Global Journal of Pure and Applied Mathematics.
ISSN 0973-1768 Volume 12, Number 1 (2016), pp. 445-452
© Research India Publications
http://www.ripublication.com

Beamforming technique to reduce Interference in Relay Broadcast Channel

R. Raja Kumar
Professor, Department of Mathematics,
Sathyabama University, Chennai-600119, India.

Abstract

We investigate a multiple input multiple output (MIMO) relay broadcast channel (RBC) with full cooperation between users. A beamforming and combining design is proposed based on singular value decomposition (SVD) of the channel matrix between users. Then, users can simultaneously relay each other's information on the same frequency band with zero interference from each antenna's transmit signal on its received signal. At the transmitter side we applied zeroforcing algorithm. For the second time slot transmission we use SVD to reduce interference between users.

Keywords: Cooperative relay broadcast channel, beam-forming, power allocation, full-duplex communication.

Introduction

In cooperative transmission a set of relays is used to improve reliability of transmission between a source and its destination by exploiting spatial diversity. The basic structure of the relay channel was introduced by van der Meulen [1]. As a distinguished work Cover and El. Gamal [2] improved the capacity bounds presented in [1]. Dedicated relays have drawn extensive attention as cooperating terminals [3-8], just to name a few. On the other hand, there exist few studies on non-dedicated relays, or namely, user cooperation [9], [15-19]. Laneman studied the performance of important relaying protocols in fading channels [3]. The authors in [4] showed that the relay channel yields a considerable gain in both outage and ergodic capacity compared to the direct transmission. The diversity-multiplexing trade-off was investigated in [5] for a general MIMO multi-relay channel using the compress and forward strategy. The optimal PA was also addressed in [6] for multi-relay MIMO cooperative networks. Motivated by reduction in the overhead needed for multi-relay cooperation, an opportunistic single-relay selection was developed in [7]. It was shown that the proposed relay selection is outage optimal like multi-relay cooperation, but with a reduced complexity. In [8], a new framework was presented for the design of relay-assisted communications based on error probability. The authors considered power allocation, node positions, coding and modulation, and link characterization. In order to cope with mobility and cost limits of dedicated relays, Sendonaris [9], focused on user cooperation in the uplink of a mobile network. The broadcast channel (BC) is one of the practical scenarios which benefits from user cooperation by exploiting distributed spatial diversity. It has been shown that a nonlinear technique known as dirty paper coding (DPC) achieves the capacity of MIMO BCs [10-12]. Because of the huge complexity of DPC, zero forcing (ZF) precoder was developed for both single and multi-antenna users in [13-14]. It was shown that combination of user cooperation in conventional BCs, which is called RBC, improves the capacity region [15]. The authors studied two general models of RBCs. In the first model called partially cooperative RBC (PC-RBC), only the user with a better channel from the source acts as a relay for the other user. In the second model mentioned as fully cooperative RBC (FC-RBC), both users relay each others' information. See also the related studies in [16-17]. The work in [18] studied half-duplex users in which the source transmits a bit concatenated version of both users' data to the relaying user. It was shown that the capacity region is improved compared to the case of a BC using ZF-DPC. The authors in [19] developed a ZF beamforming and an iterative algorithm to obtain combining vectors for a MIMO PC-RBC. They also derived a closed-form solution for the optimum PA.

Users which experience a strong channel with each other and a weak direct channel from the source can relay each other's information by doing a bi-directional relaying. Previous studies (except [19]) in the context of non-dedicated relays have only considered single-antenna users. Hence, it is worthy to study multi-antenna users which bring further improvement by exploiting local spatial diversity in addition to the distributed spatial diversity by user cooperation.

We propose a full-duplex link design between users at the same time and frequency band to avoid rate reduction. We show that the proposed full-duplex design removes the self-interference of the transmit signal of each antenna on its received signal. Also, this structure can be a promising solution for designing full-duplex MIMO communications.

Notation: Bold uppercase letters, bold lowercase letters, and$(\cdot)^H$ stand for matrices, vectors, and Hermitian, respectively. A circularly symmetric complex Gaussian random variable with mean m and variance σ^2 is represented by $CN\ (m, \sigma^2)$.

