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Effects of multiple co-channel interferers on the performance of amplify-and-forward relaying with optimum combining, multiple relays and multiple antennas

Henry W. Merino [a,*], Carlos E. Câmara [b], Celso de Almeida [a]

[a] School of Electrical and Computer Engineering, University of Campinas, SP, Brazil
[b] School of Information Systems, Padre Anchieta University Center, SP, Brazil

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ABSTRACT

Cooperative relaying is a method used mainly to improve cellular networks in terms of diversity gain and coverage extension. However, its performance is gravely affected by the co-channel interference (CCI), especially when a high channel reuse is needed. Optimum combining (OC) is the combining technique that maximizes the signal-to-interference-plus-noise-ratio (SINR) and eliminates the CCI, achieving the best diversity gain. In the present paper, the performance analysis of cooperative amplify-and-forward relaying by using OC is extended for a scenario with multiple co-channel interferers, multiple-antenna relays and multiple antenna-destination. Also, the techniques of multiple relay transmission (MRT) and relay selection with transmit antenna selection (RS-TAS) are evaluated and compared. An approximation of the SINR and the diversity gain are obtained for both transmission techniques. The moment-generating function (MGF) of SINR is derived in order to obtain the average bit-error rate (BER) of the system. Analytical results are validated using Monte-Carlo simulations, which shows that the proposed scenario combats the CCI in a non obvious way and obtains diversity gain in both transmission techniques. Moreover, the MRT technique cancels a greater number of interferers than RS-TAS, while RS-TAS achieves better spectral efficiency and obtains better performance for small number of interferers.

1. Introduction

Cooperative relaying is a well-known method in literature used to improve the performance of wireless systems in terms of coverage extension and bit-error rate (BER) by using other terminals to relay the same information. Amplify-and-forward (AF) is one of the most studied cooperative protocols, in which a relay retransmit the received signal after amplifying it. Preliminary researches like [1–6] have considered maximal-ratio combining (MRC) in order to reach a maximum diversity gain in a scenario affected only by fading and additive white Gaussian noise. Unfortunately, when co-channel interference (CCI) is considered, MRC is a suboptimal solution that does not achieve the same diversity gain [7–9].

In the coming cellular networks, efficient transmission methods that improve the spectral efficiency will be necessary, such as [10]. Reducing the channel reuse factor can be a good solution to increase the spectral efficiency, but it results in higher-power CCI. Several techniques have been studied in [11–14] with the aim of reducing the CCI even without the cooperative context. As a result, the optimum combining (OC) is the technique that maximizes the SINR and eliminates the CCI.

The concept of OC in cooperative networks was introduced by [15], in which the performance is analysed by considering CCI at destination and single-antenna nodes. The papers [16–18] have extended the analysis including CCI in both relay and destination nodes, but again for single-antenna scenarios. More recently, papers like [19] and [20] have included multiple antennas at destination but by considering one high-power CCI. Scenarios with multiple-antenna nodes affected by multiple interferers have not been yet studied jointly with the OC concept, despite being a potential scenario in cellular networks. In that sense, it is relevant to extend the performance analysis by including these considerations. The results are not at all obvious.

In this paper, the effects of multiple co-channel interferers on the performance of cooperative AF relaying is analysed in terms of the average BER. Specifically, a system with OC, as well as, multiple antennas at relay and destination is considered. The main contributions of this paper are listed below:

- Approximations of the end-to-end instantaneous SINR are proposed for the techniques of multiple relay transmission (MRT) and relay selection with transmit antenna selection (RS-TAS). The diversity gain is obtained by considering CCI at relay and destination.

* Corresponding author.
E-mail address: hmerino@decom.fee.unicamp.br (H.W. Merino).

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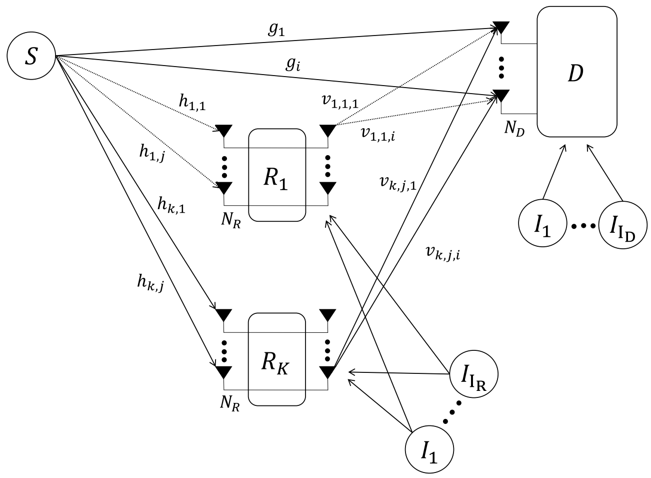

Fig. 1. Wireless cooperative network composed by multiple-antenna relays and multiple-antenna destination in the presence of multiple co-channel interferers.

- For the MRT technique, the moment-generating function (MGF) of the received SINR is obtained in closed-form for the scenarios with multiple CCI at destination and at relays. Then, the average BER is easily obtained for a wide variety of modulations.
- For the case of RS-TAS technique, the MGF is obtained for the scenario with multiple CCI at destination. The technique of RS-TAS with multiple CCI at relays is not analysed due to its limitation for improving the system diversity.

The remainder of this paper is organized as follows. In Section 2, the cooperative system and channel models are described and the basic concepts of OC are presented. The instantaneous SINR for the MRT and RS-TAS techniques are derived in Sections 3 and 4, respectively. In Section 5, the MGF of the received signal is derived for each scenario. In Section 6, numerical results and simulation are shown and commented. Finally, in Section 7, the main conclusions of the paper are summarized.

