

# Optimal Cooperative Beamforming Design to Achieve High Information Rates For MIMO DF Relay Channels

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## Abstract

The paper intends a transmit beamforming design for MIMO decode-and-forward method half-duplex two-hop relay channels with a direct source destination link. The paper frames and solves the optimal beamforming vectors for source and relay nodes jointly where the source and relay nodes are fitted out with multiple antennas and the destination node arranged with single node. There are several unique properties of the optimal sections through mathematical derivation, based on which is developed a systematic approach to arrive at the optimal beamforming vectors for the source and relay nodes for different system configurations. Low-complexity explicit expression for the optimal beamforming for some specific scenarios also derived in this paper. From the numerical design, that the proposed beam forming design scheme can achieve the optimal solution with low computational complexity for MIMO DF relay networks.

## Keywords

Beamforming and optimization, decode and forward, MIMO, relay, transmit.

## I. Introduction

Relaying is an important and effective technology in achieving coverage extension, energy saving and spectral efficiency improvement for wireless systems and therefore has received a considerable amount of research interest. Several relaying schemes have been incorporated in standard proposals, such as 3GPP release 10 for next generation wireless systems. Generally there are two popular relay strategies i) amplify-and-forward (AF), where the relay decodes the received signals and then forwards them to the destination and ii) decode-and-forward (DF), where the relay decodes the received signals and then forwards the re-encoded information to the destination. Compared with the AF strategy, the DF strategy demands relay nodes with greater signal processing capabilities, but it outperforms the AF strategy especially when the source relay channel is statistically better than the source-destination and relay-destination channels. In this paper, we consider half-duplex DF relaying systems, where the relay is only allowed to transmit and receive using orthogonal time or frequency

## A. Cooperative Communications

The classic representation of a communication network is a graph with a set of nodes and edges. The nodes usually represent devices such as a router, a wireless access point, or a mobile telephone. The edges usually represent communication links or channels, for example, an optical fiber, a cable, or a wireless link. This work deals mainly with Rayleigh fading wireless channels. Both devices and the channels may have constraints on their operation. For example, a router might have limited processing power, a wireless phone has limited battery resources, the maximum transmission distance of an optical fiber is limited by several types of dispersion, and a wireless link can have rapid time variations arising from mobility and multipath propagation of signals.

The purpose of a communication network is to enable the exchange of messages between its nodes. Due to the broadcast nature of wireless links, signal transmissions between two nodes may be received at the neighbour nodes. It has been understood in the information theory for over three decades that overhear the transmission, as these intermediate nodes may themselves generate transmissions based on processing of the overhead signals. Let

us consider the system depicted in 1.1 where one system node (source) is sending a message to another system node (destination). Due to the broadcast nature of the wireless link, this message is overheard by a third node of the network (relay). During the first phase of transmission, the source broadcasts the binary message symbols to both relay and destination using the power  $E_s$ . The second phase consists of relay transmitting a transformed version of its received signal to destination while source is silent. Note that the two phases indicate two independent transmissions. This may be achieved by using orthogonal coding; e.g. using different time slots or different frequency carriers.

## B. Cooperative Strategies

The strategies are as follows:

1. Amplify-and-forward (AF)
2. Classic multi-hop
3. Compress-and-forward (CF)
4. Decode-and-forward (DF)
5. Multipath decode-and-forward (MDF)

The above strategies can be used for both wire line and wireless networks and they require progressively more coordination. For example, consider a RC, AF and classic multi-hop do not necessarily require changes at the source or destination nodes, e.g., for multi-hop the relay can behave as if it is the destination or the source. CF does not necessarily require changes at the source but it does require some extra knowledge about the link capabilities. DF requires changes at both the source and destination, and MDF requires additional changes at higher layers of the protocol stack. DF or MDF with network coding require even more changes at higher layers.

## II. System Model

Consider a network model consisting of a source S, a relay R and a destination D, as shown in the figure. It is assumed that the direct link between S and D exists in the system and the relay R helps the information transmission from S to D. Multiple antennas are deployed at both S and R, and only one antenna is equipped at D.

