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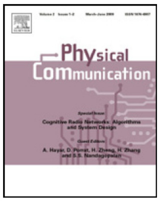

Full length article

Optimal design of energy efficient two-tier HetNets with massive MIMO by coordinated multipoint beamforming

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ABSTRACT

This paper presents an energy-efficient (EE) coordinated multipoint beamforming (CMBF) approach that minimizes the total power consumption based on both the dynamic emitted power and static hardware power while maintaining necessary quality of service (QoS) constraints and different coordinated schemes. We deduce expressions the optimal value of each parameter in a two-tier heterogeneous networks (HetNets) from the perspective of energy efficiency (EE), considering a massive multiple-input multiple output (MIMO) system in conjunction with CMBF and small cell deployment. We find that the EE of HetNets is sensitive to the coordinated scheme design, the number of macro-cell and small-cell base station antennas, and QoS constraints. As such, all these factors should be taken into account in system design. Furthermore, we provide promising analytical and simulation results demonstrating that the proposed HetNets generally provides a solution for achieving maximal EE performance with relatively low-complexity CMBF.

1. Introduction

The Green communication can be achieved through energy efficiency optimization and energy harvesting. The present exponential growth in mobile data demand requires that the capacity of wireless communications networks be increased to guarantee that mobile applications meet their quality of service (QoS) requirements. To this end, employing massive multiple-input multiple-output (MIMO) technology [1] and heterogeneous networks (HetNets) [2] has been recognized as a promising means of enhancing network capacity, and to achieve the high data rates, extremely low latency, and very high spectral and energy efficiencies required by 5G wireless communication systems.

1.1. Background and motivation

Massive MIMO is a potential technology for increasing the data throughput of 5G communication systems without an additional increase in bandwidth or transmission power [3]. This technology can improve performance by exploiting the spatial diversity and multiplexing obtained by multiple antennas. However, the energy efficiency (*EE*) should be an important performance indicator for designing such Massive MIMO systems. Hence, the critical challenge is to develop the means of further improving the *EE* of massive MIMO systems. An effective approach is to deploy an overlaid small-cell with the small bases (SBSs) to offload traffic from macro bases (MBSs). Thus, the fact that most data traffic is localized and requested by low-mobility users can be exploited using HetNets [4]. This approach reduces the average distance between users and transmitters, which translates into lower propagation losses and higher *EE*.

Recently, various approaches have been investigated to improve the *EE* [5–8]. The *EE* of HetNets employed in conjunction with massive MIMO. For example, cell size, deployment density, number of antennas, and wireless backhaul have been optimized to minimize the power consumption of small cells [9–12]. Most early studies that have analyzed the *EE* focused on the impact of the dynamic emitted power, while the static power component that depends on transceiver hardware has typically been neglected [13,14]. However, the static power consumption of Massive MIMO and small-cell networks is comparable to that of the dynamic emitted power component, and therefore cannot be neglected [15,16]. As such, the consideration of static power consumption promises substantial improvement in the *EE* of massive MIMO and small-cell networks. In addition, while existing techniques lay the foundation of massive MIMO systems, networking techniques also play a vital role for ensuring the efficient and reliable operation of practical communication systems [17,18]. In a multi-cell scenario, both inter-cell interference (ICI) and intra-cell interference degrade the performance of massive MIMO system. Coordinated multipoint beamforming (CMBF) has been proposed

