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Further results for the outage performance of multi-antenna relay cooperation in absence of direct link

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ABSTRACT

Motivated from the recent works related to multi-antenna fixed relay network, this letter investigates the outage performance of a system in which source communicates with destination via two multi-antenna relays. A new protocol has been proposed for this scheme which outperforms the previous scheme published in [1]. A closed-form expression of outage probability and average transmitted power have been derived for more versatile Nakagami-*m* fading channel, with integer values of *m*. The effect of number of relay antennas, relay placement and swapping of relay assignment in various fading condition have also been studied.

1. Introduction

Q3 Cooperative relaying is an efficient way for providing diversity gain which dramatically improves the system performance [2]. In this system multiple wireless nodes share their antennas and creates virtual antenna array [3]. An overview of such cooperation schemes and issues related to their implementation have been discussed in [4,5]. Wireless cooperative nodes are generally battery powered and have to process the signals of other cooperative nodes so they have to consume its precious battery power which is the main bottleneck for such type of system. Hence, in [6–8], various power allocation schemes for minimizing the energy consumption in cooperative relay network have been discussed. Infrastructure based fixed relays are in close proximity of power so cooperation from other nodes do not face the scarcity of power. Motivated from this fact, infrastructure based multi-antenna relay nodes in a cooperative network have been proposed in [9]. This work is further extended in [10] and closed form expressions of outage probability and bit error rate (*BER*) for binary phase shift keying (BPSK) are derived for the case where communication between source and destination is supported by multi-antenna relay and both relay and destination perform maximum ratio combining (*MRC*) of signals in Rayleigh fading channel. *MRC* requires tracking of amplitude and phase of fading envelop hence it enhances the complexity of hardware. Complexity of *MRC* can be simplified with the help of selection combining (*SC*) which only tracks the SNR. A closed form expressions of outage probability and average error rate have been derived in [11] for the case when source and destination perform *SC* of the signals. Similarly outage probability and average error rate of two-hop multi-antenna relay based system for the case when relay performs *SC* of signals and destination performs *MRC* of signals are analyzed in [12,13], respectively. Here, authors have assumed that the relay has limited hardware processing capability but relaxed the hardware constraints at destination. Average capacity and SNR analysis is also a major performance metrics so it is analyzed in [14] for similar type of cooperative relay network. Antennas installed on multi-antenna relay are some time suffer from correlated fading due to insufficient spacing among the installed antennas. Hence in [15], closed form expressions for outage probability and *BER* have been derived when multi-antenna cooperative relay network operates in correlated Nakagami-*m* fading channel and both the relay as well as destination perform *MRC* of the signals. Multiple antennas can be installed at transmitting end and receiving end of relay station with relatively higher signal processing cost which further improve the system performance. A two-way relay pre-coder for MIMO relay is designed in [16] in presence of full channel state information (CSI). In case of high mobility scenario among the nodes, availability of exact CSI is not possible so the analysis of cooperative relay network in presence of partial CSI is presented in [17].

This work is extension of previously published work in [1] for the cooperative communication scenario. Here, we have assumed more versatile Nakagami-*m* fading channel compared to the assumption of Rayleigh fading channel in previous work. A new protocol has been developed which outperforms the previous one in some specific placement of relays at cost of increase in average transmitted power. Performance of proposed system is also enhanced by swapped assignment of relays in certain placement of relays. In

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this system model, communication between source and destination takes place with the help of two multi-antenna relay nodes. Relays work in adaptive decode forward mode hence they remain silent if received signal strength is below a predefined threshold. Source and destination are outfitted with single antenna due to their small size and limited signal processing capability. However, relays are assumed to be infrastructure type fixed nodes and hence they can accommodate multiple antennas. It is assumed that the signals received directly at destination from the source are too weak to make any contribution; hence the signals received via only relays are combined at the destination. Such assumption is justified because in highly dense urban environment, direct link may not be available when the destination is located behind the sky scrapers or inside the buildings. In such cases, communication is possible through intermediate relay terminals. In a harsh multi-path fading environment, diversity systems are employed to reduce signal outage and increase the availability of the link between source and destination. Hence, the proposed system contains two relay terminals which helps to attain diversity gain. Relays operate in half-duplex mode [18], so the support of large number of relays in such type of communication is not recommended due to loss of spectral efficiency. Interference among the nodes is negligible because the nodes transmit in orthogonal time slots.

The channel seen by receiving antenna elements of relays are assumed to be statistically identical fading parameters whereas channel seen by different pair of nodes (i.e. source–relay, relay–relay and relay–destination) have been considered to be non-identical statistical parameters, whereas identical fading parameters are assumed for the channels seen by the receiving antenna elements of relays. Performance of such system model is analyzed by amending the placement of relays and antennas installed on it in Nakagami-m fading channel with different fading conditions. The contributions of this work are summarized below:

- A new protocol has been proposed which outperforms previous one [1].
- Average transmitted power of proposed protocol has been analyzed which is compared with previous one [1].
- Study the effect of exchanging roles and responsibilities of relays is conducted for proposed protocol.
- Analysis of proposed protocol is done for Nakagami-m fading channel which is more versatile fading channel.