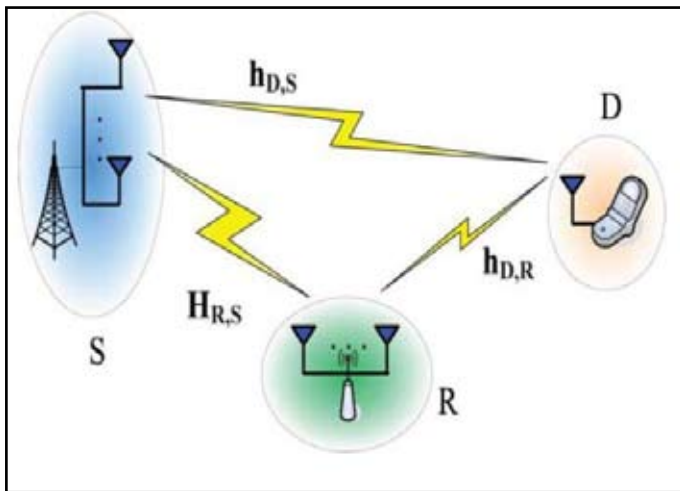


Fig.2.1. System model of MIMO relay channel

Half duplex mode is adopted so that R cannot transmit and receive signals at the same time. Therefore, each round of information transmission from S to D can be divided into two phases. In the first source phase, S broadcasts its information to both R and D, while in the second relay phase R decodes the received information and then forwards the decoded information to D. Thus, D can obtain the desired information by decoding the combined signals received over the above mentioned two phases.

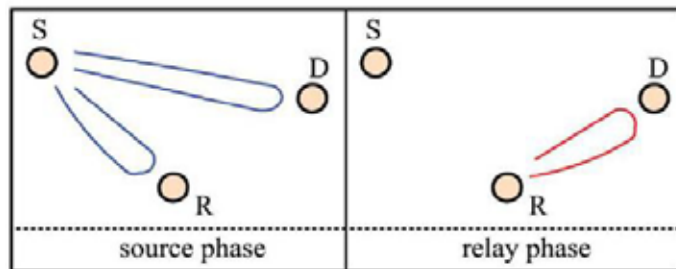


Fig.2.2 : Two-phase DF relay transmission.

All channel state information (CSI) for each round of transmission is known at the transmitters, by using techniques such as channel training, feedback and channel reciprocity exploiting etc. As a result, S and R can configure their beam forming vectors accordingly to achieve the best transmission performance. Without loss of generality, the transmitted information from S and R can be represented by symbols  $X_s$  and  $X_r$  respectively. Assume that  $N_s$  and  $N_r$  antennas are deployed at S and R, respectively.

**A. Beamforming Design Using MRT Technique**

Beamforming means when combining the received signals from multiple antennas, it is possible to create strong differentiation in gains for signals that arrive from different angles. The beamforming technique has traditionally been applied in the transmit/receive antenna pattern. With proper knowledge of the channel and accordingly setting the combining coefficients, a beamforming receiver can increase the antenna gain along the direction of the intended transmitter while at the same time suppressing the interferences from other directions.

**1. Block diagram of beamforming design using MRT technique**

Consider a network model consisting of a source S, a relay R and

a destination D, as shown in the below fig. It is assumed that the direct link between S and D exists in the system and the relay R helps the information transmission from S to D. Multiple antennas are deployed both S and R, and only one antenna is equipped at D. Half duplex mode is adopted so that R cannot transmit and receive signals at the same time.

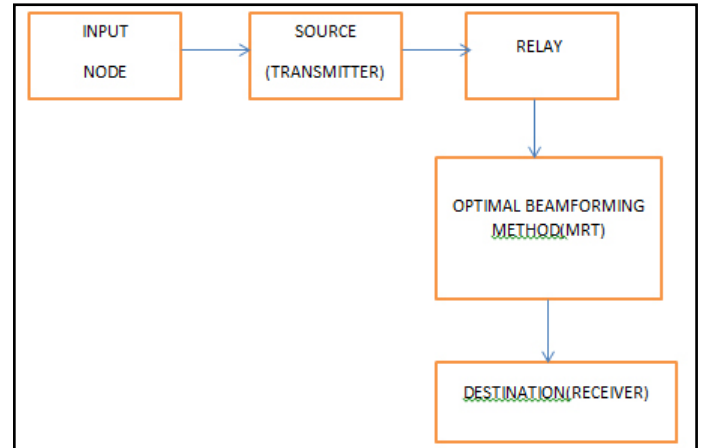


Fig.2.3 : Block diagram of Beamforming design by using MRT Technique

Therefore, each round of information transmission from S to D can be divided into two phases, In the source phase, S broadcasts its information to both R and D, while in the relay phase; R decodes the received information and then forwards the decoded information to D. Thus, D can obtain the desired information by decoding the combining signals received over the mentioned two phases.

