



Performance Comparison of Energy Efficiency of Transmitter in MIMO Decode-and-Forward Relay Channels

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ABSTRACT: Cooperative communication has achieved major research concern due to its ability to enlarge system coverage and improve spectrum efficiency. Consider, a transmit cooperative beamforming design, for the scenario with multiple-input-multiple-output (MIMO) decode-and-forward (DF) relay channel with a direct source to destination link. The achievable information rate (bits/s) for a given transmit signal-to-noise ratio (SNR) for a particular beamforming scenario is calculated based on the optimal beamforming vectors obtained. Results show that when multiple numbers of antennas are deployed at all the nodes the achievable information rate is higher. Also, the energy efficiency of the transmitter is improved when the destination is equipped with multiple number of antennas.

KEYWORDS: Beamforming, Decode-and-forward, Energy efficiency, MIMO and SNR.

I. INTRODUCTION

Relay plays an imperative and vital role in the field of communication by improving the coverage extension and providing efficient signal transmission particularly in the case of wireless systems by achieving spectral efficiency. There are two types of relay strategies: Amplify and forward (AF) and Decode and forward (DF). In case of amplify and forward (AF), the relay simply amplifies its received signals and then forwards them to the destination, and in case of decode and forward (DF), the relay decodes the received signals and then again forwards the re-encoded information to the destination. In condition, when the source-relay channel is statistically better than the source-destination and relay-destination channels the DF relay is much better than the AF relay[1].

MIMO systems have huge potential for getting better system throughputs. The use of antenna arrays at both ends of the communications link can make use of the spatial dimension, which is an additional system resource [2]. Multiple antennas may be used to perform smart antenna functions such as spreading the total transmit power over the antennas to achieve an array gain that incrementally improves the spectral efficiency and/or achieving a diversity gain that improves the link reliability (reduces fading). Thus, by deploying multiple numbers of antennas at wireless terminals or nodes in a scenario can prove beneficial to the system by improving various dominant factors like the channel capacity, reliable transmission and effective diversity combining.

II. RELATED WORK

Most of the earlier works on MIMO relay channels mainly focused on the network capacity from the information theoretic perspective. More recently only the MIMO relay beamforming design has started to receive growing interest. Most work on the DF MIMO relay beamforming assumed that no direct link exists between the source and the destination [3]. However, so far, little research has addressed the combination of MIMO beamforming and power control for both interference management and energy utilization of MIMO network model.

Energy efficiency, defined as the number of transmitted information bits per unit energy, has been studied recently and is becoming increasingly important for wireless communication systems [5]. For example, the energy efficiency analysis of MIMO systems based on Alamouti diversity schemes is studied in [6]. Energy efficient MIMO precoding is studied in [7] for a single user. In the downlink multi-user case, energy efficiency with random opportunistic beamforming is studied in [8], where the normalized beamforming vectors are randomly generated. In this paper, maximizing the energy efficiency of the transmitter i.e., the source in the given network model based on the achievable information rate obtained for the transmit SNR by solving for the optimal beamforming vector in the cooperative

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MIMO DF Relay communication system as in [4] is considered. It is found that when transmitter of the communication system with MIMO DF relay scenario where the destination is also equipped with multiple numbers of antennas is compared with the existing MIMO DF relay scenario with single antenna at destination and the energy efficiency of the former is found to be better in most of the scenarios.

The rest of the paper is organized as follows. Section III describes the system model and the mathematical formulation of the beamforming scenario. Section IV describes about the energy efficiency of the transmitter. Section V includes simulation results and discussion and the paper ends with few concluding remarks in Section VI.

III. SYSTEM MODEL

Consider a communication system model consisting of source S, a relay R and a destination D as shown in Fig. 1. It is assumed that direct link exist between S – R and relay R helps in retransmitting the information to the destination D. Consider two phases, first phase the source transmits information to relay and destination, and in second phase relay retransmits the information received from source to the destination. Thus, destination obtains the desired information by decoding the combined signals received over the abovementioned two phases. In first phase, let the information symbol x_s be multiplied with beamforming vector w_s before being transmitted. Let N_s be the number of antennas at the source node. Assume that the average power at the source node be P_s and the w_s is a unit-norm vector.