The following notations are used throughout the paper. All boldface lowercase letters represent vectors. The operations $(\cdot)^T$, $(\cdot)^*$ and $(\cdot)^{-1}$ denotes matrix transposition, conjugation and inverse, respectively. The functions $f_X(\cdot)$ and $F_X(\cdot)$ represent the probability density function (PDF) and cumulative distribution function (CDF) of a random variable X, respectively, and $\mathbb{E}[\cdot]$ denotes mean value.

2. System and channel models

In this paper, a wireless cooperative network with a source, K relays equipped with N_R antennas and a destination equipped with N_D antennas is considered. Each antenna at relay and destination are affected by I_R and I_D interferers, respectively. Moreover, to each antenna is associated an additive white Gaussian noise (AWGN) with zero mean and variance equal to σ^2. Furthermore, it is assumed that the destination has knowledge of the instantaneous channel gains.

In reference to Fig. 1, the parameters g_i, $h_{k,j}$ and $v_{k,j,i}$ correspond to the channel gains at source–destination (S–D), source–relay (S–R) and relay–destination (R–D) links, respectively, where $i = 1, 2, \ldots, N_D$, $j = 1, 2, \ldots, N_R$ and $k = 1, 2, \ldots, K$ are the destination antenna, relay antenna and relay indexes. The channel gain vectors at interferer–relay (I–R) and interferer–destination (I–D) links are $\boldsymbol{l}_m$ and $\boldsymbol{f}_q$, respectively, where $m = 1, 2, \ldots, I_R$ and $q = 1, 2, \ldots, I_D$. All gains are complex in the form $\alpha e^{j\phi}$, where α is Rayleigh fading and ϕ is the uniform distributed phase component. The transmission power by the source, by each relay, by the relay interferers and by the destination interferers are P_S, P_R, P_{I_R} and P_{I_D}, respectively.

Two stages are needed in order to perform full communication. During the first stage, the source broadcasts the symbol x with power P_S to each relay and also to the destination. Also, I_D interferers affect the destination by sending the symbol $\hat{x}_q$. Each interferer affects all destination antennas at the same time but through different fading channels, consequently, each destination antenna is affected by the same I_D interferers. The same happens with the relay antennas, which are affected by I_R interferers, each sending a symbol $\hat{x}_m$. The received signals in this stage at relays and destination can be represented by:

$$\boldsymbol{y}_{SR} = \sqrt{P_S}\boldsymbol{h}x + \sqrt{P_{I_R}}\sum_{m=1}^{I_R}\boldsymbol{l}_m\hat{x}_m + \boldsymbol{n}_{SR} \tag{1}$$

$$\boldsymbol{y}_{SD} = \sqrt{P_S}\boldsymbol{g}x + \sqrt{P_{I_D}}\sum_{q=1}^{I_D}\boldsymbol{f}_q\hat{x}_q + \boldsymbol{n}_{SD}, \tag{2}$$

where $\boldsymbol{n}_{SR}$ and $\boldsymbol{n}_{SD}$ are the noise vectors at relays and destination, respectively.

2.1. Multiple relays transmission technique

For the second stage, each jth antenna at relays receives the signal from the source, amplify it with a gain G_j and send it to the destination in different time-slots. Once KN_R relay-antennas are used, the interferers affect the destination KN_R additional times. Besides, KN_R+1 time-slots are used to perform full communication. Since each antenna uses a different time-slot for retransmission, incrementing the number of K or N_R has exactly the same result. The received signal at destination during the second stage is given by

$$\boldsymbol{y}_{RD} = \boldsymbol{y}_{SR}\boldsymbol{G}\boldsymbol{v} + \sqrt{P_{I_D}}\sum_{q=1}^{I_D}\boldsymbol{f}_q\hat{x}_q + \boldsymbol{n}_{RD}, \tag{3}$$

where $\boldsymbol{v}$ is the channel gain vector at R–D links, $\boldsymbol{n}_{RD}$ is the noise vector at destination during the second stage and $\boldsymbol{G}$ is the fixed gain vector [3] composed by the gains of each relay antenna, which are given by

$$G_{k,j} = \sqrt{\mathbb{E}\left[\frac{P_R}{P_S|h_{k,j}|^2 + P_{I_R}\sum_{m=1}^{I_R}|l_{m_{k,j}}|^2 + \sigma^2}\right]}, \tag{4}$$

where $l_{m_{k,j}}$ is the channel gain through the mth interferer to the jth antenna at kth relay.

As shown in (4), each gain is limited by the transmission power and the number of interferers at the relay [21]. The greater P_{I_R} or I_R, the lower the retransmission gain. Since all relays have the same transmission power, all gains have also the same mean value, therefore $G_{1,1} = \cdots = G_{k,j} = G$.

2.2. Relay selection technique with TAS

In this case, during the second stage, only the antenna of the relay with the highest end-to-end SINR at destination is selected to retransmit the signal. Therefore, only two time-slots are needed to perform cooperation. The received signal at destination from the selected antenna is given by

$$\boldsymbol{y}_{RD} = \tilde{y}_{SR}G\tilde{\boldsymbol{v}} + \sqrt{P_{I_D}}\sum_{q=1}^{I_D}\tilde{\boldsymbol{f}}_q\hat{x}_q + \tilde{\boldsymbol{n}}_{RD}, \tag{5}$$