Cooperative Diversity in Wireless Communications using the Estimate-and-Forward Strategy

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Abstract

Cooperative communication or cooperative diversity is a technique aimed at improving the channel capacity of wireless networks, through the enhancement of transmit and spatial diversity. This is brought about by an exploitation of the antennas on wireless devices. A major benefit of this technique is that this gain in diversity is achieved without the physical installation of these multiple antennas at the transmitter or even the receiver. In this paper, we investigate this concept of cooperation among nodes in a wireless communication system, using one of the cooperative diversity schemes, that is, the estimate-and-forward scheme. The work involves evaluating the effect of employing relays on the channel capacity as well as finding the effect while varying the number of relays. The results show that when relays are used, the channel capacity is about 10^6 times that when only direct transmission is considered.

1. Introduction

Cooperative Communication or Diversity has, not too long ago been proposed as an effective approach to combat fading and to ensure better system performance in wireless communication networks [1]. Because of the broadcast nature of a wireless channel, when data is transmitted by a node or user to another node or user, other neighbouring users can also receive the transmitted signal. In this concept of cooperation, these neighbouring nodes can act as relays or partners to forward the data received from the source node to the destination node. These kinds of supportive networks are known as relay networks [2].

To illustrate the basic idea behind cooperative communication, a simplified topology with one source node, two relay nodes and one destination node is depicted in Fig.1. Cooperative communication is carried out in two phases or in two time slots. In phase 1, the source node sends a data to the destination and relay nodes, whereas in phase 2, the relay node sends information to the destination node (possibly on different orthogonal channels). At the destination node, the data from both the source and relay nodes are combined. It has been shown that the capacity region of this communication channel can be increased significantly by this technique of relaying [3][4].

Different protocols employed in cooperative cooperation include but not limited to, 1. Amplify-and-Forward, 2. Decode-and-Forward, 3. Estimate-and-Forward, 4. Coded Cooperation. In the amplify-and-forward scheme, the relay, upon the receipt of data from the source node, amplifies it and forwards to the destination node. In the decode-and-forward scheme, the relay decodes the received signal, encodes it and forwards to the destination, while the relay sends an estimate of the signal received to the destination in the estimate-and-forward scheme. The destination then uses the relay's information as side information to decode the direct transmission of Phase 1. In the coded cooperation protocol, there is an integration of relay cooperation with channel coding [5][3].

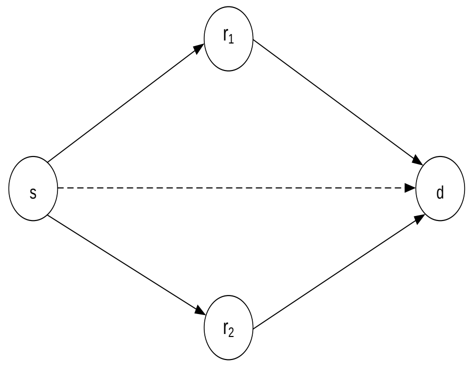

Fig. 1. Simplified topology of a 1-source, 2-relay cooperative communication system

Majority of the works done in the past in this area of cooperative diversity are based on the amplify-and-forward scheme. However this paper seeks to examine the same concept of cooperation from the perspective of the estimate-and-forward scheme. The authors in [6] worked on cooperative communication without the use of relaying partner. But in [7], the authors showed that cooperative communication with the help of partners (or relays) provides better resource usage efficiency than communication without a relay. In [8], an adhoc network model which uses mobile clients as relays to route peer-to-peer traffic within the network, was proposed, but it lacks availability guarantee. Some techniques for relay selection for amplify-and-forward and decode-and-forward-based networks are presented in [9], while in [10], the performance of cooperative networks using different types of signal modulation schemes such as phase-shift-keying (PSK), and quadrature-amplitude modulation (QAM) was compared.

The rest of this paper is organised as follows. Section 2 discusses the system model and mathematical formulation. Section 3 gives the simulation, while the simulation results are discussed in Section 4. Section 5 concludes the paper.

2. System model and mathematical formulation

Fig. 2 shows a simplified cooperative communication system model with *s* as the source node, *r* as the relay or partner node and *d* as the destination node. As mentioned earlier, cooperative communication is carried out in two phases or in two time slots. In phase 1, the source node sends a data to the destination and relay nodes, whereas in phase 2, the relay node sends information to the destination node (possibly on different orthogonal channels). At the destination node, the data from both the source and relay nodes are combined. It has been shown that the capacity region of this communication channel can be increased significantly by this technique of relaying.

