{F}_S^H\mathbf{W}_R\mathbf{r} = \mathbf{F}_S^H\mathbf{W}_R\mathbf{x} + \underbrace{\mathbf{F}_S^H\mathbf{W}_R\mathbf{n}_R}_{\text{residual noise}}, \quad (3)$$

where $\mathbf{W}_R = \mathbf{H}_{SR}^{\dagger} \in \mathbb{C}^{M\times K}$ is the filter matrix, and $\dagger$ denotes the Moore-Penrose pseudo inverse. Note that, if demodulation/decoding is not used, we have $\widehat{\mathbf{s}} = \mathbf{r}$. The relay then applies a precoding operation and transmits the resulting signal. Thus, the signal received at the destination can be written as

$$\mathbf{y} = \mathbf{H}_{RD}\mathbf{F}_R\widehat{\mathbf{s}} + \mathbf{n}_{comb} \in \mathbb{C}^{N\times 1}, \quad (4)$$

where $\mathbf{F}_R \in \mathbb{C}^{K\times K}$ is the relay precoder also chosen as a DFT matrix with typical entry given by $[\mathbf{F}_R]_{k,i} = e^{-j2\pi(k-1)(i-1)/K}$, and $\mathbf{n}_{comb} \in \mathbb{C}^{N\times 1}$ is a combined noise term that includes residual (filtered) noise produced at the relay processing.

An estimate of the transmitted symbol vector at the destination is obtained by applying a zero forcing equalizer on the combined space-time signal formed by concatenating the signals $\mathbf{y}$ (*S-R* received signal) and $\mathbf{d}$ (*S-D* received signal). Assuming correct symbol estimation at the relay, we have:

$$\begin{pmatrix} \mathbf{d} \\ \mathbf{y} \end{pmatrix} = \begin{pmatrix} \mathbf{H}_{SD}\mathbf{F}_S \\ \mathbf{H}_{RD}\mathbf{F}_R \end{pmatrix} \mathbf{s} + \begin{pmatrix} \mathbf{n}_D \\ \mathbf{n}_{comb} \end{pmatrix} \quad (5)$$

Hence, the above equation can be written as:

$$\mathbf{y}_{eq} = \mathbf{H}_{eq}\mathbf{s} + \mathbf{n}_{eq} \quad (6)$$

After the zero-forcing filter, a final estimate of the original signal is obtained as: $\widehat{\mathbf{s}} = \mathbf{H}_{eq}^{\dagger}\mathbf{y}_{eq}$. (7)

III. Simulation Results

Some computer simulations have been carried out in order to evaluate the impact of cooperative relaying, pre-coding at the relay, and number of relay antennas. The *S-R* and *R-D* MIMO channels are modeled as zero-mean unit-variance complex Gaussian random variables. We assume BPSK modulation and demodulation/decoding is used at the relay. For all experiments, the fixed system parameters are indicated on top of the corresponding figure. In Figure 2, we evaluate the impact of pre-coding at the source and relay on the BER performance. Note that the use of pre-coding provides remarkable BER performance gains in the considered cooperative MIMO system. Figure 3 shows the impact of the number of antennas used at each system device. It can be seen that the best performance is obtained when a higher number of antennas are used at the relays.

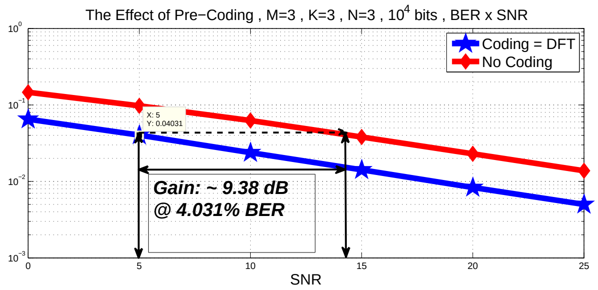

Fig. 2. Impact of the pre-coding.

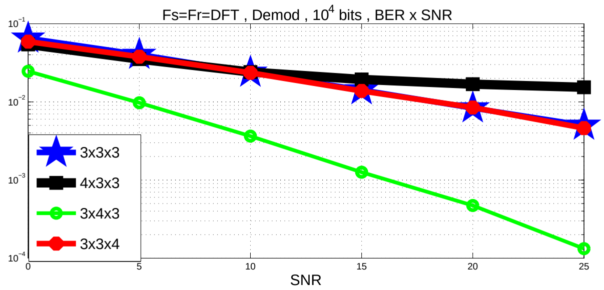

Fig. 3. Impact of the number of transmit/receive antennas.

IV. Concluding Remarks

In this work, we have studied the performance of a cooperative MIMO communication system using a single multiple-antenna relay station, where orthogonal matrix pre-coding is used at both the source and the relay in order to improve the BER performance with no reduction on the data rate. When pre-coding is used, our results have shown that the best way to improve system performance is to increase the number of antennas at the relay.

In a future work, we should consider the use of multiple relay nodes by possibly taking into account multi-hop cooperative protocols. Perspectives of this work also include the use of collaborative space-time coding techniques.

References

[1] E. Telatar, "Capacity of Multi-antenna Gaussian Channels," Euro. Trans. Telecomm., vol. 10, no. 6, pp. 585-596, Nov. 1999.

[2] A. Goldsmith, S. A. Jafar, N. Jindal, and S. Vishwanath, "Capacity limits of MIMO channels," IEEE J. Sel. Areas Commun., vol. 51, no. 6, pp. 684-702, Jun. 2003

[3] Daniel Christian Schultz, Ralf Pabst, and Tim Irnich, "Multi-hop based Radio Network Deployment for efficient Broadband Radio Coverage," in Proc.International Symposium on Wireless Personal Multimedia Communications, WPMC, Yokusuka, Japan, October 2003, vol. 2, pp. 377-381.

[4] J, Nicholas Laneman, David N.C. Tse, and Gregory W. Wornell, "Cooperative Diversity in Wireless Networks: Efficient Protocols and Outage Behavior," IEEE transactions on Information Theory, accepted publication

[5] Andrew Sendonaris, Elza Erkip, and Behnaam Aazhang, "User Cooperation Diversity, Part I: System Description," IEEE Transactions on Communications, vol. 15, pp. 1927-1938, November 2003.

[6] Andrew Sendonaris, Elza Erkip, and Behnaam Aazhang, " User Cooperation Diversity, Part II: Implementation Aspects and Performance Analysis," IEEE Transactions on Communications, vol. 15, pp. 1939-1948, November 2003.

[7] Ingmar Hammerstroem, Marc Kuhn, and Boris Rankov, "Space-Time Processing for Cooperative Relay Networks," in Proc. IEEE Vehicular Technology Conference, October 2004.