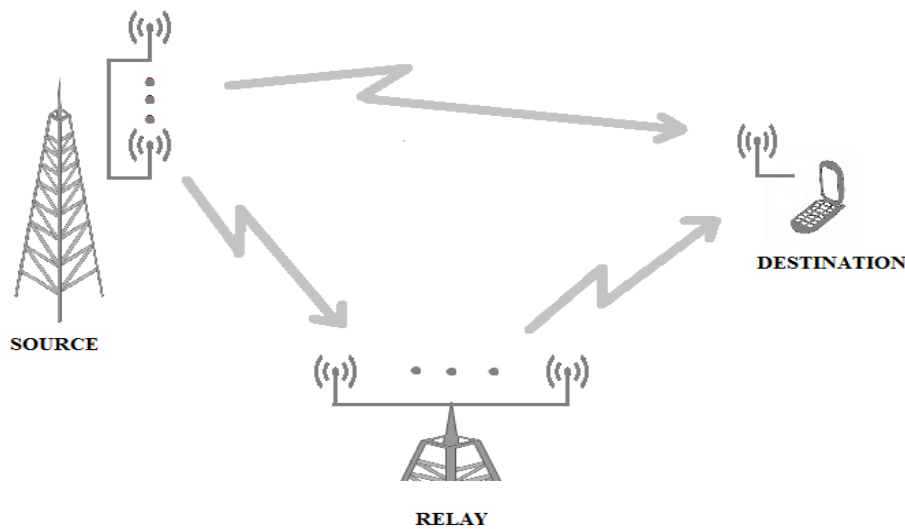


Fig. 1 System model of the three-node MIMO DF relay channel

The received information at D in the first phase is given by

$$y_{D,S} = h_{D,S}^T w_s x_s + n_{D,S} \quad (1)$$

where $h_{D,S}$ denotes the channel gain vector from S to D and $n_{D,S}$ is scalar additive Gaussian noise with unit variance. It follows that the received signal to noise ratio (SNR) at D during this first phase is given by

$$(SNR)_{D,S}^* = |h_{D,S}^T w_s|^2 P_s \quad (2)$$

Similarly, the information received at R is given as

$$y_{R,S} = H_{R,S} w_s x_s + n_{R,S} \quad (3)$$

where $H_{D,R}$ denotes the channel gain matrix from S to R and $n_{D,R}$ is scalar additive Gaussian noise with unit variance. Thus, the received SNR at R is

$$(SNR)_{R,S}^* = \|H_{R,S} w_s\|^2 P_s \quad (4)$$

So, the achievable information rate from S to R is

$$I_R = \log_2(1 + (SNR)_{R,S}^*) \quad (5)$$



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In the second phase, the relay re-transmits the information received from the source to the destination, x_r , with average power P_r with the beamforming vector w_r as given

$$y_{D,R} = h_{D,R}^T w_r x_r + n_{D,R} \quad (6)$$

where $h_{D,R}$ denotes the channel gain vector from S to D and $n_{D,R}$ is scalar additive Gaussian noise with unit variance. It follows that the received SNR at D in second phase is

$$(SNR)_{D,R}^* = |h_{D,R}^T w_r|^2 P_r \quad (7)$$

Later, D combines the signal received from R and S using Maximum Ratio Combining (MRC). The achievable information rate at D in second phase is given by

$$I_D = \log_2(1 + (SNR)_{D,S}^* + (SNR)_{D,R}^*) \quad (8)$$

Thus, its well known that the maximum information rate is bounded by I_D and I_R in [4]. Therefore, the total achievable information transmission rate at D from S over the MIMO DF relay channel is given by

$$I_{DF} = \frac{1}{2} \min\{I_R, I_D\}$$

$$I_{DF} = \frac{1}{2} \min\{\log_2(1 + (SNR)_{R,S}^*), \log_2(1 + (SNR)_{D,S}^* + (SNR)_{D,R}^*)\} \quad (9)$$

Thus, the optimisation to be done in the following equation to get the optimal beamforming vectors

$$\max_{w_s, w_r} \frac{1}{2} \log_2(1 + \min((SNR)_{R,S}^*, (SNR)_{D,S}^* + (SNR)_{D,R}^*))$$

$$s.t \ ||w_s||^2 = 1, ||w_r||^2 = 1 \quad (10)$$

Thus, according to the optimisation in [4] for getting the optimal beamforming vectors so as to maximise the achievable information rate can be obtained by solving (10).