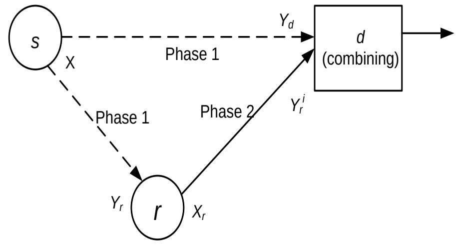

Fig. 2. *3-node* cooperative communication system model

In phase 1, the signal Y_d received as a result of direct transmission at the destination node is given as

$$Y_d = \sqrt{P_s G_{sd}}\, X + n_d \qquad (1)$$

while the signal Y_r received at the relay r is expressed as

$$Y_r = \sqrt{P_s G_{sr}}\, X + n_r \qquad (2)$$

where P_s is the transmit power from the source node, X is the unit-energy information transmitted by the source node in Phase 1, G_{sd} and G_{sr} denote the channel gains from source to destination, and from source to relay, respectively, and n_d and n_r represent samples of additive white Gaussian noise (AWGN). It is assumed, without any loss of generality, that the noise power, σ^2 is the same for all the channels.

Without employing the use of the relaying partners (direct transmission), the signal-to-noise ratio (SNR), denoted by Γ from the source node to the destination node is expressed as

$$\Gamma_{sd}^{DT} = \frac{P_s G_{sd}}{\sigma^2} \qquad (3)$$

While the capacity of the direct-transmission channel, denoted by R_{sd} is given as in (4)

$$R_{sd} = W \log_2 (1 + \Gamma_{sd}^{DT}) \qquad (4)$$

where W is the bandwidth of transmission

Now for the Estimate-and-Forward cooperative diversity scheme being considered, the signal-to-noise ratio (SNR) from the source node to the destination node, via the relay node is written as

$$\Gamma_{srd}^{EF} = \frac{P_s P_r G_{sr} G_{rd}}{\sigma^2 [P_r G_{rd} + P_s (G_{sd} + G_{sr}) + \sigma^2]} \quad (5)$$

from which the channel capacity resulting can be obtained, and given as

$$R_{srd}^{EF} = W \log_2 (+ \Gamma_{sd}^{DT} + \Gamma_{srd}^{EF}) \quad (6)$$

where the superscripts *EF* and *DT* represent estimate-and-forward and direct transmission respectively.

3. Simulation results and discussion

This work was carried out in the MATLAB environment. It was done in two ways: Firstly, the channel capacities for both the direct transmission (without relays) and for the estimate-and-forward cooperative diversity scheme were compared. Secondly, for the estimate-and-forward scheme, an increase was made in the number of relays that can be used for forwarding of information to the destination, and the effects on the channel capacity were found out.

