Digital Communications and Networks (2015) 1, 57–67

HOSTED BY

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/dcan

A full-cooperative diversity beamforming scheme in two-way amplify-and-forward relay systems ☆

Zhongyuan Zhao[a], Zhiguo Ding[b], Mugen Peng[a,*], Yong Li[a]

[a]*Key Laboratory of Universal Wireless Communications (Ministry of Education), Beijing University of Posts and Telecommunications, Beijing 100876, China*
[b]*School of Computing and Communications, Lancaster University, LA1 4WA, UK*

Received 16 December 2014; received in revised form 21 February 2015; accepted 28 February 2015
Available online 27 March 2015

KEYWORDS
Two-way relay systems;
Beamforming;
Network coding;
Amplify-and-forward;
Cooperative diversity;
Outage probability

Abstract
Consider a simple two-way relaying channel in which two single-antenna sources exchange information via a multiple-antenna relay. For such a scenario, all the existing approaches that can achieve full cooperative diversity order are based on antenna/relay selection, for which the difficulty in designing the beamforming lies in the fact that a single beamformer needs to serve two destinations. In this paper, a new full-cooperative diversity beamforming scheme that ensures that the relay signals are coherently combined at both destinations is proposed, and analytical results are provided to demonstrate the performance gains. Moreover, the impact of channel estimation error is also evaluated. Finally, numerical results are provided to verify the accuracy of the provided analytical results, and also to show that this proposed scheme can outperform existing schemes based on antenna selection.

1. Introduction

Relay-assisted cooperative transmission is an efficient method to extend the coverage and improve the throughput of wireless systems. To characterize this improvement in transmission reliability, cooperative diversity for wireless relay systems is defined [1], where one relay is applied to create a virtual array for distributed transmission and signal processing. Moreover, the definition of full cooperative diversity order, i.e., the maximum achieved diversity gain for wireless relay systems, is also provided in [1]. In [2,3], more general scenarios with multiple distributed relays are studied, and it is shown that the full diversity order achieved by relay cooperation is equivalent to the number of relays without considering the direct link. In addition, centralized relay cooperative transmissions can be implemented by using multiple antennas. By careful transceiver design, multiple-input and multiple-output (MIMO) techniques can further improve relay transmission performance [4,5].

☆This paper is was supported in part by the National Natural Science Foundation of China under Grant 61361166005, the National High Technology Research and Development Program of China (Grant No. 2014AA01A701), and the Huawei Technologies Co., Ltd., Beijing, China.

*Corresponding author.
E-mail addresses: zhaozhongyuan0323@gmail.com (Z. Zhao), z.ding@newcastle.ac.uk (Z. Ding), pmg@bupt.edu.cn (M. Peng), liyong@bupt.edu.cn (Y. Li).

Peer review under responsibility of Chongqing University of Posts and Telecommunications.

http://dx.doi.org/10.1016/j.dcan.2015.02.005

Although relay transmissions can improve robustness of performance, they can detract from spectrum efficiency since extra radio resources are required for relaying. Network coding has been introduced as a promising solution to this problem [6,7]. Unlike the complete renewal of interference as in conventional relay transmissions, network coding encourages the use of controllable interference by mixing different messages together at the relay nodes, and thus can support the transmissions of multiple data streams simultaneously. For example, in a two-way relay scenario, the spectral efficiency can be doubled by broadcasting the network coded message at the relay, and decoding the desired message by subtracting self information at each source [11-13]. To improve the efficiency without compromising reliability, the joint design of MIMO and network coding has drawn considerable attention [8-10], especially in MIMO two-way relay systems. In [14], the sum rate for two-way relay systems is optimized through collaborative beamforming, and [15] designs the precoding matrices at the sources and the relay jointly to minimize mean-square error (MSE) for maximum multiplexing in MIMO two-way relay systems.

