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TRANSMIT DIVERSITY IN COOPERATIVE NETWORKS: IMPACT ON CHANNEL

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Abstract

It has become a known fact that cooperative communication will be a veritable tool in the next generation of wireless networks. Cooperative communication, also known as user cooperation is a relatively novel technique aimed at improving the performance of wireless networks, through the enhancement of transmits diversity. The main benefit of this technique is that this gain in diversity is achieved without the installation of multiple antennas at the transmitter or even the receiver. In this paper, we attempt to evaluate the importance of the use of relay nodes in implementing this cooperative diversity by analyzing the parameter known as channel capacity. This analysis is done by modelling a wireless network as consisting of three nodes, namely, the source node, the relay node and the destination node, using the amplify-and-forward cooperative diversity protocol. Signals transmitted directly from the source to destination and from source to relay, and then to destination are investigated. Findings show that with the aid of relay nodes in signal transmission, the channel capacity is about 5 times that without a relay node.

Keywords: Channel, Destination, Diversity, Relay, Source

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Introduction

Cooperative diversity is a very novel and promising technique for addressing the high data-rate coverage demand in future wireless communication systems. The main and basic notion behind this technique is that apart from the direct transmission from the transmitter to the

receiver, there can be other nodes, used in enhancing the diversity by relaying the signal from the source to the destination. Some of the benefits of cooperative diversity include, increasing the transmission reliability and capacity, lowering the bit-error rate, and increasing the achievable transmission range. Moreover, spatial diversity is achieved by

using relay nodes as virtual antennas, and as a result, mitigate fading effects (Laneman et al., 2004).

There are three major protocols commonly employed in implementing cooperation in wireless networks. These are the Amplify-and-Forward (also called unregenerative), the Decode-and-Forward (also known as regenerative) and Coded Cooperation. In the amplify-and-forward scheme, the relay (or partner) amplifies the incoming signal before retransmitting it onward to the destination, while in the decode-and-forward scheme, the relay detects (or decodes) the signal and then retransmits it. Laneman et al. (2004) in coded cooperation, there is an integration of relay cooperation with channel coding. Instead of merely repeating the received information, as in the previous protocols, the relay node decodes the partner's transmission and transmits additional parity symbols to the destination node (Han et al., 2012).

Reviewing past works in this area of cooperative communication, quite a number of them involved cooperation without the issue of relays being involved, examples being Laneman et al. (2004) and Sendonaris et al. (2003). In Ibrahim et al. (2008), It was shown that implementing cooperation with relays makes available a better resource usage than without relays. The issue of allocating power to interacting nodes in a wireless networks is of equal importance when addressing the performance of cooperative communication, as investigated in Han et al. (2009). The work of Prasetyo et al. (2011) addressed the issue of selecting the optimal relay, with power allocation as the metric and under the influence of

interference, and using game theory. The work of Ikki and Ahmed (2007) also investigated the performance of cooperative diversity, through the selection of best relays in the network, and with the decode- and -forward cooperative diversity (CD) scheme as the protocol. In Wang et al. (2010), a coded cooperative system under Rayleigh fading and path loss was considered, where a novel algorithm for partner selection and optimal power allocation was presented. Ng and Lok (2010) provided a simple optimal rate allocation algorithm for two cooperating node pairs and closed-form optimal rate allocations for some cases.

In the work of Kadloor and Adve (2009), a system with a single base station communicating with multiple users over orthogonal channels while being assisted by multiple relays was considered, in which, using the sum rate as the design metric, a convex optimization problem that provides an extremely tight upper bound on performance was developed. And still on cooperative diversity cum relay selection (Lin et al., 2010), a novel network architecture that incorporates cooperative diversity techniques to increase the cellular network throughput was proposed. However, this paper focuses on how the use of relays affects the channel capacity of a network. In fact this paper is another way of corroborating the importance of relays in cooperative communications.

The rest of this paper is organized as follows: Section 2 discusses the wireless system model, while in Section 3, the computation using the MATLAB tool is carried out, and results are given. Finally, Section 4 concludes the paper. It should be

noted that relay and relay node are used interchangeably in this paper.

Wireless System Model Formulation

Figures 1a and b together show a model of a 3-node cooperative communication scheme. Figure 1a shows a 3-node multi-hop cooperative diversity, with the source node (S), relay node (R) and destination node (D), while Figure 1b shows in detail the cooperative scheme. During the first time slot, the source node transmits signal directly to the destination and also to the relay, while during the second time slot, the relay retransmits the signal received from the source during the first time slot to the destination. It should however be noted that there could be more than one relays in a communication network, and it is the responsibility of the source to select the optimal or the best among the relays or partners, with which to cooperate.

Figure 1a: Two-hop transmission with cooperative diversity

Figure 1b: A 3-node cooperative system model

Due to the broadcast nature of wireless networks, it is assumed that the relay and the destination nodes suffer from

interference. This is because, as the nodes are usually located within clusters, there would always be interference from neighbouring clusters during transmission, especially during the first timeslot.