**III. Optimal Cooperative Beamforming Design**

**A. Optimal Beamforming Algorithm**

In most of the cases the beamforming was fixed in the sense that the weights multiplied the signals at each element were fixed (they do not depend on the received data). Now allow those weights to change or adapt, depending on the received data to achieve a certain goal. try to adapt these weights to suppress interference. The interference arises due to the fact that the antenna might be serving multiple users. The signal received is a sum over the signals from multiple users. The signal received is a sum over the signals from multiple users, one of which will designate the "desired" signal. The received data is a sum of signal, interference and AWGN. The goal of beamforming or interference cancellation is to isolate the signal of the desired user from the interference and noise. In this project, this algorithm is used between joint source-relay node and destination node. It is used to calculate the exact capacity range of the transmission from source-relay node to destination node without loss of signals. Singular value decomposition is used to find the absolute value. From the positive and non-positive integers, the singular value decomposition is used to get the positive integers. In this project the singular value decomposition is used to find the magnitude and sum of the received signal.

**B. Optimal Cooperative Beamforming Using Zero-Forcing Precoder**

Multi-stream beamforming /spatial processing that occurs at the transmitter. Beamforming(single-stream) to same signal is emitted from each of the transmit antennas with appropriate phase

and gain weighting such that the signal over is maximised at the receiver downlink transmission of a relay-enhanced input. If the receiver has multiple antennas the cellular system where the base-station and the transmit beamforming cannot simultaneously relay can accommodate multiple antennas but the maximize the signal power at the receiver input so the precoding with multiple stream is used.

The benefits of beamforming,

- i) Increase the received signal
- ii) Reduce the multipath fading effect.

### C. Block Diagram of Optimal Beamforming Design Using Zero-Forcing Precoder

In this the zero-forcing precoder method is used instead of singular value decomposition method. Zero-forcing precoding is a method of partial signal processing by which the multiple antenna transmitters can null multiuser interference signals. It is enhanced processing to consider the impact on a background noise and unknown user interference. It is a method of beamforming for narrowband signals where we want to have a simple way of compensating delays of receiving signals from a specific source at different elements of the antenna array. If the transmitter knows the downlink channel state information (CSI) perfectly, ZF precoding can achieve almost the system capacity when the number of users is large.

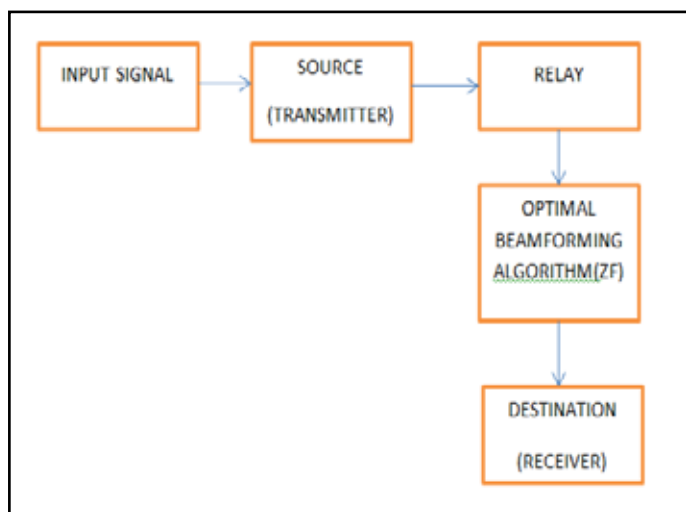


Fig .3.1 : Block diagram of optimal beamforming design using zero-forcing precoder

In this paper, the joint source-relay beamforming design for the three-node MIMO DF relay network with source-destination direct link is considered. Assume that both the source and relay nodes are equipped with multiple antennas while the destination node is only deployed with single antennas. Such a transmission scenario is readily applicable to the downlink transmission of a relay-enhanced cellular system where the base-station and the relay can accommodate multiple antennas but the mobile user equipment can only afford a single antenna due to size or other constraints. Note that downlink transmission to resource-limited mobile terminals limits the overall performance of cellular systems. As such, this design aims to fully explore the spatial diversity advantage of MIMO-DF relay channels, while relies on complex numerical solutions, it strikes to derive the explicit expressions for the optimal beamforming design for our concerned model.

