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MIMO Relay

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Synonyms

MIMO relay channel; MIMO relay network

Definitions

Multiple-input multiple-output (MIMO) relay refers to a cooperative communication technology employing relay nodes, when one or more nodes of a relay system have multiple transmit/receive dimensions. MIMO relay communications can improve the reliability and extend the coverage of communication systems.

Historical Background

A relay channel, also known as three-terminal communication channel, was first investigated in van der Meulen (1971). The capacity of this channel was studied in 1979 (Cover and El Gamal 1979). During 1980s and 1990s, further information theoretic results on the relay channel were discovered (Vanroose and van der Meulen 1992). Since the turn of the century, the relay channel has attracted a renewed interest due to the boom of applications of wireless communications (Sendonaris et al. 2003).

When multiple antennas are deployed at one or more nodes of the relay system, we call such relay system a MIMO relay channel. The achievable rate and capacity upper bound of a MIMO relay channel have been studied in Wang et al. (2005). A diversity-multiplexing trade-off of multi-antenna cooperative systems has been studied in Yuksel and Erkip (2007).

More applied issues of wireless relay system have been discussed in Sendonaris et al. (2003) in terms of user cooperation diversity, where the key idea is to enable multiple terminals (source and/or relays) to cooperate with each other to create a virtual antenna array that provides some form of spatial diversity. The authors of Sendonaris et al. (2003) showed that user cooperation is beneficial in terms of increasing system throughput and cell coverage, as well as decreasing sensitivity to channel variations.

Recent surveys on topics in *amplify-and-forward* (AF) MIMO relay systems can be found in Sanguinetti et al. (2012). A testbed implementation of MIMO relay system was reported in Maltsev et al. (2010). A general framework of optimizing the source and relay precoding matrices has been developed in Rong et al. (2009). There are special issues in *IEEE Journal on Selected Areas in Communications* on the topic of MIMO relay (Hua et al. 2012).

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Foundations

The simplest MIMO relay system consists of three nodes as illustrated in Fig. 1, where one source node (S) transmits information to one destination node (D) with the aid of a relay node (R). Each node has multiple transmit/receive dimensions. Let us denote the number of dimensions at node i as N_i, $i \in \{s, r, d\}$. Mathematically the channel response from one node to another is represented through a matrix. As an example, the source-relay, relay-destination, and source-destination channels are represented by matrices $\mathbf{H}_{sr}$, $\mathbf{H}_{rd}$, and $\mathbf{H}_{sd}$, respectively. MIMO relay channel is an important extension of single-hop MIMO channel, which has been extensively studied in the last decade. Similar to a single-hop MIMO channel, the multiple transceiving dimensions (degrees of freedom) in a MIMO relay channel can be used to achieve various trade-offs between diversity gain and multiplexing gain (Yuksel and Erkip 2007), where the diversity gain helps improving the system reliability, while the multiplexing gain is mainly used to increase the system throughput.

Since each hop of the relay system in Fig. 1 forms a MIMO channel, the input-output relationship from node $j \in \{s, r\}$ to node $i \in \{r, d\}$ is given by

$$\mathbf{y}_i = \mathbf{H}_{ji}\mathbf{x}_j + \mathbf{v}_i \qquad (1)$$

where $\mathbf{x}_j$ is the transmitted signal vector at node j with a dimension of N_j and $\mathbf{y}_i$ and $\mathbf{v}_i$ are $N_i \times 1$ vectors of received signal and noise at node i, respectively.

