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MIMO cooperative communication network design with relay selection and CSI feedback

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ABSTRACT

In this paper, we investigate an amplify-and-forward (AF) multiple-input multiple-output – spatial division multiplexing (MIMO-SDM) cooperative wireless networks, where each network node is equipped with multiple antennas. In order to deal with the problems of signal combining at the destination and cooperative relay selection, we propose an improved minimum mean square error (MMSE) signal combining scheme for signal recovery at the destination. Additionally, we propose two distributed relay selection algorithms based on the minimum mean squared error (MSE) of the signal estimation for the cases where channel state information (CSI) from the source to the destination is available and unavailable at the candidate nodes. Simulation results demonstrate that the proposed combiner together with the proposed relay selection algorithms achieve higher diversity gain than previous approaches in both flat and frequency-selective fading channels.

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1. Introduction

Next-generation wireless networks will rely on the cooperation among network nodes in order to reduce outage probability of communication links within the networks, to improve spectral and power efficiency, as well as to enhance network coverage. Similarly to communication links using multiple-antenna transceivers, cooperative communication is able to provide diversity by creating multiple replicas of the desired signal via the use of the spatially distributed relay nodes, which act as a virtual antenna array. Many previous publications focused on the research of cooperative communication networks, where network nodes utilize a single antenna for signal transmission and reception [1–6]. However, it is well known that the data rate of the cooperative system employing single-antenna system is still limited due to lack of multiplexing gain.

Meanwhile, multiple-input multiple-output (MIMO) wireless communication systems have been shown to be capable of increasing the channel capacity over rich scattering fading environment [7]. Among MIMO transmission schemes, spatial division multiplexing (SDM) is a typical approach that attains high spectral efficiency thanks to achievable high multiplexing gain [8]. Consequently, combining MIMO-SDM transmission with cooperative communications is a natural research trend in order to exploit the strong points of these schemes [9–16].

A high-performance amplify-and-forward (AF) cooperative network requires effective approaches for relay selection, signal amplification at the relay and signal combination at the destination. In [12] and [13], the problem of signal amplification was solved almost completely by providing the closed-form amplification factors to compensate for the energy loss of the received signal. Since a relay plays a critical role in the performance of cooperative networks, the problem of selecting a relay among a number of candidate nodes is of particular interest to the researchers and was widely considered [3–6], [16]. In [3], two distributed node selection schemes based on the maximum channel gains and the maximum harmonic mean of the channel gains were proposed for cooperative nodes equipped with single antenna. In [4] a relay selection scheme based on the partial channel state information (CSI) was developed so that a compromise between the bandwidth efficiency and diversity order could be attained. Relay selection schemes for a decode-and-forward (DF) cooperative network, which take the energy consumption into consideration, were investigated in [5]. In another work [6], Jing and Jafarkhani derived the diversity of various single-relay selection schemes in the literature and subsequently generalized the problem of single relay selection to the

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scenario of multiple cooperative relay selection. Several results related to the relay selection in MIMO cooperative networks were reported in [11,13,15], and [16]. In [11], dual-hop non-coherent AF wireless MIMO relay networks were considered and a distributed orthogonal relay selection based on the maximum harmonic mean of the channel gains was constructed. The problem of combining relay and antenna selection was studied and a greedy antenna selection based on the minimum mean square error (MMSE) criterion was proposed in the work of [13]. In [15], the authors proposed a set of joint transmit diversity selection and multi-relay selection algorithms for the uplink of cooperative MIMO systems. Both DF and AF multirelay schemes with linear MMSE, successive interference cancellation, and adaptive reception were investigated. Relays were selected such that the MSE at the receiver was minimized or the mutual information of the relay channels was maximized. Regarding the problem of combining and detecting the received signals within two time slots at the destination, effective approaches should be developed so that diversity gain from the two communication links could be exploited. For single-antenna cooperative networks, maximal ratio combining (MRC) was proposed to use as the optimal combiner for maximizing the diversity gain [3]. Nevertheless, MRC cannot be utilized in MIMO-SDM cooperative networks due to the inherent co-channel interference (CCI) among transmit streams.

In the recent work of Tran et al. [16], the problems of distributed relay selection and signal combining for MIMO-SDM cooperative communication networks were considered. Specifically, the authors proposed three distributed relay selection algorithms based on the maximum channel gains, the maximum harmonic mean of the channel gains, and the mean square error (MSE) of the signal estimation. In addition, an MMSE signal combining scheme was also proposed to combine the signal from the direct and relaying path. In the MMSE combining scheme, the general combining weight matrix is decoupled into separate combining matrices associated with the direct and relaying paths, whereby reducing computational complexity of the signal combiner at the destination. However, the decomposition of the general combining weight matrix is probably the main reason that leads to the following limitations: (1) the system is unable to achieve significant diversity gain; and (2) the bit error rate (BER) performance of the system could not be improved when the number of candidate nodes increases.

