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Blind channel estimation and signal retrieving for MIMO relay systems ☆

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ABSTRACT

In this paper, we propose a blind channel estimation and signal retrieving algorithm for two-hop multiple-input multiple-output (MIMO) relay systems. This new algorithm integrates two blind source separation (BSS) methods to estimate the individual channel state information (CSI) of the source-relay and relay-destination links. In particular, a first-order Z-domain precoding technique is developed for the blind estimation of the relay-destination channel matrix, where the signals received at the relay node are pre-processed by a set of precoders before being transmitted to the destination node. With the estimated signals at the relay node, we propose an algorithm based on the constant modulus and signal mutual information properties to estimate the source-relay channel matrix. Compared with training-based MIMO relay channel estimation approaches, the proposed algorithm has a better bandwidth efficiency as no bandwidth is wasted for sending the training sequences. Numerical examples are shown to demonstrate the performance of the proposed algorithm.

1. Introduction

In an effort to provide reliable and high rate wireless communications, multiple-input multiple-output (MIMO) relay communication systems have attracted great research interests in the last decade [1–3]. For the MIMO relay systems in [1–3], the knowledge of the instantaneous channel state information (CSI) is necessary for the retrieval of the source signals at the destination node. The individual instantaneous CSI for both the source-relay and relay-destination links is also important for the optimization of MIMO relay systems through precoding matrices design and power allocation [1–5]. However, the instantaneous CSI is unknown in real wireless communication systems, and thus, has to be estimated at the destination node.

One of the possible solutions is by transmitting known training sequences to assist the estimation of the instantaneous CSI [6–13]. In [6], a channel estimation algorithm based on the least-squares (LS) fitting is proposed for MIMO relay systems. The performance of the algorithm in [6] is further analyzed and improved by using the weighted least-squares (WLS) fitting in [7]. A tensor-based channel estimation algorithm is developed in [8] for a two-way MIMO relay system. Since the algorithm in [8] exploits the channel reciprocity in a two-way relay system, its application in one-way MIMO relay systems is not straightforward. A superimposed training based channel estimation algorithm has been developed recently for orthogonal frequency-division multiplexing (OFDM) modulated relay systems in [9]. A two-stage linear minimum mean-squared error (LMMSE)-based channel training algorithm was proposed in [10]. The source-relay link CSI estimation in [10] was improved in [11] by taking into account the mismatch between the estimated and true CSI of the relay-destination link. In [12], a superimposed channel training algorithm for two-way MIMO relay systems was proposed, where the channel estimation is done in one stage through superimposing a training sequence at the relay node. A parallel factor (PARAFAC) analysis based MIMO relay channel estimation algorithm was developed in [13].

The main drawback of the training-based channel estimation algorithms is the high cost involved in sending the training sequences, considering the limited bandwidth available for wireless communication. Moreover, in some applications such as asynchronous wireless network and message interception, training-based algorithms are unrealistic and not suitable for implementation [14,15]. In these applications, blind channel estimation

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techniques, which do not require training sequences, become important. Recursive least squares (RLS) and least mean squares (LMS) subspace-based adaptive algorithms were proposed in [16] for blind channel estimation in code-division multiple access (CDMA) systems. A subspace-based blind channel estimation algorithm with reduced time averaging was proposed in [17] for MIMO-OFDM systems. However, the algorithms in [16] and [17] were developed for point-to-point (single-hop) communication systems, and the extension to MIMO relay systems is not straightforward. A blind channel estimation algorithm based on the deterministic maximum likelihood (DML) approach was developed in [18] for two-way relay networks with constant-modulus (CM) signaling. In [19], non-redundant linear precoders are applied at the source nodes to blindly estimate the channels for two-way relay networks operating under OFDM modulation.

In this paper, we develop a blind channel estimation algorithm for two-hop MIMO relay communication systems by exploiting the link between blind source separation (BSS) and channel estimation. BSS techniques are able to separate a mixture of signals into individual source signals, without the knowledge (or little knowledge) of the source signals or the channel between the source and receiver. The proposed algorithm integrates two BSS methods to estimate the instantaneous CSI for the individual source-relay and relay-destination links. We would like to note that channel matrices of both the first-hop and second-hop are estimated at the destination node. The advantage of directly estimating both channel matrices at the destination node is to avoid sending the CSI from the relay node to the destination node [12,13]. As the blind channel estimation algorithm we propose uses the communication data for channel estimation, unlike [10], there is no need for sending training signals from the relay node to the destination node.

In particular, we develop a first-order Z-domain precoding technique for the blind estimation of the relay-destination channel matrix using signals received at the destination node. In this algorithm, the signals received at the relay node are filtered by properly designed precoders before being transmitted to the destination node. By utilizing the Z-domain properties of the precoded signals, an estimation criterion is derived to recover the relay-destination channel matrix and signals received at the relay node. Note that in this algorithm, the order of the precoders is fixed to one, while a second-order Z-domain precoding algorithm was developed in [20] for blind separation of spatially correlated signals. Obviously, the computational complexity of the first-order precoder is smaller than that of the second-order precoder.