IV. ENERGY EFFICIENCY OF TRANSMITTER

By incorporating multiple numbers of antennas at the destination the energy efficiency of the transmitter can be improved further. The system model of MIMO DF relay channel is improvised with multiple number of antennas at all the nodes. As far as energy efficiency of transmitter is concerned the total power consumption along the signal path of a link can be divided into two main parts: the power consumption of the power amplifiers (P_{PA}), and the power consumption of all other circuit blocks (P_C). The power consumed by the power amplifiers P_{PA} , can be modelled as

$$P_{PA} = \beta \cdot P_T \quad (11)$$

the reciprocal of the power amplifier efficiency (β), which is assumed to be a constant, P_T is the total transmit power.

The circuit power P_C includes the power consumed by the digital signal processor (DSP), frequency synthesizer, mixer, etc. The power consumption of the DSP should be the dominant component and mainly depends on the number of computations required for a given algorithm. There are several different ways to evaluate this circuit power. In [6] and [9] the circuit power is the sum of the power consumed in the circuit blocks (not including the DSP). Since accurately quantifying P_C is still an open issue, here, as in [10], assume that P_C is fixed and consider different values for P_C in the simulations. Thus, as in [11] the energy efficiency (in bits/Joule) of the k^{th} link can be written as

$$\eta_{Tr}^k = \frac{B \cdot I_{DF}}{\beta \cdot P_K + P_C} \quad (12)$$

where, B is the bandwidth. The numerator in (12) is the rate (in bits/sec) achieved according to the MIMO DF relay cooperative beamforming design, and the denominator is the total power consumption during transmission over the k^{th} link. P_K is the normalized (with respect to bandwidth) energy efficiency of the k^{th} link in Bits/Hz/Joule formed by the traces of the optimal beamforming vectors obtained from the algorithm in [4].

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Thus, with the fixed circuit power and also based on the achievable information rate obtained in the scenario i.e. MIMO DF relay and proposed MIMO DF relay with multiple number of antennas in the destination as per the beamforming design in [4] and the energy efficiency of transmitter based on the aforementioned situation is calculated.

V. RESULTS AND DISCUSSION

The effectiveness of proposed optimal beamforming design for MIMO DF relay channels is showed through numerical examples with the assumption that the power $P_s = P_r = P$ in all simulations. Rayleigh fading channel model is adopted in simulations, where it generate all the elements of channel matrix from complex Gaussian distribution with zero mean and unit variance.

The cooperative beamforming communication network model consists of source, relay and destination. The number of antenna equipped at source, relay and destination is N_s , N_r and N_d respectively. The simulation results for energy efficiency of transmitter is shown for various scenarios represented as $N_s : N_r : N_d$. Also in the simulation, the power amplifier efficiency is assumed to be 38%.

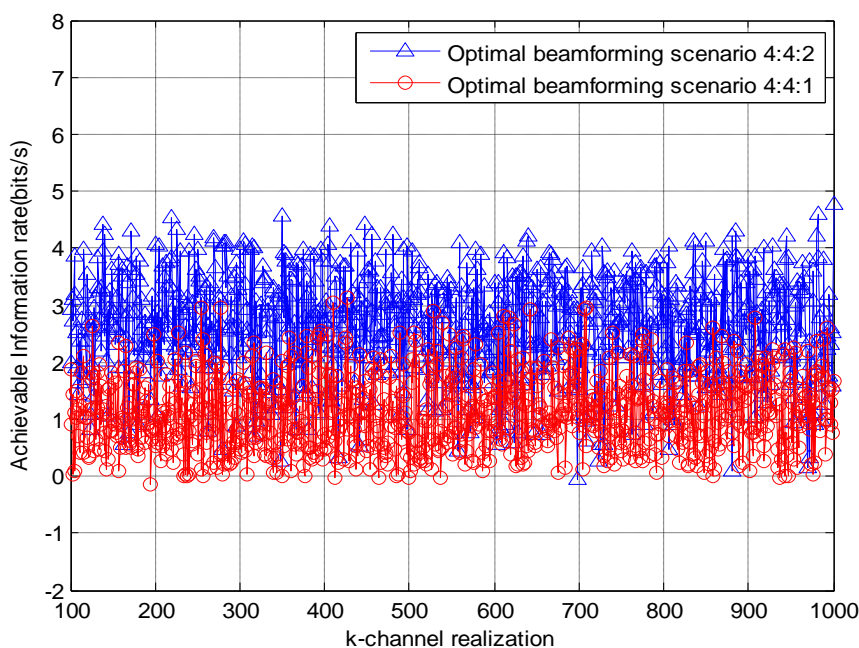


Fig. 2 Comparison of achievable information rate in optimal beamforming in scenario 4:4:2 vs. 4:4:1

In Fig. 2 the comparison between the two scenarios 4:4:2 and 4:4:1 is shown for the achievable information for 100 to 1000 sample channel realization where k represents the index of samples. It is seen that the scenario with destination equipped with multiple number of antennas outperforms the destination with single antenna.

