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Backhaul traffic reduction using limited feedback in cellular frequency division duplex uplink networks☆

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A B S T R A C T

In this paper, we propose an enhanced signal-to-generating interference ratio (SGIR)-based resource scheduling scheme to reduce the feedback overhead in backhaul links for frequency division duplex (FDD) uplink networks. In the proposed scheme, each base station (BS) transfers only the information of dominant interference channels greater than a given threshold instead of the whole interference channels. We analyze the performance of the proposed scheme in terms of the amount of feedback reduction in the backhaul links and average uplink sum-rate. In addition, we derive a closed-form solution to determine an adequate threshold level. The numerical results show that the proposed scheme can significantly reduce the amount of feedback traffic in the backhaul links, while yielding almost the same average uplink sum-rate.

1. Introduction

As mobile traffic is growing exponentially, ultra-dense networks (UDNs) have been considered a promising technology for the next-generation mobile communication networks due to their higher spectral efficiency [1–5]. However, extremely high concentration of mobile devices and base stations (BSs) in the UDNs causes a severe inter-cell interference (ICI), which degrades the network performance [6]. Although the ICI in the UDNs is critical in both downlink and uplink, it is much more critical in the uplink because transmitters are apart from a resource controller. Various radio resource management schemes have been proposed to solve the performance degradation caused by the ICI [7,8]. Maximum signal-to-interference and noise ratio (maxSINR)-based resource scheduling schemes that only consider the information of desired channels cause the performance degradation in high interference environments because the interference generated by transmissions is not taken into account [9]. Conversely, minimum interference-to-noise ratio (minINR)-based resource scheduling schemes cause the performance degradation in weak interference environments because they only consider the interference generated by transmissions ignoring the information of desired channels [7]. Maximum signal-to-generating-interference ratio (maxSGIR)-based scheduling schemes select the user with the maximum value of SGIR in order to consider both the desired and the interference channels [8], and a user with strong desired channel and weak generating interference is thus more likely to be allocated radio resources. In many previous studies, it was shown that the maxSGIR resource scheduling schemes yield a remarkable performance enhancement compared to both the maxSINR and minINR schemes in various interference environments [8,10–15].

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In order for a maxSGIR-based resource scheduling scheme to work in uplink, a centralized controller needs to know the SGIR values of all users. In time-division duplex (TDD)-based networks, each user can estimate uplink channels by measuring downlink channels due to a channel reciprocity. Thus, it can easily calculate its own SGIR value by measuring pilot signals from all surrounding BSs and feeds the SGIR value back to the centralized controller through its serving BS [14,15]. However, unfortunately, it is impossible for the users to estimate their uplink channels in frequency-division duplex (FDD) because uplink and downlink channels are not reciprocal. Thus, the centralized controller should gather entire channel information of whole users to calculate the SGIR values of all users. First, each user should transmit its own sounding symbols toward all surrounding BSs. Each BS estimates all uplink channels by measuring the sounding symbols transmitted by the users and transfers the whole information of all channels to the centralized controller through reliable backhaul links. Despite this tremendous amount of feedbacks over backhaul links from the BSs to the centralized controller, no previous studies investigated the feedback overhead in the backhaul links. The backhaul links account for a considerable portion of operating expenses (OPEX) for mobile service providers, which has been steadily increasing in recent years [16].

In this paper, we thus propose an enhanced maxSGIR-based resource scheduling scheme to decrease the excessive feedback traffic in the backhaul links of FDD uplink UDNs and to reduce the OPEX of mobile service providers. In the proposed scheme, the centralized controller manages BSs to transfer only dominant interference channels greater than a predetermined threshold level instead of the whole interference channels received from the users in all neighboring cells. Based on the limited information of interference channels transferred by the BSs, the centralized controller approximately calculates the SGIR values of all users. We analyze the performance of the proposed scheme in terms of the amount of reduction in backhaul feedback traffic and average uplink sum-rate. The numerical results show that the proposed scheme can significantly reduce feedback traffic in the backhaul links with a marginal loss in the average uplink sum-rate.

1.1. Related works

Motivated by their outstanding performance, many maxSGIR-based resource allocation and user scheduling schemes have been investigated for downlink [8,10–13] and uplink [14,15]. A distributed user scheduling algorithm for the downlink was proposed by employing the SGIR to reduce the system overhead of exchanging channel state information and computational complexity [8]. It was shown that the maxSGIR can outperform a traditional scheduling method based on maxSINR [10]. A user scheduling scheme based on a novel SGIR criterion for a multiuser MIMO downlink has been also presented in [11], where the users are selected to guarantee that the minimum SGIR is large enough. An SGIR-based scheduling method with finite rate feedback was proposed in a multiuser MIMO downlink [12] and it was shown that the first user can be selected randomly without loss of performance [13]. In downlink, the SGIR-based resource management schemes do not cause any overhead in backhaul networks because each user can calculate its SGIR value when it receives data from BS [8,10–13].

On the other hand, an SGINR-based precoding scheme was proposed for uplink MIMO systems, where it was assumed that each user can perfectly estimate uplink channel coefficients by the channel reciprocity of uplink and downlink [14]. A resource management scheme maximizing SGIR in each user was proposed for interference-limited uplink cellular networks [15]. However, both [14] and [15] considered TDD systems where the uplink and downlink channels are reciprocal, and each BS can thus easily obtain each user's SGIR value by the feedback from the user. Despite aforementioned intensive previous works, no studies considered uplink FDD networks, where the severe feedback overhead is caused inevitably in the backhaul links.

1.2. Organization of this paper

The rest of this paper is organized as follows. In Section 2, we describe network and channel models which are considered in this paper. In Section 3, a conventional resource scheduling scheme based on maxSGIR is explained and an enhanced scheme to reduce backhaul feedback traffic is also proposed. The amount of feedback traffic in the backhaul links required is analyzed for both the proposed and conventional schemes in Section 4. Numerical results are shown in Section 5 and the conclusions of this paper are drawn in Section 6. Finally, Section 7 describes the limitations of this paper and presents the direction of future research.

2. Network and channel models

We consider a cellular FDD uplink network that consists of K cells and one centralized controller. Each cell includes a BS with single receive antenna and N users with single transmit antenna. All BSs are connected to the centralized controller through backhaul links. In this paper, we assume that all the BSs have the same number of users N, which can significantly simplify the mathematical analysis while not limiting the contributions of this paper and the feasibility of the proposed scheme. We assume that the backhaul links consist of optic fibers or fast Ethernets, and transmission delay in backhaul links is thus ignorable. Fig. 1 illustrates the cellular FDD uplink network where $K = 3$ and $N = 2$. First, each user broadcasts sounding symbols for uplink channel estimation in the BSs. We assume that dedicated resources are allocated to each user for sounding symbols, and each BS can therefore exactly measure all the uplink channels from $(K \times N)$ users. $[k, i]$ denotes the user i in cell k and $h^j_{[k,i]}$ denotes an uplink channel coefficient from user $[k, i]$ to BS j, where $j, k \in \{1, \cdots, K\}$ and $i \in \{1, \cdots, N\}$. We consider a Rayleigh block channel fading. Thus, $h^j_{[k,i]}$ is complex normally distributed $\sim \mathcal{CN}(0, (\sigma^j_{[k,i]})^2)$ and all the