Rest of this letter is organized as follows: Section 2, briefly discusses the system model of two multi-antenna cooperative relay network. Outage of this system model is analyzed in Section 3. In Section 4, transmitted power for this system model is presented. Numerical results are discussed in Section 5. Finally, conclusions are drawn in Section 6.

2. System model

A setup for cooperative communication network is shown in Fig. 1. Here, direct path between source (s), two multi-antenna relays (r_1, r_2) and destination (d) is present but no direct path is available between s and d. Here, r_1 and r_2 are outfitted with one transmitting antenna and n_1, n_2 receiving antennas, respectively. In this work, we have assumed that the channel between two nodes is quasi-static and flat faded. It remain unchanged in a particular time-slot but changes independently from one time-slot to another time-slot. In setup of original assignment, s broadcasts the message which is received by r_1 and r_2 in first time-slot (i.e. $s \to r_1$ and $s \to r_2$). Relays r_1 and r_2 are half-duplex in nature and receive the signals via multiple antennas. On the other hand, r_1 will become inactive if the received signal strength at r_1 is less than the predefined threshold,

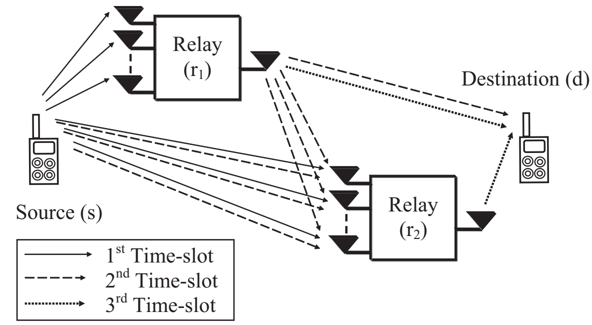

Fig. 1. Two-hop multi-antenna cooperative relaying in absence of direct link between s and d.

it will broadcast single bit negative acknowledgement signal. After receiving negative acknowledgement signal, s re-transmit same information to r_2 in second time-slot. The relay r_2 executes the process of co-phasing and combining of the message sent by s in the first time-slot and signals sent by s or r_1 in the second time-slot. If the message signal strength at r_2 is above a predefined threshold, message is regenerated and transmitted to d (i.e. $r_2 \to d$) in the third time-slot. In case the received SNR at r_2 is below the threshold, r_2 will remain silent and broadcast single bit negative acknowledgement signal. After receiving negative acknowledgement signal, r_1 re-transmits same information to d in third time-slot. Destination d coherently combines the buffered copies of signals sent by r_1 in the second time-slot and signals sent by r_1 or r_2 in the third-time slot. However, in swapped assignment, roll and responsibility of r_1 and r_2 is exchanged from each other. The fading envelope of the wireless environment among all the nodes is supposed to be Nakagami-m distributed, so the probability density function (PDF) of received SNR (γ_{ij}) can be written as [19]

$$f_{\gamma_{ij}}(\gamma_{ij}) = \frac{(\lambda_{ij} m_{ij})^{m_{ij}\eta} \gamma_{ij}^{(m_{ij}\eta - 1)}}{\Gamma(m_{ij}\eta)} \exp(-\lambda_{ij} m_{ij} \gamma_{ij}) \quad (1)$$

here $i \in \{s, r_1, r_2\}, j \in \{r_1, r_2, d\}$, $\lambda_{ij} = (2\ell_{ij}/\ell_{sd})^{\psi}/\omega$, ψ is the path loss exponent, ℓ_{ij} represents distance between the nodes i and j, which is normalized by reference distance $\ell_{sd}/2$, ω is average received SNR at reference point, $\Gamma(\cdot)$ is gamma function [20, Eq.(8.310.1)] and m_{ij} represents severity of fading. Value of η will be n_1, n_2, 1, if j is assign to r_1, r_2, d, respectively. As stated earlier, it is assumed that the relays operates in half-duplex mode and can not transmit and receive the signal simultaneously (i.e. $\{i, j\} \notin r_1$ or $\{i, j\} \notin r_2$ at same time). Relays r_1 and r_2 regenerate the message if the signal strength is above a particular threshold. In such circumstances, mutual information (I) should be greater than target data rate R (spectral efficiency) [18]:

$$I = \frac{1}{3}\log_2(1 + SNR) > R. \quad (2)$$

3. Outage analysis

In this section, we will derive the PDF of total received SNR at d, after that we will derive the expression for outage probability.

3.1. Probability of r_1 is in inactive mode

Probability of r_1 is in inactive mode, if upper bound of the broadcasted information between $s \to r_1$ (i.e. I_{sr_1}) is below R i.e.

$$P[r_1^{inactive}] = P[I_{sr_1} \le R] = P[\gamma_{sr_1} \le \chi], \quad (3)$$