Chapter 9
Relay Selection in Cooperative Networks

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ABSTRACT

Cooperative diversity has the potential of implementing spatial diversity and mitigating the adverse effects of channel fading without requiring multiple antennas at transmitters and receivers. Traditionally, cooperative diversity is implemented using maximal ratio combining (MRC), where all available nodes relay signals between the source and destination. It has recently been proposed, however, that for each source-destination transmission, only a single best node should be selected to act as a relay. The resulting scheme, referred to as selection cooperation or opportunistic relaying, outperforms MRC schemes and can be implemented in a distributed fashion with limited feedback. This result is not unexpected, as selection requires some (though very limited) information regarding instantaneous channel conditions, while MRC does not. When implemented in a distributed network, however, MRC does require feedback for the synchronization of nodes, rendering a comparison of the two schemes worthwhile and fair. In this chapter, we provide a detailed overview of selection. We begin with a single source-destination pair, and discuss its implementation and performance under various constraints and scenarios. We then discuss a less-common scenario, a multisource network where nodes act both as sources and as relays.

INTRODUCTION

In distributed wireless systems, cooperative diversity and relaying can harness the advantages of multiple-input multiple-output (MIMO) systems without requiring multiple antennas at each receiver and/or transmitter. For practical networks this is motivated by the need for simple, inexpensive nodes with limited processing power and a single receive antenna. Examples of such networks, of particular interest

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in this chapter, include mesh networks comprising a mesh of access points and sensor networks comprising cheap, potentially battery operated, wireless nodes. In recent years there has been an enormous effort invested in the development of cooperative diversity schemes and protocols. However, most of this effort has been for the 3-node case: a source node communicating to a destination with the help of a single relay node. This chapter deals with the more practical case wherein a source communicates to a destination with many relays available to help in this communication. We then generalize this scenario to the case of multiple sources and multiple destinations communicating simultaneously. Given that a source may avail of multiple relays, a natural question arises: how many relays should help the source? The answer to this question is the central theme of this chapter – only a single best one should help.

In distributed networks, scaling cooperation to multiple nodes presents important challenges. The most straightforward approach is to ask all relays to cooperate. The maximal ratio combining (MRC) scheme requires the coherent addition of multiple, independently-faded, copies of the transmitted signal and is analogous to MRC in traditional MIMO transmission with co-located antennas. In general, this combination can be achieved through pre-coding (Sendonaris & Erkip & Aazhang, 2003), orthogonal transmissions and a maximal-ratio-combiner (Boyer & Falconer & Yanikomeroglu, 2004; Laneman & Tse & Wornell, 2004; Herhold & Zimmermann & Fettweis, 2005), or through distributed space-time codes (DSTC) (Barbarossa & Scutari, 2004; Laneman & Wornell, 2003; Uysal & Canpolat, 2005). Orthogonal transmissions are inefficient and suffer from a bandwidth penalty (Laneman & Wornell, 2003), and precoding and DSTC require accurate channel state information (CSI) and strict symbol-level synchronization, respectively. Neither solution, therefore, seems practical from an implementation point of view.

To overcome these difficulties, selection has been proposed as a practical and efficient method of implementing diversity in distributed systems. Selection restricts cooperation to one "best" relay. In this regard, selection in cooperative networks could be considered the analog of selection combining in a traditional receive or transmit diversity scheme using co-located antennas. In a traditional MIMO system, selection suffers a significant performance loss compared to MRC. However, due to the distributed nature of the networks of interest here, as we will see, selection makes effective use of limited power and bandwidth resources and outperforms MRC-based schemes, including DSTC.

Selection omits the problem of multiple relay transmissions by requesting only a single relay to forward the information from the source. Because a single best relay is selected each time the channel conditions change, the diversity order is clearly equivalent to that of MRC. The process of relay selection does involve some feedback. If the decision is made by the destination, the system requires $log_2(m\text{-}1)$ bits of feedback, where (m-1) is the number of relays. If the decision is made by the relays, the channel magnitude must be quantized and fed back to the relays. This feedback, however, is significantly lower than that required for precoding (which requires the channel phase), and arguably lower than that required for symbol-level node synchronization necessary to implement DSTC. Recently selection was shown to be the optimal linear beamforming scheme under the constraint of $log_2(m\text{-}1)$ bits of feedback (Zhao & Adve & Lim, 2007).

Selection schemes have been analyzed theoretically in terms of outage probability and multiplexing diversity trade-off for both amplify-and-forward and decode-and-forward transmissions and under various power constraints and signal-to-noise ratio (SNR) regimes (Beres & Adve, 2007; Beres & Adve, 2008; Bletsas & Khisti & Win, 2007; Michalopoulos & Karagiannidis, 2008; Zhao & Adve & Lim, 2007). In addition, one implementation of selection using repeat-accumulate codes and demodulate-and-forward is available in the literature (Chu & Adve & Eckford, 2007). In this chapter, we present a detailed review