Proposed Model

The flat fading model for the proposed FC-RBC scheme is shown in Fig. 1, where T_x shows a source and R_{xi} (i = 1, 2) depict the users. Transmission takes place in two consecutive time slots. In the first time slot, T_x transmits a combination of both users' data. Each user applies two combining vectors to the received signal to extract its own information as well as the other users' information. In the second time slot, each user transmits the other users' information on the same frequency band. Finally, each user combines the received information from two time slots and decodes its own data.

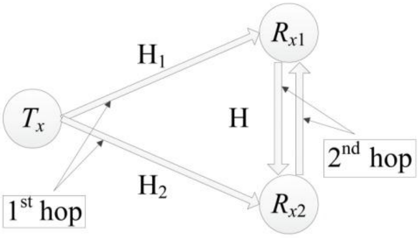

Figure 1: Block Diagram

The source and users are equipped with N_{Tx} and N antennas, respectively. The structure of the users is seen in Fig. 2. We make use of the structure presented in [20] for an antenna, which can transmit and receive simultaneously on the same frequency band by using active quasi-circulators at the feeder of each antenna.

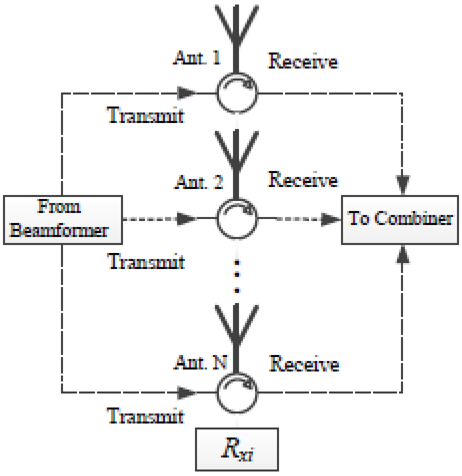

Figure 2: Multi-antenna $R_{xi}(i = 1,2)$ equipped with active quasi-circulators

The channels from T_x to R_{xi} and R_{x1} to R_{x2} are represented by $\mathbf{H}_i \in \mathrm{R}^{N\times N_{Tx}}$ and $\mathbf{H} \in \mathrm{R}^{N\times N}$, respectively. Also, the entries of $\mathbf{H}_i$ $(i = 1, 2)$ and $\mathbf{H}$ are $CN(0, \rho_i)$ and $CN(0, \rho)$, respectively. We assume that all nodes have full knowledge of the channels $\mathbf{H}_1$, $\mathbf{H}_2$ and $\mathbf{H}$, which is an acceptable assumption when channels' variations are relatively slow and some feedback channels are available [19]. We assume that the channel between users is reciprocal and thus the channel from R_{x2} to R_{x1} can be represented by $\mathbf{H}^H$. This assumption is reasonable due to using identical antennas for simultaneous transmission and reception by the users.

In the first time slot, T_x transmits a combination of the users' data denoted by x_i. The received signal vector at R_{xi} is

$$y_i = H_i X_{Tx} + z_j \tag{1}$$

where $\mathbf{X}_{Tx}$ is the signal vector transmitted by T_x defined as

$$X_{Tx} = \sqrt{k_1}\, w_{T_{x1}} x_1 + \sqrt{k_2}\, w_{T_{x2}} x_2 \tag{2}$$

in which $\mathbf{w}_{Txi}$ and k_i are the beamforming vector and power coeffecient for R_{xi}. Also, $\mathbf{z}_i$ is an AWGN vector at R_{xi}. Each user applies two combining vectors $\mathbf{w}_{Ei}$ and $\mathbf{w}_{Ri}$ to $\mathbf{y}_i$ to extract its own information and the other users information, respectively. We use the ZF method to design $\mathbf{w}_{Txi}$ and in the second time slot, each user transmits a scaled and properly time-shifted version of the other users' information. However, because of simultaneous transmission and reception on the same frequency band, the users cope with the self-interference problem. The self-interference is generated at each user for two reasons: *a*) receiving the transmit signal of the i^{th} antenna, $i = 1, 2, 3 \ldots,$ N, by itself and *b*) receiving the transmit signals of the other antennas of that user, $j = 1, 2, \ldots, i-1, i+1, \ldots, N$, by the i^{th} antenna. The second type of interference can be cancelled out by using a combination of proper antenna separation and noise cancellation in either analogue or digital domain. This is practical due to separation of the i^{th} and j^{th} antennas. In this way, the signal received by the i^{th} antenna from the j^{th} one is attenuated enough to be within the dynamic range of practical noise cancellers.