With the estimated received signals at the relay node, we then develop a blind channel estimation algorithm based on the constant modulus and signal mutual information (MI) properties to estimate the source-relay channel matrix. The constant modulus property of many modulated communication signals such as phase-shift keying (PSK) is exploited in this blind estimation algorithm. However, using the constant modulus property of signals alone does not guarantee the complete separation of the source signals and the channel matrix, as the constant modulus algorithm might capture the same signal even though there are multiple signal streams. To overcome this difficulty, we minimize a cost function which includes the MI of the estimated signals in addition to the constant modulus property, to ensure that all estimated signals are distinct. This algorithm does not have the problem of estimation error propagation as in [21] and [22]. A similar method was adopted in [15] for the extraction of unknown source signals, essentially in single-hop (point-to-point) MIMO wireless networks. However, in this paper, we apply this algorithm for channel estimation in dual-hop MIMO relay communication systems.

Comparing the proposed blind channel estimation algorithm with the training-based channel estimation techniques, the former one has a better bandwidth efficiency as all the bandwidth is used for the transmission of the communication signals. Simulation results show that the proposed blind channel estimation algorithm yields a better system bit-error-rate (BER) than that of the training-based algorithm at low signal-to-noise ratio (SNR) due to a better utilization of the power available at the source and relay nodes for channel estimation. We would like to note that the proposed algorithm can be applied in dual-hop MIMO relay systems with multiple distributed source nodes and multiple distributed relay nodes.

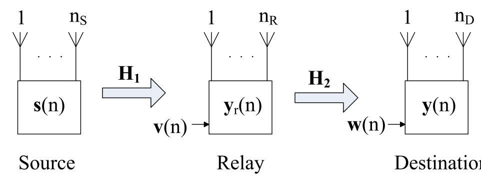

Fig. 1. Block diagram of a general two-hop MIMO relay communication system.

The rest of this paper is organized as follows. The system model of a three-node two-hop MIMO relay system is presented in Section 2. In Section 3, the first-order Z-domain precoding technique is developed to estimate the relay-destination channel matrix, while the signal MI modified constant modulus algorithm is proposed in Section 4 to estimate the source-relay channel matrix. Section 5 shows numerical simulations to demonstrate the performance of the proposed algorithm. Finally, conclusions are drawn in Section 6.

2. System model

Let us consider a three-node two-hop MIMO communication system where the source node transmits information to the destination node through a relay node as shown in Fig. 1. The source, relay, and destination nodes are equipped with n_S, n_R, and n_D antennas, respectively. In this paper, we assume that the direct link between the source node and the destination node is sufficiently weak and thus can be ignored. This scenario occurs when the direct link is blocked by obstacles, such as tall buildings or mountains.

The communication process is completed in two time slots. In the first time slot, the source signal vector $\mathbf{s}(n) = [s_1(n), s_2(n), \cdots, s_{n_S}(n)]^T$ is transmitted from the source node, where $(\cdot)^T$ denotes the vector (matrix) transpose. The signal vector received at the relay node can be expressed as

$$\mathbf{y}_r(n) = \mathbf{H}_1\mathbf{s}(n) + \mathbf{v}(n) \tag{1}$$

where $\mathbf{y}_r(n)$ is the $n_R \times 1$ received signal vector, $\mathbf{H}_1$ is the $n_R \times n_S$ MIMO channel matrix between the source node and the relay node, and $\mathbf{v}(n)$ is the $n_R \times 1$ noise vector at the relay node.

In the second time slot, each received signal stream in $\mathbf{y}_r(n)$ is preprocessed separately by a first-order precoder $p_i(z)$ as

$$p_i(z) = 1 - r_i z^{-1}, \quad i = 1, \cdots, n_R \tag{2}$$

where r_i is the zero of the precoder $p_i(z)$. Note that all zeros are distinct and satisfy $0 < |r_i| < 1$, for $i = 1, \cdots, n_R$, and are known at the destination node. Here $|\cdot|$ denotes the modulus of a scalar and the determinant of a matrix. From (2), the ith precoded signal at the relay node can be written as

$$\begin{aligned} x_i(n) &= p_i(z)y_{r,i}(n) \\ &= y_{r,i}(n) - r_i y_{r,i}(n-1), \quad i = 1, \cdots, n_R \end{aligned} \tag{3}$$

where $y_{r,i}(n)$ is the ith element of $\mathbf{y}_r(n)$. It is worth noting that the precoding operation (3) can be readily implemented at physically distributed relay nodes, as there is no need for cooperation