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Utility-based resource allocation for interference limited OFDMA cooperative relay networks

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ABSTRACT

This paper proposes a utility-based resource allocation algorithm for the uplink OFDMA Inter-cell Interference (ICI) limited cooperative relay network. Full channel state information (CSI) is assumed to be available at the resource controller at initial stage, then the work is extended to consider more realistic assumption, i.e., only partial channel state information (PCSI) is available. The proposed algorithm aims to maximize the total system utility while simultaneously satisfying the individual user's minimum data rate requirements. In the proposed algorithm, relay selection is initially performed based on the consideration of ICI. Then, subcarrier allocation is performed to achieve maximum utility assuming equal power allocation. Finally, based on the amount of ICI, a modified water-filling power distribution algorithm is proposed and used to optimize the per-carrier power allocation across the allocated set of subcarriers. The results show that, compared to conventional algorithms, the proposed algorithm significantly improves system performance in terms of total sum data rate, outage probability and fairness.

1. Introduction

Cooperative communications are emerging as an important area within the field of wireless communication systems. The fundamental idea is that intermediary nodes, called *relay stations* (RSs), who are neither the data source nor the destination, are used to assist in communications between senders and receivers. In order to maximize their performance, networks which employ RSs require a new resource allocation and optimization technique, which takes the RSs into account as a new resource.

Several resource allocation algorithms have been proposed for the purpose of maximizing the average data rates under power constraints [1–5]. The authors of [6,7] presented resource allocation algorithms which aim to optimize the distribution of resources between users while maintaining a satisfactory degree of fairness amongst them. In fact, there exists a trade-off between fairness and capacity; the imposition of fairness constraints on the optimization problem will often degrade aggregate system capacity. Utility-based resource allocation algorithms have been developed to balance the trade-off between subscribers fairness, system capacity and other performance metrics such as latency [8,9].

The authors of [10] proposed a resource allocation scheme with adaptive priority thresholds. The proposed algorithm balances the trade-off between the minimum data rate requirement satisfaction and the capacity. Yen et al.

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proposed a different utility-based throughput maximization and complexity-reduction scheduling scheme [11], which allocates subcarriers, antenna sequence, and modulation order to multimedia users for the purpose of maximizing the total capacity under the minimum data rate requirements constraints. In both of these papers, a single cell scenario has been considered only, i.e., interference from other cells is neglected. However, it is important to consider the effects of interference caused by neighboring cells (Inter-cell Interference or ICI) in the resource optimization due to its impact on the system performance [12].

Recently, Zhang et al. investigated the joint uplink subchannel and power allocation problem in cognitive small cells with the presence of cross-tier interference under the assumption of imperfect channel state information (CSI) [13]. The proposed cooperative Nash bargaining resource allocation algorithm aims to maximize the achievable sum rate without compromising the outage probability and fairness among users. The work of [13] has been extended in [14] to include cotier and cross-tier interference mitigation taking spectrum sensing errors into account. However, in these papers cotier and/or cross-tier interference is considered as the main interference source while co-channel interference between small cells is assumed as part of the thermal noise. Additionally, these papers do not specify the relaying protocol that is used by the small cells.

Inter-cell interference has been considered in [15]. This paper assumes cooperation between neighboring base stations (BSs). However, the information exchange across different cells introduces an overhead on the backbone network.

Most of the existing literature considers the minimum data rate requirements and capacity trade-off and aims to balance this trade-off sequentially [16,17]. This approach implies that priority will always be given to the subscriber with the highest instantaneous rate requirements. This may lead to excessive use of available resources by a single subscriber if that subscriber is in a deep fade. Thus, the aggregate capacity is degraded.

In addition to that, another limitation was observed in previous related papers which relates to the availability of channel state information (CSI). It can be seen the proposed algorithms assume that the CSI is fully and accurately available at the resource controller. However, this assumption is unrealistic due to channel estimation error and the feedback delay.

Motivated by the above review, in this paper we study the resource allocation and optimization for inter-cell interference limited OFDMA-based cooperative relay network with full and partial CSI available at the resource controller.

More specifically, this paper proposes a utility-based resource allocation, in which the current minimum data rate requirements of every user and the impact of the allocation of every subcarrier on the total capacity will be jointly considered to dynamically update the selection priority. Furthermore, the CSI is assumed to be available at the resource controller at initial stage, then the work is extended to consider more realistic assumption, i.e., only partial channel state information (PCSI) is available.

The proposed utility-based resource allocation algorithm is divided into three stages: relay selection, subcarrier allocation and then power allocation. The proposed algorithm aims to maximize the total achievable network data rate. ICI and fairness issues are taken into account during the resource allocation.

The contributions and novelties of this paper are summarized in the following.

- New utility and performance degradation functions are developed and incorporated into the proposed utility-based resource allocation algorithm in order to optimize the available resources, such that the aggregate data rate is maximized while meeting the constraints on the minimum data rate requirements and fair resources distribution.
- A modified water-filling power allocation algorithm has been developed by which the available power is allocated across subcarriers based on the amount of ICI on each subcarrier such that subcarriers with high ICI are avoided.
- The system performance has been evaluated under realistic assumptions and considerations, such as partial channel state information (PCSI), presence of inter-cell interference (ICI) and fairness requirements.

The remainder of this paper is organized as follows: Section 2 presents the system model. Section 3 defines and models the utility and performance degradation functions. Section 4 formulates the optimization problem. Section 5 presents the proposed utility-based resource allocation algorithms, while the proposed ICI-based water-filling algorithm is presented in Section 6. Section 7 presents the partial channel state information model, while in Section 8, performance of the proposed algorithms is evaluated by simulations. finally, Section 9 concludes the paper.

2. System model

This paper considers a multiple-cell scenario as shown in Fig. 1. The subscriber stations, amplify and forward (AF) relay stations and destination are denoted as S, R, and D respectively. The cell under consideration receives an ICI from the interference sources I of neighboring cells. This ICI interference is received from neighboring cells with varying signal strength levels depending mainly on the distances between each one of the interference nodes and the node under consideration. The interference on the rth relay station from the ith interference node denoted as $I_{i,r}$ and can be expressed as [18]:

$$I_{i,r} = H_{i,r} L(d_{i,r}) p_i \tag{1}$$

where, p_i, $L(d_{i,r})$ and $H_{i,r}$ are the transmission power at the interference node, the pathloss and the instant channel respectively. Parameter $d_{i,r}$ represents the distance between the ith interfering node and the rth node of interest which is variable parameter as different interfering nodes are located at different distances from the node of interest.

Moreover, the available bandwidth is divided into (N) subcarriers and are available at the destination. Denote the set of source nodes, relay nodes, interference nodes and subcarriers as $\mathcal{S} = \{1, \ldots, s, \ldots, S\}$, $\mathcal{R} = \{1, \ldots, r,$