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Coordinated multipoint in dense heterogeneous networks with overlapping microcell expanded regions and its effect on backhaul links

Jessica Khoriaty, Hassan Artail *, Youssef Nasser

American University of Beirut, Department of Electrical and Computer Engineering, Bliss Street, Beirut, Lebanon

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ABSTRACT

One of the goals of Heterogeneous Networks (HetNets) is to offload traffic from the macrocell BS to the microcell base stations (BSs). It has been proposed that in order for the microcell to acquire more users and offload increasing amounts of traffic, its region of coverage must be expanded. This however causes significant cross-tier interference, which can be remedied by utilizing coordinated multipoint (CoMP) within the microcell expanded region (ER). Our methodology considers the effect of overlapping ERs, and proposes the cooperation of concerned microcell BSs with the macrocell BS to further reduce the outage probability and improve throughput. Another important consideration in our analysis is the effect of having non-ideal backhaul on the system's performance. That is, CoMP increases the strain on the backhaul network, since additional data that is proportional to the number of cooperating BSs needs to travel on the backhaul links. Furthermore, the delay should be minimal and less than one subframe duration in order for reported channel state information to remain valid. With this in mind, our proposed system considers the effect of having non-ideal backhaul in a cellular network with CoMP, while taking into account overlaps in the microcell ERs.

1. Introduction

The migration from 3G to 4G systems, brought on by a need to satisfy improved performance requirements, was not achieved by LTE systems, and the enhancements to LTE, under the umbrella of LTE-Advanced, necessitated the introduction of the concept of heterogeneous networks and CoMP to better serve increasing traffic demands [1]. Heterogeneous cellular networks (HetNets) consist of a traditional macrocell tier overlaid with several small cell tiers, each of which is served with a base station (BS) that operates at a lower power and works to offload traffic from the macrocell network. In a homogeneous cellular network, cell association is based on maximum downlink received signal strength [2]. However, in the case of HetNets, this method hinders efficient traffic offloading from the macrocell since the received signal strength from distant macrocell BSs may be stronger than that of closer small cell BSs. Another problem that arises in HetNets is due to the uplink transmission of the macrocell BSs to UEs in the neighborhood of microcells, thus creating interference at those microcells. This issue can be remedied through applying a bias factor [2] at such UEs, which allows for the expansion of the small cell BS coverage area by an amount which is referred to as Expanded Region (ER). This factor is a multiplicative term that serves to increase the received signal strength perceived at the UE, thus causing small cell handover to occur sooner. However, the application of the bias factor increases the level of interference and noise in the ER since the UE is not connected to the cell that provides the strongest signal [3]. Inter cell interference (ICI) coordination is therefore needed to provide better signal quality at the UEs in the ER.

Cooperation between BSs is one of the solutions for ICI, where Coordinated Multipoint (CoMP) is a technique that allows for the transmission and reception of data to a user from a set of different BSs simultaneously. This can make ICI a useful signal in regions that are close to the cell edge and improve signal quality. In joint transmission CoMP, BSs cooperate to transmit the same data to the UE, thus allowing for the mitigation of ICI and the increase of throughput for users at the cell edge [1,4]. Recent works in the literature, as shown in Section 2, benefit from CoMP by allowing cross tier coordination between macrocell and microcell BSs.

Our proposed scheme, unlike previous works on CoMP, considers possible overlaps in the microcell ERs, which are likely to exist when the density of the microcells is high. We use the ER around the microcell as the determining factor for employing the type of CoMP joint transmission. At the perimeter of the microcell

* Corresponding author.
E-mail addresses: jjk11@mail.aub.edu (J. Khoriaty), hartail@aub.edu.lb (H. Artail), yn10@aub.edu.lb (Y. Nasser).

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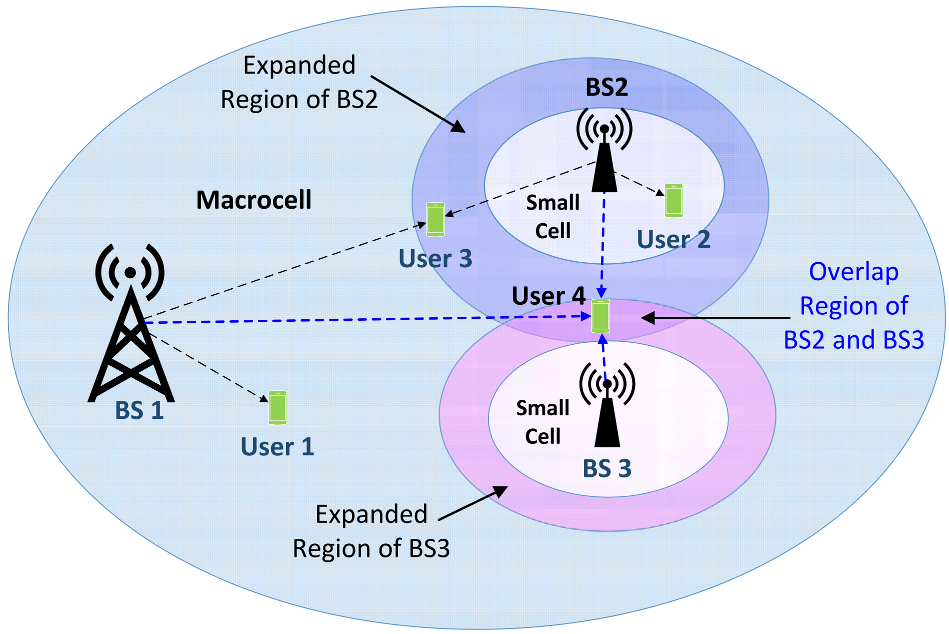

