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Energy efficiency based joint cell selection and power allocation scheme for HetNets☆

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ABSTRACT

Heterogeneous networks (HetNets) composed of overlapped cells with different sizes are expected to improve the transmission performance of data service significantly. User equipments (UEs) in the overlapped area of multiple cells might be able to access various base stations (BSs) of the cells, resulting in various transmission performances due to cell heterogeneity. Hence, designing optimal cell selection scheme is of particular importance for it may affect user quality of service (QoS) and network performance significantly. In this paper, we jointly consider cell selection and transmit power allocation problem in a HetNet consisting of multiple cells. For a single UE case, we formulate the energy efficiency of the UE, and propose an energy efficient optimization scheme which selects the optimal cell corresponding to the maximum energy efficiency of the UE. The problem is then extended to multiple UEs case. To achieve joint performance optimization of all the UEs, we formulate an optimization problem with the objective of maximizing the sum energy efficiency of UEs subject to QoS and power constraints. The formulated nonlinear fractional optimization problem is equivalently transformed into two subproblems, i.e., power allocation subproblem of each UE-cell pair, and cell selection subproblem of UEs. The two subproblems are solved respectively through applying Lagrange dual method and Kuhn–Munkres (K-M) algorithm. Numerical results demonstrate the efficiency of the proposed algorithm.

1. Introduction

In recent years, high-speed mobile Internet applications, such as voice over Internet protocol (VoIP), video streaming, Internet surfing, online games, etc, have experienced rapid development, which pose great challenges on the transmission performance of traditional cellular networks. Cellular heterogeneous networks (HetNets) consisting of both macro cells and small cells, such as femto cells, pico cells and relay nodes, etc. are expected to improve the transmission performance of data service significantly [1–3].

As small cells can be deployed densely in HetNets, it is highly possible that user equipments (UEs) might be located in the overlapped area of multiple cells, in which case UEs may be able to access various base stations (BSs) of the cells, resulting in various transmission performances due to cell heterogeneity especially in terms of channel characteristics and available network resource. Hence, the design of optimal cell selection scheme is of particular importance for it may affect user quality of service (QoS) and network performance significantly.

Cell selection or network selection problem has been considered in the literature. In [4], the authors propose a load-aware cell selection approach for HetNets. In particular, they investigate the properties of a hierarchical (Stackelberg) Bayesian game framework, in which the macro cell dynamically chooses the offset about the state of the channel in order to guide users to perform intelligent network selection decisions between macro cell and small cell networks. The authors in [5] study the machine learning based strategies for dynamic channel selection in cognitive access points (CogAPs) of WLANs. They employ multi-layer feed forward neural network models that utilize historical traffic information from network environment to predict traffic loads of the channels. Based on the obtained load information, the CogAPs choose the best channel for serving wireless clients.

In the case that cell selection strategies have been designed for HetNets, the resource allocation schemes play an important role in affecting the transmission performance of users. References [6,7] stress the power allocation problem of HetNets. The authors in [6] study the downlink power allocation problem of HetNets consisting of femto BSs (FBSs) and MBSs, and formulate the power allocation problem of the FBSs as a non-cooperative game model under the constraint of the outage probability of macro UEs (MUEs). Through solving the Nash

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equilibrium solutions of the game model, the transmit power strategies can be obtained. In [7], the authors jointly consider time domain and power domain optimization of a two-tier macro-pico HetNet. Time domain performance optimization is achieved by applying an adaptive almost blank subframes (ABS) configuration scheme which dynamically matches network resources to the real-time load of the network. To further enhance network performance and achieve the performance tradeoff between the two tiers, a utility function maximization based power control and scheduling scheme is proposed.

The authors in [8] propose a resource allocation scheme for co-channel interference avoidance in long term evolution (LTE) heterogeneous networks with universal spectrum reuse where both macro users and cognitive FBSs within the same macrocell coverage can dynamically reuse whole spectrum. The proposed scheme addresses co-channel interference by employing fractional frequency reuse for resource block (RB) allocation in the outer region of the macrocell and increasing the distance of users that reuse the same RB within the macrocell. In [9], the authors consider the interference problem in two-tier femtocell networks and propose two frequency partitioning methods to mitigate the interference between the macrocell and femtocells. The authors in [10] consider the resource allocation problem of cloud mobile gaming (CMG) on mobile devices and address the problem of making the CMG approach scalable and economically feasible by proposing a novel wireless cloud scheduler.