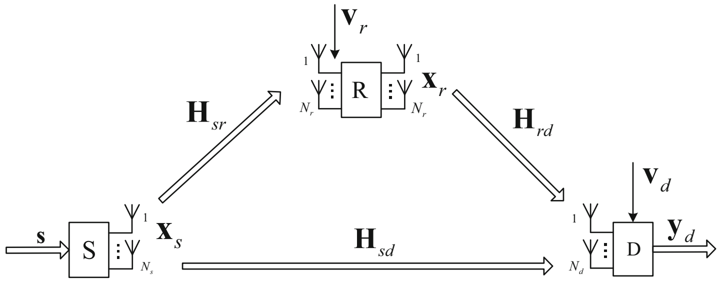
Compared with single-hop MIMO systems, dual-hop or multihop MIMO systems provide more freedoms to system designers. In particular, for an optimal dual-hop relay system performance, both of the transmitted signal vectors $\mathbf{x}_s$ and $\mathbf{x}_r$ from two different nodes need to be optimized, and both of the received signal vectors $\mathbf{y}_r$ and $\mathbf{y}_d$ at two different nodes need to be optimally processed. On the other hand, such a flexibility also makes the optimization problems much more challenging than those for single-hop MIMO systems. In fact, most of the optimization problems in MIMO relay systems are highly nonconvex involving multiple matrix/vector variables. As a matter of fact, except for some upper bounds (Wang et al. 2005), the exact capacity of a MIMO relay channel is still not available.

A relay can be half-duplex or full-duplex. A half-duplex relay receives and transmits in two separate time/frequency channels. A full-duplex relay receives and transmits at the same time and same frequency (Cirik et al. 2014).

Relay Strategies

An important part of a relay system is known as relay strategy, which determines how the relay processes $\mathbf{y}_r$ to generate $\mathbf{x}_r$. Mathematically, the relay strategy can be represented by a function of $\mathbf{x}_r = \mathbf{f}(\mathbf{y}_r)$, where $\mathbf{f}$ represents the relay strategy. Interestingly, so far, there is no relay strategy that works best under all scenarios. Generally speaking, there are two main categories of relay strategies: *regenerative* relay and *non-regenerative* relay. In a regenerative strategy, the relay node first extracts out (decodes) the information from $\mathbf{y}_r$. Then, the relay node generates $\mathbf{x}_r$ by re-encoding the information. This strategy is also known as *decode-and-forward* (DF). A relaxed form of this strategy is called *compress-and-forward* where the signal received at the relay node is partially compressed before it is forwarded. There are also other variations of this strategy (Kramer et al. 2005).

For a *non-regenerative* strategy, the relay node only amplifies (including a possible linear transformation) and retransmits its received signals, without attempting to decode the information-carrying symbols. Thus, a non-regenerative relay is also referred to as AF relay. The authors of Fan and Thompson (2007) compared the performance-complexity trade-offs of non-regenerative and other MIMO relay techniques. Both regenerative and non-regenerative strategies are affected by the noise at the relay node, although in different ways. The complexity and the processing delay of a non-regenerative strategy are generally much smaller than those of a regenerative strategy. The non-regenerative strategy is



MIMO Relay, Fig. 1 Block diagram of a dual-hop MIMO relay system

also believed by many to provide a better trade-off between benefits and implementation costs.

With a linear AF relay, we can in general write $\mathbf{x}_r = \mathbf{F}_r \mathbf{y}_r$, where $\mathbf{F}_r$ is the relay amplifying (precoding) matrix.

Key Applications

Relay nodes are needed in situations where the path loss between source and destination is too high, and/or the transmission power from the source is too limited by regulation and/or hardware constraints. Relay nodes are easy to install to extend the reach of a backbone network. Special relay nodes can be equipped with multiple antennas to compensate the limitation of most user terminals such as handsets. Cooperative relay nodes can form a virtual multi-antenna relay (Sendonaris et al. 2003), which increases the spatial diversity order of the source-relay-destination channel and thus improves the reliability of communication.

MIMO relay has applications in many physical forms of communication channels, such as:

- Multi-antenna multihop wireless networks, which are perhaps the most commonly referred to in the context of MIMO relays. Multihop wireless backhaul networks are being considered in several industry standards such as IEEE802.16j (Genc et al. 2008).
- Underwater acoustic relay channel. Since the bandwidth of underwater acoustic channel is inversely proportional to the transmission distance, MIMO relay techniques can enhance the capacity of underwater acoustic communication systems over a long distance (Al-Dharrab et al. 2013).
- Wireline DSL relay channel, which can be modeled as MIMO relay channel due to the crosstalk arising from the electromagnetic coupling between neighboring twisted-pairs.
- Powerline relay channel. Recently, cooperative relay communication technology has been adopted into the indoor powerline communication environment (Wu and Rong 2015).

Cross-References

▸ Network MIMO
▸ Relaying in LTE-Advanced

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