Fig. 1. A network with users in different scenarios (UE4 is served by BS1, BS2, and BS3).

coverage area the power ratio between the macrocell BS (macBS) and the microcell BS (micBS) is 1, whereas at the perimeter of the ER, the same power ratio is equal to a value that is denoted by β. Hence, within the microcell coverage area, the interference from the macBS is no longer significant, and users can be served solely by the micBS. On the other hand, beyond the ER, the power ratio between the macBS and the strongest micBS is greater than β, and the user would be served from the macBS, since interference from the microcell is not significant. Finally, when the power ratio is between 1 and β, CoMP will be employed between the concerned microcell and the macBSs, which is a case that is treated in previous works. However, what has not been addressed in the literature is the case of User 4 in Fig. 1, which lies in the overlap of the two microcell ERs, thus necessitating the three BSs (of the macro and of the two micros) to participate in CoMP.

In addition of addressing the case of UEs that fall within the overlap region of the ERs of multiple microcells, our work also tackles a research challenge that was discussed in [1], namely the effect of having non-ideal backhaul (i.e., an infrastructure with latency and capacity limitations) on CoMP performance. This challenge is not addressed in [5], which we base our work on, although the literature includes work that proposes to reduce the CoMP backhaul burden by selecting a subset of BSs for cooperation, and other work that investigates the effect of non-ideal backhaul on the network. The importance of studying the effect of non-ideal backhaul lies in the fact that CoMP requires an increase in the amount of overhead traveling on the X2 interface, consisting of the data that needs to be transmitted from the serving BS to the other BSs taking part in joint transmission CoMP (JTCoMP), so that multiple BSs can subsequently transmit the same data to the UE simultaneously. In terms of delay, the requirement is that the latency must be less than the duration of one subframe (1 ms), which would ensure the validity of Channel State Information (CSI) against aging channel conditions. In this regards, our work studies the effect of non-ideal backhaul in terms of capacity as well as delay limitations on our JTCoMP scheme.

In this work, we use stochastic geometry to derive performance metrics for location aware CoMP taking into account overlaps in microcell ERs. Relative to the literature (including our previous work in [6]), the contributions of this work can be summarized as follows:

- Deriving performance metrics, most notably outage probabilities, related to location aware CoMP transmission, while accounting for overlaps in microcell Expanded Regions.
- Providing a scalable framework for CoMP by means of a general UE–BS association model, in which an overlap may exist between two or more ERs. This supports scenarios of dense deployment of wireless access devices associated with a large number of microcell base stations, which consequently gives rise to overlaps among microcell ERs.
- Studying the effect of non-ideal backhaul on CoMP in terms of capacity and delay, given the additional load that CoMP adds to the backhaul, especially in terms of data traffic.

In the remainder of this paper, Section 2 discusses the related work, whereas Section 3 presents our scheme and the analysis. Section 4 presents the performance results of our JTCoMP scheme, Section 5 generalizes the number of CoMP cooperating set to more than 3, Section 6 considers the effect of non-ideal backhaul, and finally, Section 7 concludes the paper.

2. Related work

2.1. CoMP in HetNets

CoMP provides several advantages that include mitigating user interference at the cell edge, increasing throughput, and raising average rates. There are two CoMP schemes to be considered. In coordinated scheduling or beamforming, cooperation involves scheduling and control decisions, with data only being transmitted from one BS. In joint transmission CoMP, on the other hand, data is sent simultaneously from several cooperating BSs to be decoded coherently at the receiver. This mitigates the effect of inter-cell interference and increases throughput.

CoMP can be realized through either a centralized or distributed architecture. In the centralized setup, control information and data is collected at a central unit, which then makes decisions on clustering, precoding, and power allocation. On the other hand, a distributed architecture requires CSI to be collected at the serving cell, which then forwards the required information to other BSs within the cooperating cluster. The channel information that is