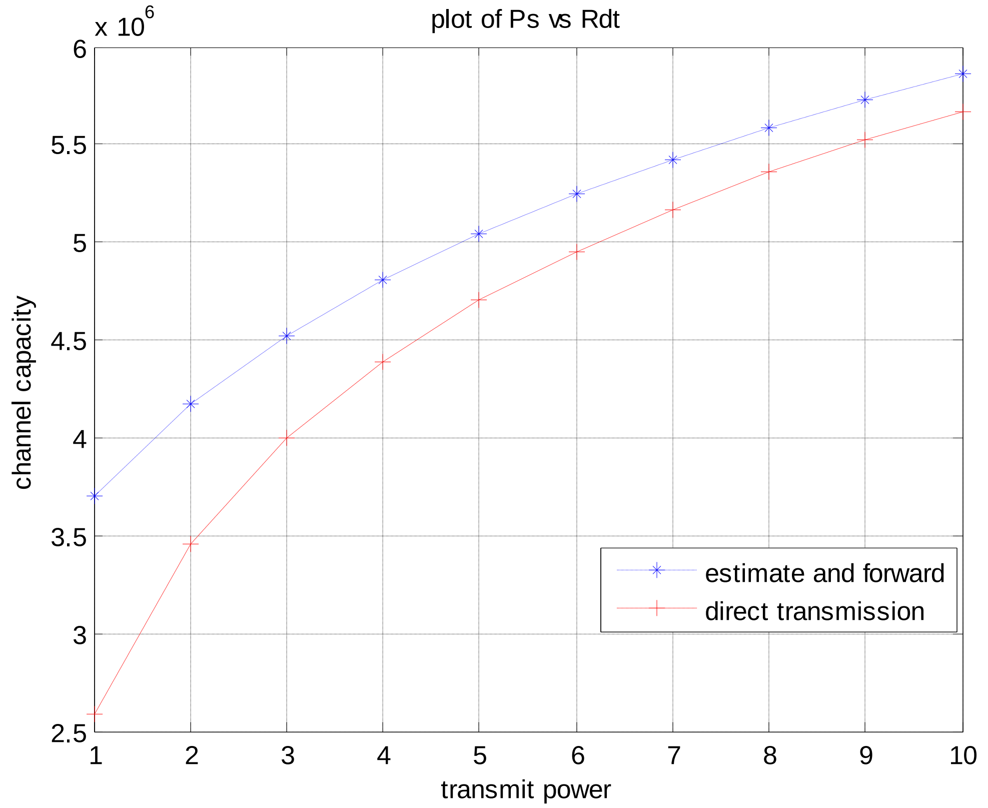

Fig.3 Plots of the source transmit power against channel capacities for the direct and the relayed transmissions

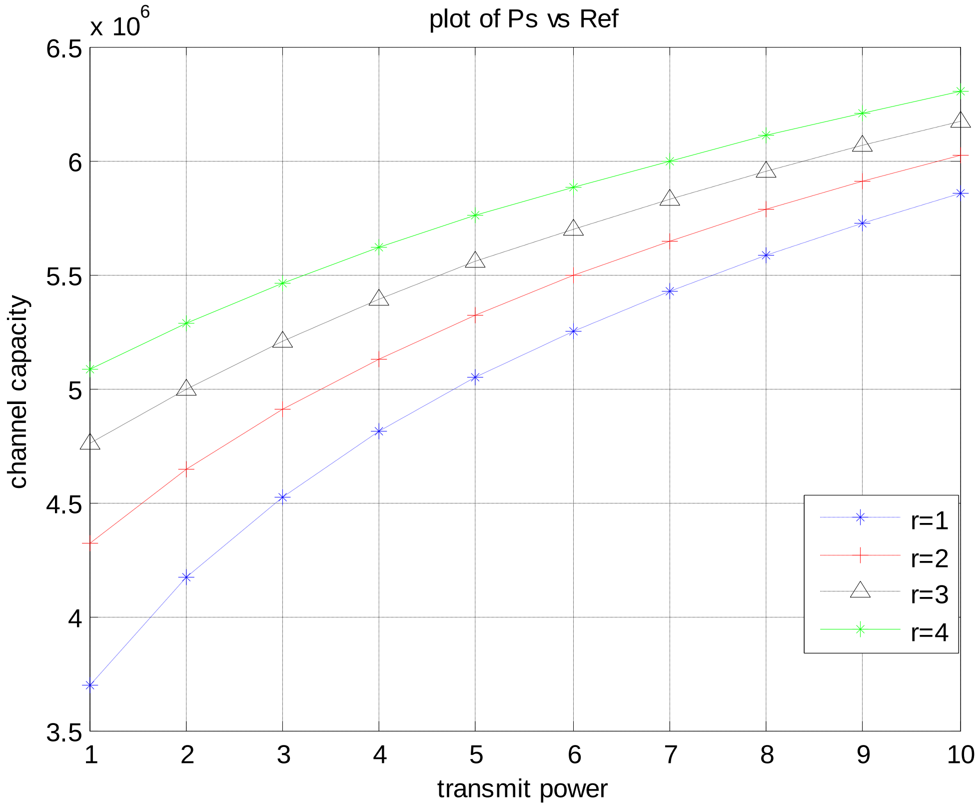

Fig.4. Plots of the source transmit power against channel capacity with varying number of relays

Fig. 3 shows the plots of the source transmit power P_s against the channel capacity for a direct transmission from source node to the destination node without the use of a relaying partner in the first instance; and in the second instance, the plots when a relay is employed with the estimate-and-forward topology. It can be seen from the plots that there is a higher transmission channel capacity between the source node and the destination node when a relay node is employed in helping to forward the data from the source to the destination. From the figure, using a relay yields a channel capacity that is about 1.42 times that without a relay.

In Fig.4, results of the scenario where the number of relays used in the cooperation is increased from one to four (*r* = 1 to *r* = 4). As can be observed from the figure, as the number of the relays used is increased, there is a corresponding increase in the channel capacity, even at fixed source transmit power. These results further confirm the importance of employing the use of relays in cooperative diversity.

4. Conclusion

In this paper, we have been able to further establish, by using the estimate-and-forward cooperative diversity protocol, that user cooperation or cooperative communication brings about a higher channel capacity and that increasing the number of relays used further increases the capacity.

5. References

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