In Fig 3 the comparison between the two scenarios 2:2:2 and 2:2:1 in the energy efficiency of transmitter for circuit power consumed is plotted and it's shown that 2:2:2 scenario perform better when compared to the 2:2:1. The circuit power is kept fixed and the efficiency is calculated for the information rate achieved in the given scenarios.

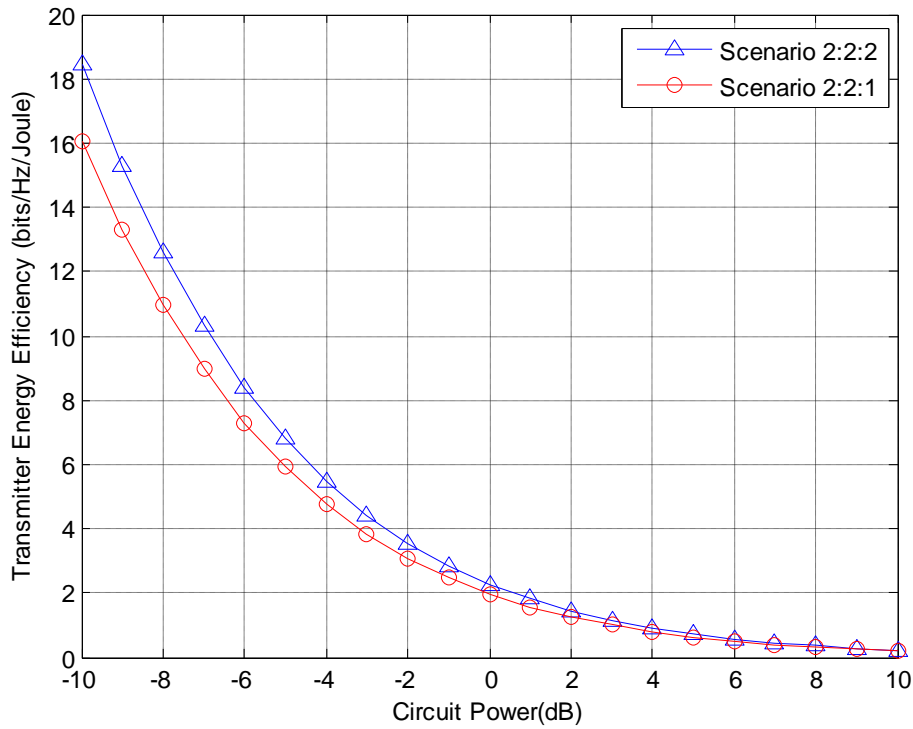


Fig. 3 Comparison of energy efficiency of transmitter in scenario 2:2:1 vs. 2:2:2