### D. Optimal Beamforming Design for 2:2:1 Scenario

The reasons are, firstly, the deployment of two antennas is more realistic than deploying two more antennas in many practical cases. Especially on some size-limited devices such as notebook PC. Secondly, the MIMO scenario also applies to the situation that only two antennas are selected to transmit signals at the source and relay nodes and 2 X 2 MIMO channel has attracted much attention. Although, in the later versions, more antennas are suggested to be employed, deploying two antennas is commonly considered as the most practical antenna choice strategy due to the larger quantity of time-frequency resource consumption of channel estimation and feedback they produce. Especially for the channels with fast variation and large Doppler frequency spread which makes channel estimation more complex and resource consumptive. Hence, in this subsection, we will give out the close-form result for the overall optimal beamforming design for the scenario. With the closed-form solution at hand, the beamforming design is significantly simplified. In the scenario, Lemma 1 is still valid, which presents the optimal phase design, and in this case the optimization problem is reduced to

$$\gamma_{D,S} = (|h^T_{D,S} v_1| |W_1| + |h^T_{D,S} v_2| |W_2| + \dots + |h^T_{D,S} v_{N_s}| |W_{N_s}|)^2 P_S \quad (1)$$

Where  $v$  unitary matrix of full rank

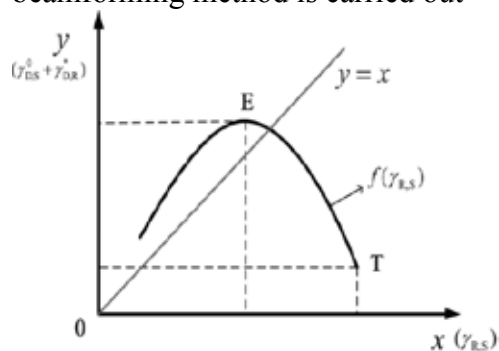
$$\max_{\alpha_1, \alpha_2} \min (\lambda_1^2 \alpha_1 + \lambda_2^2 \alpha_2, (\beta_1 \alpha_1 + \beta_2 \alpha_2)^2 + \gamma_{D,R}) \quad (2)$$

$$\begin{aligned} \text{s.t. } & \alpha_1 + \alpha_2 = 1 \\ & \alpha_1, \alpha_2 \geq 0 \\ & \alpha_1 = \frac{K - \lambda_2^2 P_S}{\lambda_1^2 - \lambda_2^2} \\ & \alpha_2 = \frac{\lambda_2^2 P_S - K}{\lambda_1^2 - \lambda_2^2} \end{aligned} \quad (3)$$

Which leads to maximum values

$$\gamma_{D,S}^0 + \gamma_{D,R}^* = \frac{1}{\lambda_1^2 - \lambda_2^2} x \left[ \beta_1 \sqrt{k - \lambda_1^2 P_S} + \beta_2 \sqrt{\lambda_1^2 P_S - k} \right]^2 + \gamma_{D,R}^* \quad (4)$$

According to the flow diagram the optimal beamforming method is carried out



The points  $\mathbf{x}_E$ ,  $\mathbf{x}_T$ ,  $\mathbf{y}_E$  and  $\mathbf{y}_T$  can be calculated from the following equations:

$$\mathbf{x}_T = \lambda_1^2 P_S$$

$$\mathbf{y}_T = \beta_1^2 P_S + \|h_{D,R}\|^2 P_S \quad (5)$$

$$\mathbf{x}_E = \left( \frac{\sum \lambda_i^2 \beta_i^2}{\beta_1^2 + \dots + \beta_{N_S}^2} \right) P_S$$

$$\mathbf{y}_E = \sum \beta_i^2 P_S + \|h_{D,R}\|^2 P_S \quad (6)$$

Then if the condition satisfies the flow will come to 2:2:1 scenario. Then for 2:2:1 scenario the alpha value can be calculated according to the following equations

$$\begin{cases} \alpha_1 + \alpha_2 = 1 \\ \lambda_1^2 \alpha_1 + \lambda_2^2 \alpha_2 = (\beta_1 \sqrt{\alpha_1} + \beta_2 \sqrt{\alpha_2})^2 + \gamma_{D,R}^* \end{cases} \quad (7)$$

$$\alpha_1 = \frac{1 - 2AB \pm \sqrt{1 - 4ABPS - 4B^2}}{2 + 2P_S^2}$$

$$\alpha_1 = 1 - \alpha_2, \alpha_1, \alpha_2 \geq 0,$$

where

$$\begin{cases} A = \frac{\lambda_1^2 - \lambda_2^2 - \beta_1^2 + \beta_2^2}{2 \beta_1 \beta_2} \\ B = \frac{\lambda_1^2 P_S - \beta_2^2 P_S - \gamma_{D,R}^*}{2 \beta_1 \beta_2} \end{cases} \quad (8)$$