The first type of interference, however, cannot be completely removed by noise cancellers, which is the major focus of our beamforming and combining design. Without loss of generality, we assume that the channel between T_x and R_{x2} is weaker than that of T_x and R_{x1}, *i.e.,* $\rho_1 > \rho_2$. We propose to use the first and second columns of $\mathbf{V}$ as the beamforming and combining vectors, respectively, at R_{x1}, and also the first and second columns of $\mathbf{U}$ as the combining and beamforming vectors, respectively, at R_{x2}. The matrices $\mathbf{V}$ and $\mathbf{U}$ are obtained from the SVD of $\mathbf{H}$ given by $\mathbf{U\Sigma V}$. The proof for cancellation of the above interference is presented in the Appendix. In the second time slot, the received information y_i^R at R_{xi} is obtained as

$$y_1{}^E = w_{E1}^H y_1 = w_{E1}^H H_1 w_{Tx1} \sqrt{k_1 x_1} + w_{E1}^H z_1 \tag{1}$$

$$y_2{}^E = w_{E2}^H y_2 = w_{E2}^H H_2 w_{Tx2} \sqrt{k_2 x_2} + w_{E2}^H z_2 \tag{2}$$

$$y_1{}^{ER} = w_{R1}^H y_1 = w_{R1}^H H_1 w_{Tx2} \sqrt{k_2 x_2} + w_{R2}^H z_1 \tag{3}$$

$$y_2{}^{ER} = w_{R2}^H y_2 = w_{R2}^H H_2 w_{Tx1} \sqrt{k_1 x_1} + w_{R2}^H z_2 \tag{4}$$

In the second time slot, each user transmits a scaled and properly time-shifted version of the other users information.

$$y_1^R = v_2^H H^H u_2 x_{R2} + z11 \tag{5}$$

$$y_2^R = u_1^H H v_1 x_{R1} + z22 \tag{6}$$

We assume that all beamforming and combining vectors have unitary norm and the users data and entries of all AWGN vectors have unit variance.

Numerical Results

We present numerical results to demonstrate the efficiency of the proposed FC-RBC. The parameters are set as $NTx=4$, $N = 2$, $\rho = 10$ dB, $\rho 1 = -9$ dB, $\rho 2 = -10$ dB and an uncoded QAM is used. Also, we set $PTx= PT/2$ and $PRxi= PT/4$ to assign equal total transmit powers for PA under IPC and TPC. Because of the unit variance assumption for all noise vectors, $\gamma T= PT/2$ is considered as the average transmit power per user.

In Fig 3, we compared the BER of the proposed FC-RBC Scheme with no cooperation [14] and PC-RBC [19] schemes. With PA under TPC for both blind and BC optimization combining, the FC-RBC has a larger diversity order compared to the PC-RBC. This improvement in the proposed FC-RBC compared to the PC-RBC is due to the extra relaying from R_{x2} to R_{x1}. By using blind and BC-optimization combining, the FC-RBC improves over the PC-RBC about 0.6 and 0.3 dB, respectively, at BER = 10^{-4}. Also, the FC-RBC outperforms the no cooperation scheme about 2 dB for blind combining and 4.9 dB for BC-optimization combining. The FC-RBC with the optimal PA under IPC reaches the maximum diversity order with BC-optimization combining, which leads to a lower BER compared to the PC-RBC with PA under TPC for blind combining as well as the no cooperation scheme. Since in practice each node has its own power limit, the PA under IPC is a more realistic scenario than the TPC. However, the latter one has a better performance due to having a more degree of freedom than the IPC to share the available power among the nodes. When $\mathbf{H}$ is weaker than $\mathbf{H}_1$ and $\mathbf{H}_2$, the PA under TPC allocates zero power to the users. In contrast, the PA under IPC always limits k_3 and k_4 to nonzero values.

It is required for R_{x1} and R_{x2} to know the CSI of $\mathbf{H}$ in order to perform the SVD. However, it is usually difficult to set a backhaul link between users, especially when they are mobile. Using the proposed FC-RBC scheme, R_{x2} can use $\mathbf{H}^H$ as a feedback link to send its estimation of $\mathbf{H}$ toR_{x1},while receiving its relayed information from R_{x1}.