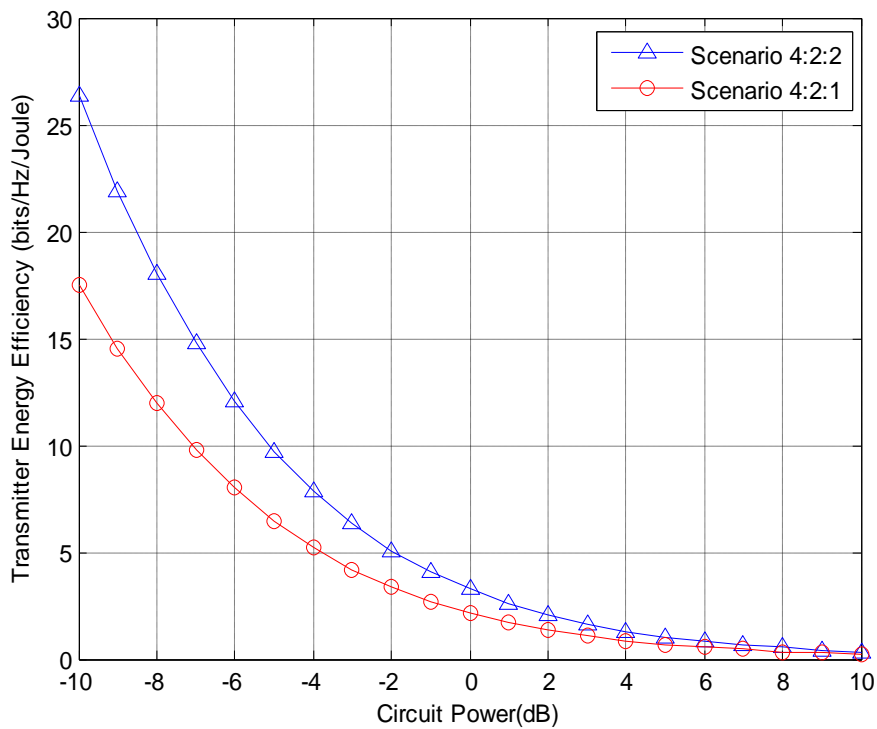


Fig. 4 Comparison of energy efficiency of transmitter in scenario 4:2:1 vs. 4:2:2

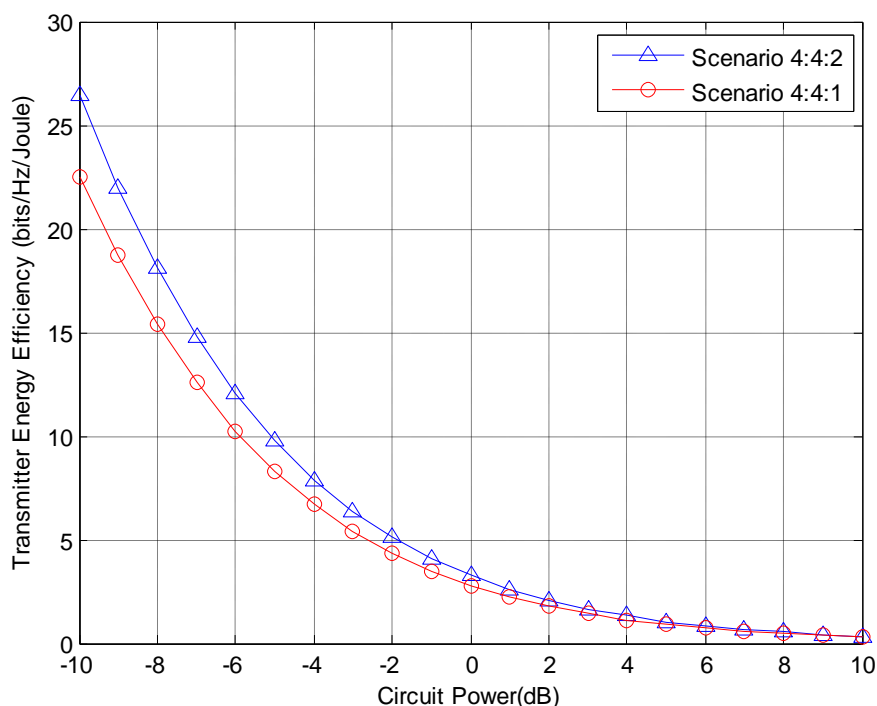


Fig. 5 Comparison of energy efficiency of transmitter in scenario 4:4:1 vs. 4:4:2

Similarly, in the Fig 4 the comparison between the two scenarios 4:2:2 and 4:2:1 in the energy efficiency of transmitter for circuit power consumed is plotted and it's shown that 4:2:2 scenario perform better than 4:2:1. It can be noticed that as the number of antennas deployed at the nodes are increasing the efficiency of the transmitter is also increasing accordingly. In Fig. 5 the comparison between the two scenarios 4:4:2 and 4:4:1 in the energy efficiency of transmitter for circuit power consumed is plotted and it's shown that 4:4:2 scenario perform better when compared to the 4:4:1. Thus, it's noticeable that in all the scenarios the energy efficiency of the transmitter in MIMO DF relay is found to be better when the destination is equipped with multiple number of antennas. Also, as the number of antenna at each node is increasing the energy efficiency also increases.

VI. CONCLUSION

In this work, the beamforming design for MIMO DF relay channels, where the source node, relay node and destination node are equipped with multiple antennas with an assumption that a direct link exist between source and destination is considered. The capacity formulation is done based on the optimal beamforming vectors obtained for maximising the achievable information rate for given transmit SNR value. Also, the use of multiple number of antennas at the destination increases the performance. The results also show that the energy efficiency of the source i.e. the transmitter is better when the destination is also equipped with multiple number of antennas.

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