If the solutions are all non-negative, only the one which maximizes  $\lambda_1^2 \alpha_1 + \lambda_2^2 \alpha_2$  should be selected as the final optimal solution. Once find out the alpha value by using lemma 1 the beamforming matrix  $w^*$  can be calculated.

#### IV. Results And Discussion

MATLAB is a high-performance language for technical computing. It integrates computation, visualization and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. In this project, MATLAB 7.5 version is used to get the efficient simulation results. The simulation results has been given in this chapter. 100 channel realizations has been used for simulations in matlab. Then SNR values from -10 to 20 dB has been used.

##### A. OPTIMAL BEAMFORMING DESIGN 2:2:1 and 2:2:4 SCENARIO

The optimal beamforming design for 2:2:4 scenario achieves the maximum achievable information rates when compared to 2:2:1 scenario

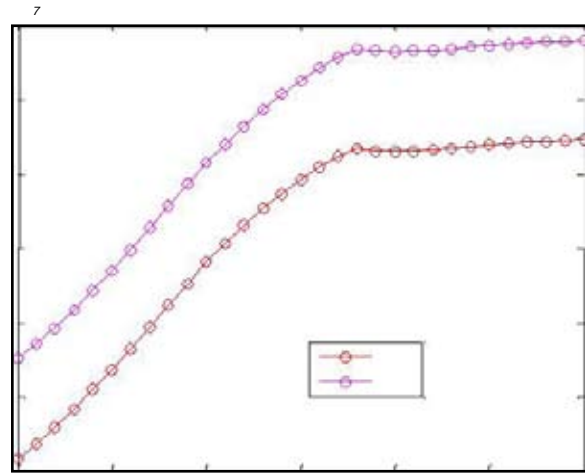


Fig.4.1 : Optimal beamforming design for 2:2:4 and 2:2:1 scenario

##### B.OPTIMAL BEAMFORMING DESIGN 2:4:1 and 2:4:4 SCENARIO

The optimal beamforming design for 2:4:4 scenario achieves the maximum achievable information rates when compared to 2:4:1

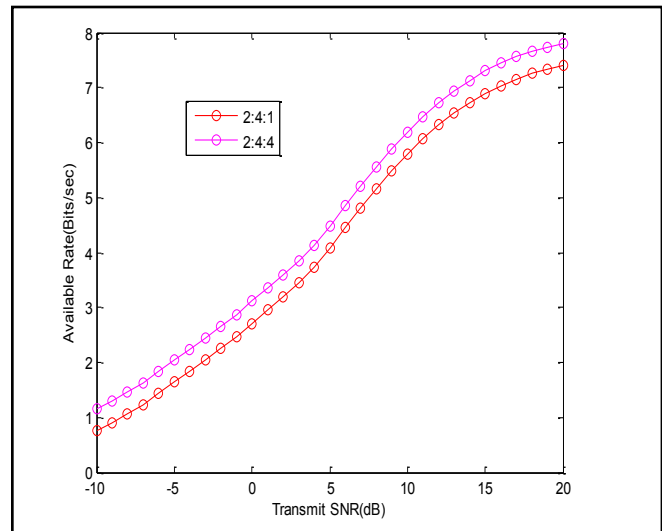


Fig.4.2 : Optimal beamforming design for 2:4:1 and 2:4:4 scenario

#### V. Conclusion

In this work, consider the beamforming design for MIMO DF Relay channels, where both the source node and relay node are equipped with multiple antennas ,an efficient scheme is developed to solve the optimization problem and determine the optimal beamforming vector for MIMO DF rela networks. Unlike previous work on beamforming design of MIMO DF channels, this beamforming design was based on the exact capacity formulation, which can achieve high accuracy. As an ongoing effort, to extent the beamforming design to the scenario where all the three nodes are equipped with multiple antennas in future work. We can extend to the beamforming design to the scenario where can implement this MIMO concept using some other pre-coder designs in future work and also we can implement the different scenarios practically in future work.

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