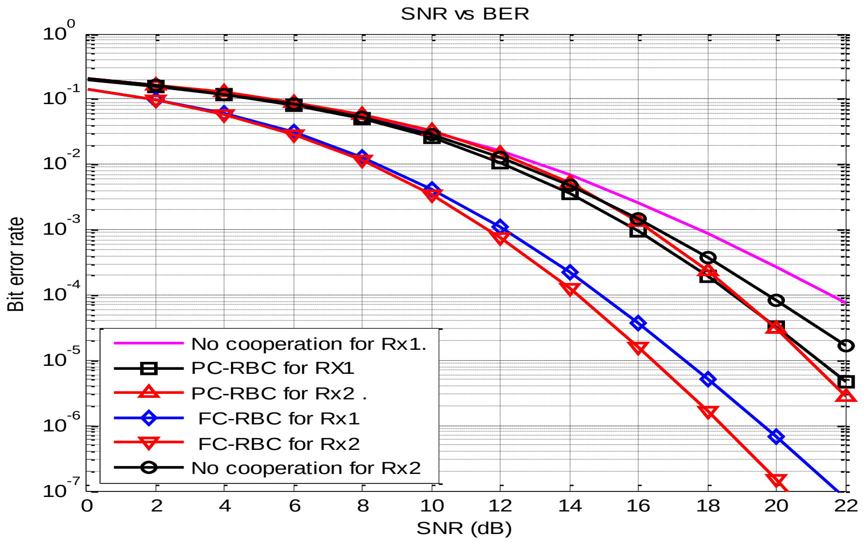

Figure 3: BER Comparison of the proposed fully cooperation scheme with no cooperation and Partially cooperation scheme

Conclusion

We investigated a MIMO FC-RBC and proposed a practical beamforming and combining scheme for simultaneous transmission and reception on the same frequency band between two cooperative users. Numerical results showed BER improvement for the proposed FC-RBC compared to the non-cooperative and partially cooperative transmission schemes.

Appendix

Here, we inspect the zero self-interference property of the proposed full-duplex communication scheme for the users working on the same frequency band.

The schematic diagram in Fig. 4 shows the transmit signal and the self-interference at each antenna. We assume x is the data transmitted by R_{x1}. The self-interference at the i^{th} antenna, $i = 1, 2, \ldots\ldots, N$, is modelled by $\mu v_{i1} x$ where μ is a complex coeffcient indicating the self-interference channel and v_{i1} shows the i^{th} element of $\mathbf{v}_1$. As stated earlier, R_{x1} uses $\mathbf{v}_2$ forcombining to have $\mathbf{v}^H{}_2 \mu \mathbf{v}_1 x = 0$. This is due to the orthogonality of the columns of $\mathbf{V}$. We can similarly derive the zero self-interference property for R_{x2} by using the 1^{st} and 2^{nd} columns of $\mathbf{U}$ for combining and beamforming, respectively. It should be noted that all the antennas should have the same μ, since any mismatch among μ values can lead to some orthogonality loss. We have assumed that each user has full knowledge about its self-interference channel coeffecients (denoted by μ values), which is reasonable for the channels with relatively slow variations. In the case of mismatch among them, by obtaining μ values, each user can subtract the residue of its self-interference after the combiner.

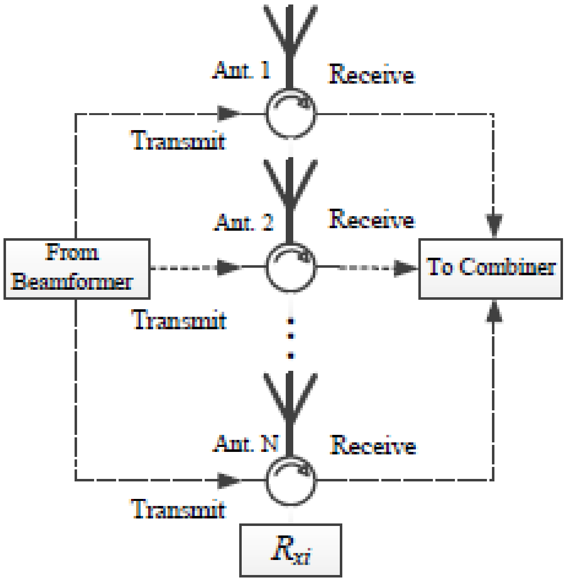

Figure 4: Self-interference modeling of the proposed structure for multi-antenna users with active circulators.

References

[1] E. C. van der Meulen, 1971, “Three-terminal communication channels”, *Adv.Appl. Probab.*, vol. 3, pp. 120-154.

