Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
December 2008, 15(4): 24–29
www.sciencedirect.com/science/journal/10058885
The Journal of China Universities of Posts and Telecommunications
www.buptjournal.cn/xben

Linear beamformer schemes with simple relay selection in MIMO relay networks

MENG Qing-min (✉)[1,2], PAN Su[1], ZHENG Bao-yu[1], ZHU Hong-bo[1], YOU Xiao-hu[2]

1. Jiangsu Key Laboratory of Wireless Communications and Institute of Signal Processing and Transmission, Nanjing University of Posts and Telecommunications, Nanjing 210003, China
2. National Mobile Communications Research Lab, Southeast University, Nanjing 210096, China

Abstract

This article considers a wireless multi-hop/mesh network where single multi-antenna source-destination pair communicates through a selected relay subset using simple relay selection under the constraint of fixed relay's number. Compared with random selection, the simple relay selection can yield certain capacity advantages while linear zero-forcing (ZF) receiver and linear beamformer are considered at the relay. For match-filter (MF) beamformer and amplified-and-forward (AF) beamformer with a fixed number of relays, the capacities are given. Furthermore, we extend the simple selection methods to the relaying scheme with orthogonal-triangular (QR) beamformer and investigate these linear beamformer schemes over spatially correlated multi-input multi-output (MIMO) links for both the backward and forward channel over the two-hop MIMO relay networks.

Keywords wireless mesh networks, multi-hop relaying, capacity, beamformer

1 Introduction

Cooperative relaying has been widely accepted as an efficient technique for spatially distributed users or nodes in wireless networks to relay signals for a source node to exploit spatial diversity in fading channels [1–2]. It is used to obtain high spectral efficiency in large scale distributed (Ad-hoc) networks [3–4], and transmit information with minimum power or optimal power allocation [5–6]. In particular, low-complexity linear beamformer relaying is proposed to achieve tradeoff between energy efficiency and spectral efficiency in large scale relay networks [7]. For capacity maximization in a two-hop single source-destination pair system, some other linear beamformers in conjunction with certain advance signal processing techniques are proposed to enhance the performance in terms of spatial multiplexing, receive diversity, and distribute array gain. For example, the QR beamformer [8] is a method, of which QR decomposition on the backward and forward channel is performed with phase control at each relay node. In a real-world wireless mesh network, the number of active relays that can effectively assist a single multi-antenna source-destination pair is usually limited by channel characteristics, network geometry, and the relay's power cost as well as the design of the receiver at the relay and/or the destination. Thus it is necessary to extend the above investigations to a realistic problem, i.e., how to select an appropriate subset of relays under the constraint of fixed relay's number for capacity maximization. However, the case of searching a subset of active relays to maximize achievable capacity under the constraint for a linear beamformer scheme is still less examined so far. It is natural to select a subset which has a better link quality in the source-relay channels than that of the other subsets from all intermediate nodes and thus simultaneous transmission from these nodes or relays can be expected to improve the capacity of the pair.

In this article, under the guidance of the perspectives on multi-hop relaying for broadband wireless mesh networks [9–10], we aim to develop simple relay selection schemes in a dense multi-hop/mesh network, and discuss various linear beamformer schemes under the constraint of fixed relay's number, especially in the MF scheme and the AF scheme. The relay selection we use is similar to the max-min diversity schedule for multiuse system to maximize the sum of the average date rate [11], while we focus on simple relay subset selection with linear receiver and linear beamformer. The capacity advantage is expected to be obtained owing to the

Received date: 01-06-2008
Corresponding author: MENG Qing-min, E-mail: mengqm@njupt.edu.cn

fact that in the system with several relays, whose channels vary independently, it is likely to be a relay's subset whose channel is near good during certain time intervals even in the presence of realistic fading correlation. The remaining sections of this article are organized as follows. Section 2 introduces the channel and system model. In Sect. 3, two simple selection methods in fixed active relays case are provided. In Sect. 4, we derive the capacity for the MF scheme and the AF scheme with the selection methods. Section 5 presents simulations and Sect. 6 concludes the article.