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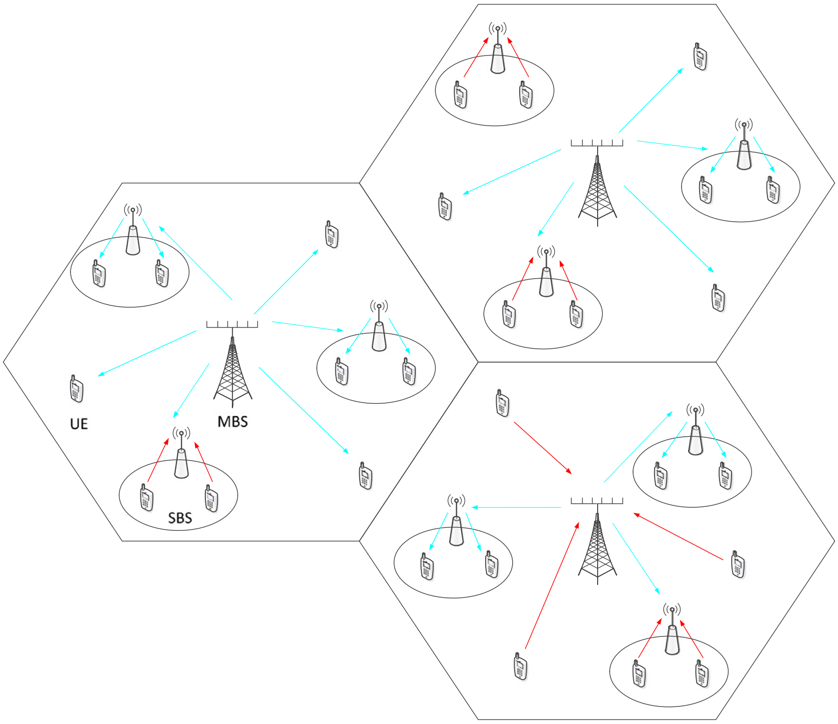

Fig. 1. Illustration of MBSs overlaid with small cells. Each MBS has N_{MBS} antennas and the SBSs have N_{SBS} antennas. The K single antenna users can be served (non-coherently) by any combination of transmitters, but the circles indicate typical coverage areas.

to improve the system performance of multi-cell massive MIMO HetNets systems [19–22]. Moreover, is responsible to aggregate traffic from SBSs towards MBSs, the CMBF may significantly affect the rates and therefore the energy efficiency of the entire network. With the potential development of increasingly massive MIMO and dense infrastructures employing many SBSs with their corresponding hardware power consumption, adopting CMBF is of critical importance for the energy-efficient design of HetNets.

1.2. Approach and major contributions

In this work, we consider the total power consumption divided into two components. One is the consumption of the static part that depends on the transceiver hardware, which is an important consideration in large array design, and the other one is the dynamic component, which is proportional to the emitted signal power. Therefore, Massive MIMO HetNets must be properly deployed and optimized to actually improve the overall *EE*. First, we analyze the possible improvements in the *EE* of massive MIMO HetNets systems in conjunction with CMBF under a modified HetNets topology that employs massive MIMO at MBSs with an overlaying of different numbers of SBSs. The goal is to minimize the total power consumption while satisfying different QoS constraints at the user end and power constraints at the MBSs and SBSs. We show that the structure of this optimization problem enables the determination of an optimal solution. The solution is demonstrated to dynamically assign each user to the optimal transmitter of available SBSs. A low-complexity algorithm based on zero-forcing (ZF) precoding is proposed for CMBF to achieve the optimal solution with respect to *EE*. The potential merits of different HetNets topologies are analyzed by simulations based on different QoS constraints.

The remainder of this paper is organized as follows. The system and signal model is introduced in Section 2. In Section 3, we describe the power consumption of a HetNets and the coordination scheme in detail. In Section 4, we analyze the *EE* of a HetNets, and we provide simulations that confirm the accuracy of our analysis. Numerical results are presented in Section 5 to provide insights into the energy-efficient design of HetNets with different CMBF and OoS criteria. The paper is concluded in Section 6.

2. System and signal model

2.1. Two-tier cellular network model

We consider the downlink environment of a HetNets shown in Fig. 1, where the first tier includes MBSs, each of which is equipped with N_{MBS} antennas, where N_{MBS} is a number up to several hundred, representing massive MIMO, while the second tier includes SBSs, each with N_{SBS} antennas, and the network has K service users. In this work, the macro-cell and small-cell tiers are spatially distributed as two uniform processes with different transmission powers. Furthermore, the users are located according to an independent homogeneous Poisson point process (PPP) with different densities, and we assume that the user density is much greater than that of the SBSs. Hence, there is always an active user for every SBS and multiple active users for every MBS. In particular, we define M_S SBSs that form an over layer, and are arbitrarily and uniformly deployed over the entire plane with strict power constraints. In comparison, an MBS has more generous power constraints that can support high QoS targets over a large coverage area.

2.2. Signal model

Here, we assume that the channels are independent and identically distributed and a typical user U_k experiences block fading from serving and interfering base stations (BSs). We assume perfect channel acquisition to support CMBF, which employs the standard power loss propagation model with path loss exponent α. The impact of fading on the signal power follows an exponential distribution with a unitary mean value. The noise power is assumed