Single-User Broadcasting Protocols over a Two-Hop Relay Fading Channel

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Abstract—A two-hop relay fading channel is considered, where only decoders possess perfect channel state information (CSI). Various relaying protocols and broadcasting strategies are studied. The main focus of this work is on simple relay transmission scheduling schemes. For decode-and-forward (DF) relaying, the simple relay cannot buffer multiple packets, nor can it reschedule retransmissions. This gives rise to consideration of other relaying techniques, such as amplify-and-forward (AF), where a maximal broadcasting achievable rate is analytically derived. A quantize-and-forward (QF) relay, coupled with a single-level code at the source, uses codebooks matched to the received signal power and performs optimal quantization. This is simplified by a hybrid amplify-QF (AQF) relay, which performs scaling, and single codebook quantization on the input. It is shown that the later is optimal by means of throughput on the relay-destination link, while maintaining a lower coding complexity than the QF setting. A further extension of the AQF allows the relay to perform successive refinement, coupled with a matched multi-level code. Numerical results show that for high SNRs the broadcast approach over AF relay may achieve higher throughput gains than other relaying protocols that were numerically tractable.

Index Terms—Ad-hoc networks, amplify-and-forward, code layering, decode-and-forward, multi-hop relays, quantize-and-forward, single-user broadcasting.

I. INTRODUCTION

Cooperation among network users, in the form of relaying, has been of wide interest recently. The growing demand for capacity and coverage has exceeded the limits of a single server network. This challenge can be accommodated by allowing network users to act as relays, and improve the signal quality at its final destination. Wireless networks with multi-ray signals exhibit fading, sometimes even deep fading, which may highly distort the original signal. In a rapidly changing environment, it is customary to assume that transmitters have no access to channel state information (CSI), and only receivers possess perfect CSI. The performance is also usually evaluated by the outage capacity. The notion of capacity versus outage was introduced and discussed in [1] and [2, see references therein].

In the sequel we consider a relay channel, where the direct link channel quality is so poor, that it can be assumed there is no direct link between the source and the destination, as sketched in Figure 1. This is a special case of the classical relay channel [3], [4], [5], where the channel between the source and destination has very poor signal-to-noise ratio (SNR). In this setting, the source transmits to a single relay, which decodes/amplifies/quantizes its input data and forwards/retransmits its signal over to the destination. This setting is also known as a two-hop relay system [6].

Several contributions [7], [8], [9], and more, demonstrate practical examples for the two-hop relay setting. In these examples single rate codes are used and only the medium access (MAC) layer is modified so that an ad-hoc network can be supported, and a network member may serve as a relay, and thus increase the coverage and overall network capacity. This is also a special case of multi-hop relays [6]. It is observed in [10] that substantial capacity and coverage gains can be obtained with a simple two-hop relay architecture, where CSI or partial CSI is available at the transmitters. Notice that solutions in the MAC layer necessarily require a relay that decodes and retransmits information. This is the decode-forward relay, which might introduce non-negligible additional delays and complexity. Cooperation in the physical layer may allow non-regenerative decode-forward or amplify-forward [11] or quantize-forward [4] relays. This type of cooperation can cleanly lead to higher aggregate throughput, provide lower delay, and complexity reduction.

The two-hop relay setting is also a special case of parallel relaying, where there is only one relay. The two relay symmetric network for the additive white Gaussian noise (AWGN) channel is studied in [12], where capacity bounds are obtained. Diversity gains in simple parallel relaying with receivers CSI and space-time permutations among relays is presented in [13], with further extensions in [14], [15].

Study of the relay channel [3], [4], [5] is of fundamental importance to cooperation in wireless networks, since it captures the ability of a user to assist in transferring information from a source to its destination - a situation which is prevalent in wireless networks due to the sharing of the wireless medium among all users. Unfortunately, the capacity of the relay channel is only known for some specific cases (e.g. degraded and reversely degraded relay channel, semi-deterministic relay channel, relay channel with feedback) which do not apply directly to common wireless settings. Recently, however, there has been some extensive work reported concerning the capacity of the relay channel and its implications on cooperation in wireless channels. For example, upper and lower bounds