2 Channel and signal model

Suppose a simple multi-hop/mesh network, i.e., a two-hop MIMO relay network as shown in Fig. 1, which comprises a source node denoted by *S*, finite *K* relay nodes denoted by R_k, $k=1,2,...,K$ and a destination node denoted by *D*. Here, *S* and *D* are respectively equipped with *M* transmit/receive antennas, and R_k with *N* transmit/receive antennas and all relays enable multi-hop routing of data packets from *S* to *D*. To mitigate the effect of the network geometry, we consider a homogeneous relay network, where all relays in an associated group to the $S-D$ pair have the same energy normalization factor $B_{1,k} \in R$ (related to the backward channel) and $F_{1,k} \in R$ (related to the forward channel) to account for path loss and shadowing. The symbol vector $\boldsymbol{s} \in C^M$ satisfying $E\{\boldsymbol{s}^{\mathrm{H}}\boldsymbol{s}\} = P_S$ and symbol vector $\boldsymbol{t}_k \in C^N$ satisfying $E\{\boldsymbol{t}_k^{\mathrm{H}}\boldsymbol{t}_k\} \leqslant P_{R,k}$ are respectively the transmitted signal vector from *S* and R_k, and $\boldsymbol{u}_k$ (the linear estimate for $\boldsymbol{s}$ at R_k) is multiplied by the linear beamformer matrix $\boldsymbol{U}_k$ to produce $\boldsymbol{t}_k$. The element of the noise vector $\boldsymbol{n}_k$ at R_k and the noise vector $\boldsymbol{z}_k$ at *D* are spatial-temporally white zeros-mean circularly symmetric complex Gaussian variables with variance σ_n^2, i.e., $E\{\boldsymbol{n}_k\boldsymbol{n}_k^{\mathrm{H}}\} = \sigma_n^2\boldsymbol{I}_N$, $E\{\boldsymbol{z}_k\boldsymbol{z}_k^{\mathrm{H}}\} = \sigma_n^2\boldsymbol{I}_M$. Furthermore, half time-division-duplex (TDD) is assumed in the relay network model and thus each entire transmission takes two time slots to send signal from *S* to *D*. Then, the received signal vector $\boldsymbol{r}_k$ for the $S \to R_k$ link and $\boldsymbol{y}$ for the $R_k \to D$ link are respectively:

$$\boldsymbol{r}_k = \boldsymbol{H}_k\boldsymbol{s} + \boldsymbol{n}_k\,;\quad k=1,2,...,K \tag{1}$$

$$\boldsymbol{y} = \sum_{k=1}^{K}\boldsymbol{G}_k\boldsymbol{t}_k + \boldsymbol{z}_k \tag{2}$$

where $\boldsymbol{H}_k$ is a backward channel matrix and $\boldsymbol{G}_k$ is a forward channel matrix in the two-hop MIMO relay network. We consider the case where only semi-correlation is presented, which is valid when the transmitter at *S* and the receiver at *D* are sufficiently high above the local scattering environment while all relays are at lower locations [12]. Here, the studied scenario where distributed relays are used as active scatterers in the field of cooperative MIMO systems is similar to the scenario in Ref. [13] but no direct link between *S* and *D* is assumed. Then, $\boldsymbol{H}_k$ and $\boldsymbol{G}_k$ can be modeled [12,14] as $\boldsymbol{H}_k = \boldsymbol{H}_{wk}\boldsymbol{R}_{tk}^{1/2}$ and $\boldsymbol{G}_k = \boldsymbol{R}_{rk}^{1/2}\boldsymbol{G}_{wk}$, where $\boldsymbol{H}_{wk} \in C^{N\times M}$ and $\boldsymbol{G}_{wk} \in C^{M\times N}$ contain i.i.d. complex Gaussian entries with zero-mean and unit variance., $\boldsymbol{R}_{tk}$ and $\boldsymbol{R}_{rk}$ represent a transmit covariance matrix and a receive covariance matrix, respectively. We assume that there is no channel state information (CSI) at *S*, each selected R_k using certain relay selection has perfect local knowledge of its $\boldsymbol{H}_k$ and $\boldsymbol{G}_k$, and *D* has perfect knowledge of all channel variables. We further suppose that all channels are frequency flat and constant over two consecutive slots but vary from one two-slot to another. We note that although we assume $N=M$ to simplify our description in the remaining sections of this article, this constraint can be relaxed to $N \geqslant M$ while transmit antenna selection is selected at each R_k. Here, we omit this problem and leave it for future investigation.

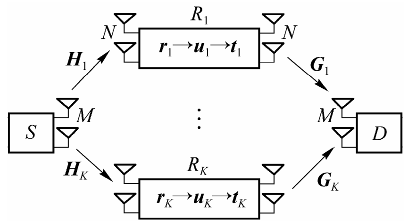

Fig. 1 A two-hop MIMO relay network model

3 Two simple selection methods

In this section, we discuss the two-hop MIMO relay network with multiple relay nodes, each of which has CSI for the forward link at the transmitter, and the linear beamforming such as MF, QR, and ZF are preferred because of their achievable array gain with sustainable implementation-complexity. Based on the results in Refs. [3,7], we consider linear beamformer with simple relay selection for high link capacity with a fixed K_R selected relay's constraint. Note that while each R_k is assumed to have the same maximum transmitted power as *S*, i.e., $P_{R,k} \leqslant P_R = P_S$, the full-transmitted power by all relays is fixed, e.g., $K_R P_R$. In the rest this article, we always make the assumption of equal power for all active relays to simplify selection problems. Denote $A_R = \{k\}$, ($k=1,2,...,K_R$) as a relay's index subset selected by *D* based on certain selection algorithms, and denote the Cardinality of A_R as $|A_R|$. When small Cardinality is selected, the less reverse channel