Buffer-Aided Relaying in Cooperative Networks

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***Abstract*—Traditional half-duplex relaying schemes partition the packet transmission slot into two phases, where the Source-Relay link transmission is in the first phase, and the Relay-Destination link transmission occurs in the second phase. As a result, the relay that received the source signal is the same as the one that is subsequently forwarding the signal towards the destination. However, these relaying schemes halve the maximum achievable multiplexing gain and result in bandwidth loss. In order to overcome these limitations, several techniques have been proposed in the literature. With the adoption of buffer-aided relays, the coupling between receiving and transmitting relays is broken, since different relays could be selected for transmission and reception, thus allowing increased degrees of freedom. In this contribution, we exploit the potential of buffer-aided relays and adopt a single phase slot in which either the Source-Relay or the Relay-Destination link is activated, or both provided certain conditions hold. This new approach opens a new avenue for research and design of relay selection policies and transmission schemes that facilitate increased throughput and multiplexing gains; we propose several such schemes and discuss both their benefits and limitations.**

***Index Terms*—Cooperative networks, relay channel, buffers, relay selection, outage probability.**

I. Introduction

Cooperative relaying has received considerable attention lately due to the provably improved performance and their wide variety of applications (see, for example, [1], [2] and references therein). Relay selection has been an efficient cooperative technique in networks with multiple relays that can assist the transmission from the source. The main advantage of relay selection is its implementation simplicity, since it does not require complex physical layer transmission techniques (e.g., distributed space-time codes) or explicit synchronization processes.

The seminal work of Bletsas *et al.* [3] where the fundamental benefits from the relay selection have been emerged, initiated extensive research towards the design of efficient relay selection policies for different cooperative contexts (e.g., [5]–[8]). In earlier works, in which relays were assumed to lack data buffers, relay selection was mainly based on the $\max-\min$ criterion and its variations (see, for example, [3], [8]–[10] and references therein). As a result, based on either proactive or reactive criteria, the relay that received the source signal is the same as the one that is subsequently forwarding the signal towards the destination.

With the adoption of buffer-aided relays, this coupling is broken, since different relays could be selected for transmission and reception, thus allowing increased degrees of freedom for scenarios where delay insensitive applications take place, or, when delay-aware relay selection is adopted. Buffering at the relay nodes is a promising solution for cooperative networks and motivates the investigation of new protocols and transmission schemes, even though it can result in delayed packet transmission making them inappropriate for some delay sensitive applications. The first works that studied the benefits offered by buffer-aided relays, to the best of the authors' knowledge, are [11], [12]; the authors in [11] investigated the performance of a network using "rateless" codes in terms of throughput, end-to-end delay and queue stability when buffer-aided relay selection is employed, while [12] presented an opportunistic buffered decode-wait-and-forward protocol which exploited mobile relays with buffers to increase the throughput and reduce the delay of the network. Subsequently, Ikhlef *et al.* [13] proposed a novel criterion based on $\max-\max$ Relay Selection (MMRS), in which the relay with the best Source-Relay (SR) link is selected for reception and the relay with the best Relay-Destination (RD) link is selected for transmission. In order to recover the half-duplex loss, [14] adopts the MMRS, while at the same time adopting successive transmissions (SFD-MMRS). As the proposed topology aims to mimic full-duplex relaying, different relays are selected at the same time slot. However, relays are considered isolated and the effect of inter-relay interference is ignored, while relay buffers are never considered to be either full or empty.

Krikidis *et al.* [15] proposed the $\max-\text{link}$ protocol, which allows all the SR and RD links to enter the competition for the best link through which a signal will be transmitted, thus providing additional freedom in the scheduled transmissions at each time slot. This work has been the prime mover towards more advanced protocols making use of the suggested framework. Herein, we propose several buffer-aided schemes with successive and non-successive opportunistic relaying, accompanied by power adaptation and inter-relay interference (IRI) cancellation whenever necessary, with which we aim to recover the half-duplex loss of cooperative relaying.

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