[2] T. Cover and A. E. Gamal, 1979,“Capacity theorems for the relay channel”,*IEEE Trans. Inf. Theory*, vol. 25, no. 5, pp. 572-584.

[3] J. N. Laneman, D. N. C. Tse, and G. W .Wornell, 2004, “Cooperative diversity in wireless networks: efÞcient protocols and outage behaviour,” *IEEE Trans. Inf. Theory*, vol. 50, no. 12, pp. 3062-3080.

[4] A. Host-Madsen and J. Zhang, 2005, “Capacity bounds and power allocation for wireless relay channels,” *IEEE Trans. Inf. Theory,* vol. 51, no. 6, pp. 2020-2040.

[5] M. Yuksel and E. Erkip, 2007, “ Multi-antenna cooperative wireless systems: a diversity-multiplexing tradeoff perspective,” *IEEE Trans. Inf. Theory*. vol. 53, no. 10, pp. 3371-3393.

[6] J. Liu, N. B. Shroff, and H. D. Sherali, 2012,“Optimal power allocation in multi-relay MIMO cooperative networks: theory and algorithms,” *IEEEJ. Select. Areas Commun.*, vol. 30, no. 2, pp. 331-340.

[7] A. Bletsas, H. Shin, and M. Z. Win, 2007, “Cooperative communications with outage-optimal opportunistic relaying,” *IEEE Trans. Wireless Commun.*, vol. 6, no. 9, pp. 3450-3460.

[8] C. L. Palombara, V. Tralli, B. M. Masini, and A. Conti, 2013, 2013, “ Relay-assisted diversity communications,” *IEEE Trans. Veh. Technol.*, vol. 62, no. 1, pp. 415-421.

[9] A. Sendonaris, E. Erkip, and B. Aazhang, 2003, “ User cooperation diversityÑ part I and part II,” *IEEE Trans. Commun.*, vol. 51, no. 11, pp. 1927-1948.

[10] G. Caire and S. Shamai (Shitz), 2003, “On the achievable throughput of a multiantenna Gaussian broadcast channel,*IEEE Trans. Inf. Theory,* vol. 49, no. 7, pp. 1691-1706.

[11] H. Weingarten, Y. Steinberg, and S. Shamai, 2004 “The capacity region of the Gaussian MIMO broadcast channel,” in *Proc. 2004 IEEE Int. Symp.Information Theory,* p. 3936 – 3964.

[12] W. Yu and J. Cioffe, 2004, “Sum capacity of Gaussian vector broadcast channels,” *IEEE Trans. Inf. Theory,* vol. 50, no. 9, pp. 1875-1892.

[13] K. K. Wong, R. D. Murch, and K. B. Letaief, 2003, “A joint-channel diagonalization for multiuser MIMO antenna systems,” *IEEE Trans. WirelessCommun.*, vol. 2, no. 4, pp. 773-786.

[14] Q. H. Spencer, A. L. Swindlehurst, and M. Haardt, 2004, “ Zero-forcing methods for downlink spatial multiplexing in multiuser MIMO channels,” *IEEE Trans. Signal Process.*, vol. 52, no. 2, pp. 461-471.

[15] Y. Liang and V. V. Veeravalli, 2007, “Cooperative relay broadcast channels,” *IEEE Trans. Inf. Theory,* vol. 53, no. 3, pp. 900-928.

[16] Y. Liang and G. Kramer, 2007, “ Rate regions for relay broadcast channels,” *IEEE Trans. Inf. Theory,* vol. 53, no. 10, pp. 3517-3535.

[17] R. Dabora and S. Servetto, 2006, “Broadcast channels with cooperating decoders,” *IEEE Trans. Inf. Theory*, vol. 52, no. 12, pp. 5438-5454.

[18] J. Y. Ryu, E. Y. Ahn, and W. Choi, 2011, ” User relaying in a two-user MIMO broadcast channel,” in *Proc. 2011 IEEE Global Telecommunication Conference*, pp. 1-5.

[19] Z. Zhou and B. Vucetic, 2011’ “ A cooperative beamforming scheme in MIMO relay broadcast channels,” *IEEE Trans. Wireless Commun.*, vol. 10, no. 3, pp. 940-947.

[20] S. Cheung, T. Halloran, W. Weedon, and C. Caldwell, 2009, “Active quasi-circulators using quadrature hybrids for simultaneous transmit and receive,” in*IEEE MTT-S Int. Microw. Symp.*, pp. 381-384.