As earlier mentioned, during the first time slot, the source transmits signal to the destination and the relay. So the received signal, y at the destination from this source node is given by Han et al. (2012) as

$$y_{sd} = \sqrt{P_s G_{sd}} x + \eta_{sd} + \omega_d, \quad (1)$$

the received signal at the relay, from the source is given as (2)

$$y_{sr} = \sqrt{P_s G_{sr}} x + \eta_{sr} + \omega_r \quad (2)$$

and the received signal at the destination, from the relay is denoted as

$$y_{rd} = \sqrt{P_r G_{rd}} X + \eta_{rd} + \omega_d \quad (3)$$

where P_s = transmit power of the source node, G_{sd} , G_{sr} and G_{rd} represent the channel gains between the source node and destination node, between the source and the relay nodes and between the relay node and the destination node, respectively; x is the signal transmitted by the source node, X is the amplified copy of x which is retransmitted from the relay node to the destination node, and is given by Han et al. (2012) as

$$X = \frac{\sqrt{P_s G_{sr}} x + \eta_{sr} + \omega_r}{\sqrt{P_s G_{sr}} + \Omega_n + \Omega_{int}}; \quad (4)$$

$\square$ represents the additive white Gaussian noise (AWGN) having zero mean and

variance σ_n^2 in the relay and destination nodes. σ_r^2 and σ_d^2 represent the interference from the neighbouring clusters in the relay and destination nodes, respectively (Han et al., 2009).

According to the Central Limit Theorem, which states that, given certain conditions, the mean of a sufficiently large number of independent random variables, each with finite mean and variance, will be approximately normally distributed, the interference can be modelled as a zero mean Gaussian distributed variable, with a variance σ_{int}^2 (Prasetyo et al., 2011).

If the signal-to-interference-plus-noise ratio (SINR) is denoted by Γ , then the SINR at the destination node from the source node is given by Han et al. (2012) as

$$\Gamma_{sd} = \frac{P_s G_{sd}}{\Omega_n + \Omega_{int}} \quad (5)$$

while at the relay from the source, the SINR is given by

$$\Gamma_{sr} = \frac{P_s G_{sr}}{\Omega_n + \Omega_{int}} \quad (6)$$

Also, from the relay to the destination, we have

$$\Gamma_{rd} = \frac{P_r G_{rd}}{\Omega_n + \Omega_{int}} \quad (7)$$

Combining (6) and (7), we obtain the SINR at the destination node from the source node, via the relay node, given as

$$\Gamma_{srd} = \frac{P_r P_s G_{rd} G_{sr}}{(\Omega_n + \Omega_{int})(P_r G_{rd} + P_s G_{sr} + \Omega_n + \Omega_{int})} \quad (8)$$

Given that W is the transmission bandwidth and R is the link capacity, then from the Shannon's capacity theorem,

$$R_{sd} = W \log_2 (1 + \Gamma_{sd}) \quad (9)$$

Where, R_{sd} is the capacity of the source – destination link.

Similarly,

$$R_{sr} = W \log_2 (1 + \Gamma_{sr}) \quad (10)$$

Where, R_{sr} is the source-relay link capacity, and the capacity of transmission link at the destination node from the relay node is given by

$$R_{srd} = W \log_2 (1 + \Gamma_{srd}) \quad (11)$$

However, as mentioned earlier, there is the possibility of the source having to use more than one relays (or partners) in transmitting its information. In this case, if we assume that M relay nodes were to be used by the source node where $M \leq N$, then the total transmission capacity at the destination node is given by (12)

$$R_{srd} = W \log_2 (1 + \Gamma_{sd} + \sum_{i \in M} \Gamma_{srd}) \quad (12)$$

Computation, Results and Discussion

Computation and Results

In this work, computation was carried out on the MATLAB platform. In the implementation, the source power P_s was varied with the transmission capacity, R of the different links, source – destination, source – relay and source – relay-destination. The bandwidth was fixed at 256 Hz while the source transmit power P and P_r were put at 20 dB and at other times P_s was varied from 5 to 20 dB. The source-destination channel and source-relay channel gains were assumed equal while the relay-destination channel gain was assumed lower.

The plots of the results in the next section are obtained from the following equation, where all the parameters are as defined earlier:

$$R_{sd} = W \log_2 \left[1 + \left(\frac{P_s G_{sd}}{\Omega_n + \Omega_{int}} \right) \right] \quad (13)$$

Discussion of Results

The plots shown in Figures 2 to 5 were generated through computation. Figure 2 shows the plot of the source power P_s against the link capacity between the source node and the destination node, R_{sd} ; while Figure 3 shows the plot of the source power P_s against the transmission link capacity between the source and relay nodes, R_{sr} .

As can be seen, the transmission in the case is without the help of a relaying partner, and the transmission link capacity in both scenarios is approximately the same.

Figure 2: Plot of P_s vs. R_{sd}

Figure 3: Plot of P_s vs. R_{sr}

Figure 4 shows the plot of power source P_s against the link capacity for the source-relay-destination nodes, R_{srd} . In this case, unlike in Figures 2 and 3, the relaying partner is employed here to help retransmit the information from the source to the destination, via the relay node. There is an obvious, or rather expected increase in the link capacity of up to about 5 times that of the direct („no relay“) transmission. Figure 5 gives a clearer graphic detail of the comparison among P_s vs. R_{sd} , P_s vs. R_{sr} and P_s vs. R_{srd} , where R_{srd} is the link capacity from the source to the destination, with the help of a relaying partner.

Figure 4: Plot of P_s vs. R_{srd}

Figure 5: Plots of P_s vs. R_{sd} , R_{sr} and R_{srd}

From the results, it can be seen that additional nodes improve channel diversity. The reason is because, unlike direct transmission from a single node, signals are transmitted on independent fading paths towards the destination node, in cooperative cooperation; and at the destination, there is combining to get back the original signal, and as such the diversity is improved on.

Conclusion

In this paper, we have been able to analytically verify that employing the use of a relay node in cooperative

communication increases the transmission link capacity of a link. This would undoubtedly offer the advantages of reduced bit-error rate, increase in the signal-to-noise ratio, higher throughput and diversity and the accommodation of more data services.

Future area of work would be to analytically investigate the effect of varying the number of partners or relay nodes on the SINR of each link and by extension, the effect on the link capacity as well.

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