Inspired by the above problems, in this paper we revisit the problem of MIMO-SDM cooperative communication network design and try to overcome the limitations of the previous approaches in [16]. We first derive a general MMSE signal combiner at the destination, taking into account the cross-correlation between the received signal from the source to the destination and that from the relay to the destination. With the additional cross-correlation term, the proposed MMSE combiner can achieve more signal energy to obtain improved BER performance as compared to its former counterpart in [16]. The trade-off for this improvement is, however, the cost of increased computational load since the proposed combiner can no longer be decoupled. Next, we evaluate the estimated MSE using the proposed combiner at the destination. The result is then utilized to develop two relay selection schemes under the following assumptions: (1) a candidate node knows not only the channels from the source to it and from it to the destination but also the one from the source to the destination; and (2) a candidate node only knows the channels from the source to it and from it to the destination. Simulation results show that the proposed relay selection schemes in combination with the proposed MMSE combiner outperform those in [16] remarkably under both flat fading and selective fading channels. The remainder of the paper is organized as follows. The system model is presented in Section 2. The proposed MMSE combiner is derived in Section 3. Section 4 and Section 5 respectively presents the derivation of MSE and the proposed relay selection schemes. Simulation results are provided and discussed in Section 6, and finally conclusions are given in Section 7.

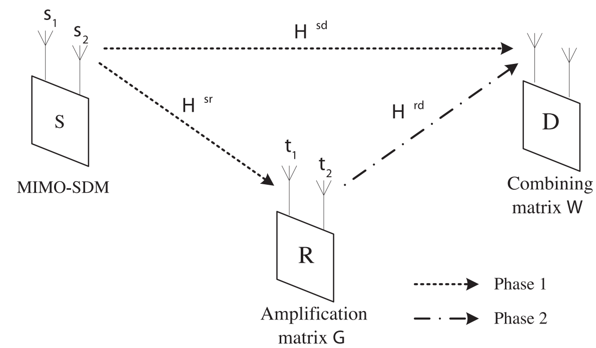

Fig. 1. MIMO cooperative network model, $N = 2$ for simple presentation.

2. System model

We consider an ad hoc wireless communications network which consists of a source (S), a destination (D), and K capable neighbouring nodes which are randomly distributed between the source and the destination as illustrated in Fig. 1. It is assumed that the distance d between the source and the destination is close enough such that the direct communications between the nodes is possible. All nodes including the source, the destination and neighbouring nodes have $N > 1$ antennas for both transmission and reception. The cooperative communications in the network is done in two consecutive phases, namely, *relay selection* and *cooperative transmission*. During the first phase, a distributed relay selection algorithm such as presented in [3,16] is used to select the best neighbouring node to act as the relay to support the transmission from the source to the destination. In order to facilitate the distributed selection algorithm, the neighbouring nodes are assumed to perfectly know the CSI of the links from them to the destination as well as from them to the source. Depending on the considered situations, the neighbouring nodes are further assumed to know or not to know the CSI from the source to the destination. These two cases are referred to as the one with CSI feedback (CSIF) and non-CSI feedback (NCSI). In the second phase, with the help of the relay, communications from the source to the destination can be done in the cooperative mode, i.e., via both the direct and relaying path. The cooperative transmission from the source to the destination is conducted in two time slots. In the first time slot, the source broadcasts its data to both the destination and the relay. During the next time slot, the relay forwards its received data to the destination. In this paper, we only focus on the popular AF strategy. For simplicity, half-duplex relaying is assumed in our system. We further assume that there is no transmission delay in the second hop, i.e., second time slot. Although the cooperative communications happens in two phases and two time slots, the signal model is the same. The only difference is that during the relay selection phase, all the neighbouring nodes k, ($k = 1, 2, \ldots, K$) are involved in the signal exchange while during the cooperative transmission only the relay r is active. Therefore, in the next sections we simplify the cooperative model to only two time slots: from the source to the destination and from the relay to the destination. In our general model, k is used to denote the neighbouring node index, which in fact relates to the first phase. This model can certainly be used in the cooperative transmission phase by replacing k by the relay index r. The channels between the nodes are assumed to be affected by flat Rayleigh fading.

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