Despite these studies of MIMO two-way relaying channels, some challenging issues are still left as open problems. For example, consider a simple two-way relaying channel in which two single-antenna sources exchange information via a multiple-antenna relay. To such a scenario, the existing precoding design aims to maximize the sum rate, or minimize transmit power, such as proposed in [16]. However, such precoding schemes cannot achieve full-cooperative diversity, since two different beams are formed at the relay and directed to the two sources, and to the best of the authors' knowledge, how to design a full cooperative diversity relay beamformer is still an open problem. The difficulty in designing the beamforming lies in the fact that a single relay beamformer needs to serve both destinations. Moreover, the study of such a scenario is necessary since it can be commonly found in practical systems, and some typical cases are listed as follows: in cellular systems, users are exchanging information via a base station, where the base station is equipped with multiple antennas and users have only a single antenna due to the limited size and battery capacity of handsets. In wireless sensor networks, single-antenna low-cost sensors communicate with each other via a data fusion center with multiple antennas. In addition, in many emerging data networks, such as smart home and healthcare networks, it can be commonly found that low-cost single-antenna terminals/devices communicate with each other via a network hub with more capability. In this paper, we propose a solution to the addressed problem and the main contribution can be summarized as follows.

Firstly, a full-cooperative diversity relay beamformer is designed for the scenario under consideration, which is more challenging than the scenario with more antennas at the sources. Particularly, when the sources have multiple antennas, the cooperative diversity gain can be achieved by design the precoding at the sources and the relay jointly, and there exist some techniques which can achieve superior outage performance, such as signal alignment in [17], and channel parallelization based precoding design [15]. However, when each source has only a single antenna, these existing schemes cannot work since the signal space is flattened into one dimension at the sources. To the best knowledge of the authors, how to design a full-cooperative diversity beamformer for such a scenario is still an open issue. In this paper, we propose an efficient solution, and the key idea is to use the symmetry of the observation phases at both destinations, and the relay signals can be coherently combined.

Secondly, to evaluate the performance of the proposed transmission scheme, the outage probability is analyzed in this paper. Particularly an upper bound on the signal-to-noise ratio (SNR) is first developed, which facilitates the development of a closed-form expression for the outage probability. The asymptotic analysis of such an bound is also provided to demonstrate the full-cooperative diversity gain achieved by the proposed scheme. *Finally*, the impact of channel estimation error is evaluated, and both analytical and numerical results show that our proposed scheme can still achieve full cooperative diversity gains when the MSE is equivalent infinitesimal to the reciprocal of average SNR.

The rest of this paper is organized as follows. Section 2 describes the system model, and introduces the proposed full-cooperative diversity transmission scheme. In Section 3, the performance analysis of the proposed scheme is studied. The impact of channel estimation error is evaluated in Section 4. In Section 5, the simulation results are shown, followed by the conclusions in Section 5.

Notation: Vectors are denoted as boldface small letters, i.e., $\mathbf{a}$, and a_m denotes the mth element of $\mathbf{a}$ and $\mathbf{a}^T$ is the transpose of $\mathbf{a}$. $|c|$ is the Frobenius norm of c, and c can be either a vector or a number. $\mathbb{E}\{x\}$ is the expectation of x, and $\Pr\{x<p\}$ denotes the probability that the value of a random variable x is less than p. $\Gamma(d)$ is the Gamma function, $\gamma(a,x)$ denotes the lower incomplete Gamma function, $K_\nu(z)$ is the modified Bessel function with imaginary argument, and all the referred special functions follow the form given in [19]. σ^2 is the variance of additive white Gaussian noise at each antenna.

2. System model and protocol description

Consider a two-way relay system, in which two sources S_1 and S_2 exchange messages via a relay R. As illustrated in Fig. 1, each source node is equipped with one antenna, while the relay is equipped with N antennas. For simplicity, all nodes are assumed to employ time division duplexing, where the incoming channel and the corresponding outgoing channel are symmetric. All the channels are modeled as quasi-static Rayleigh fading channels, and each node has access to full perfect source-relay channel state information (CSI).

The transmission can be accomplished in two phases by applying network coding. During the first phase, both sources transmit their own messages to the relay simultaneously, and a network coded observation at the relay can

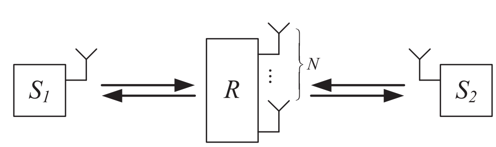

Fig. 1 System model.