In [11,12], resource allocation problems and cell selection (or user association) problems are jointly considered for HetNets. In [11], the authors propose a unified static framework to study the interplay of user association and resource allocation in HetNets and formulate the joint optimization problems as non-convex integer programs. To increase the energy efficiency of the BSs in HetNets, BS on-off switching schemes are considered in [12], where the authors propose an optimal BS on-off switching and user association scheme with the objective to maximize the system energy efficiency. In [13], the authors formulate the joint BS assignment and downlink beamforming scheme in HetNets as a weighted sum rate maximization problem. Through solving the optimization problem, the optimal joint BS assignment and downlink beamforming strategies can be obtained.

References [14,15] focus on transmitting power optimization based cell selection, i.e., selecting the optimal cells for users so that the total transmitting power can be minimized under a predefined signal and interference to noise ratio (SINR) constraint. The authors in [16] propose a distributed base station association and power control scheme for HetNets which aims of maximizing the sum rate across the network. In [17], the authors consider the optimization of user and BS association in a wireless downlink cellular HetNet under the proportional fairness criterion and propose a utility maximization based joint user association and power allocation scheme.

Previous research works on joint cell association and power allocation in HetNets [14–17] mainly focus on maximizing the transmission rate or system utility, fail to consider the tradeoff between the transmission rate and energy consumption of UEs. In general, to achieve high transmission rate, large transmitting power of the UEs is required, resulting in higher energy consumption, which is highly undesired especially for energy-sensitive devices.

In this paper, we study joint cell association and power allocation problem in HetNets. To achieve the tradeoff between the transmission rate and energy consumption, we propose an energy efficient joint cell selection and power allocation scheme for UEs. To reduce the computation complexity of the scheme, candidate cells are selected among all the cells of the HetNet and the proposed scheme is then only applied to the candidate cells. We first consider a single UE case and propose an energy efficient optimization scheme which selects the optimal cell corresponding to the maximum energy efficiency of the UE. The problem is then extended to multiple UEs case. To achieve joint performance optimization of all the UEs, we formulate an optimization problem with the objective of maximizing the sum energy efficiency of UEs subject to QoS and power constraints. The formulated nonlinear fractional optimization problem is equivalently transformed into two subproblems, i.e., power allocation subproblem of each UE-cell pair, and cell selection subproblem of UEs. The two subproblems are solved respectively through applying Lagrange dual method and Kuhn–Munkres (K-M) algorithm.

The rest of the paper is organized as follows. In Section 2, the system model considered in this paper is outlined. Section 3 proposes candidate cell selection scheme. A joint cell selection and power allocation scheme is proposed for a single UE case in Section 4. In Section 5, we propose a joint cell selection and power allocation scheme for multiple UEs case. In Section 6, the optimization problem formulated is solved. Simulation results are presented in Section 7. Finally, we conclude this paper in Section 8.

2. System model

In this paper, we consider a HetNet comprising of multiple cells including macro cells, pico cells, and femto cells, etc., the coverage region of which may overlap with each other. A number of UEs located in the area of the HetNet may access the BS of various cells for information interaction. We assume that orthogonal spectrum sharing scheme is applied for the cells, i.e., various spectrum is allocated to different cells, hence no inter-cell interference exists. In addition, to avoid intra-cell interference, different time–frequency resource blocks are allocated to UEs of each cell. Fig. 1 shows the system model considered in this paper.

We denote the number of UEs as M and the number of cells as N. In this paper, we consider that UEs may select one cell for network accessing and study the problem of joint cell selection and transmitting power allocation of the UEs. For convenience, it is assumed that at certain time–frequency resource blocks, one BS can only access one UE for data forwarding and vice versa.

3. Candidate cell selection scheme

As UEs in a HetNet may have various QoS requirements, in this paper, to stress user QoS requirement on transmission rate, we assume each UE might have different data rate requirement, which poses constraints on target access cell in turn. More specifically, as some cells may not be able to meet the data rate constraint of certain UEs, they cannot be selected as the serving cell of these UEs. In this paper, to reduce the computation complexity of the proposed cell selection and power allocation scheme, we first propose a candidate cell selection scheme which selects the qualified cells based on the QoS requirements of UEs, then a joint cell selection and power allocation scheme is presented which only applies to the candidate cells of the UEs.

To offer data transmission service to a UE with a transmission rate requirement, which is in general characterized by a minimum data rate constraint, the target cell has to meet the data rate requirement. Denoting R_{ij} as the achievable data rate of the ith UE when accessing

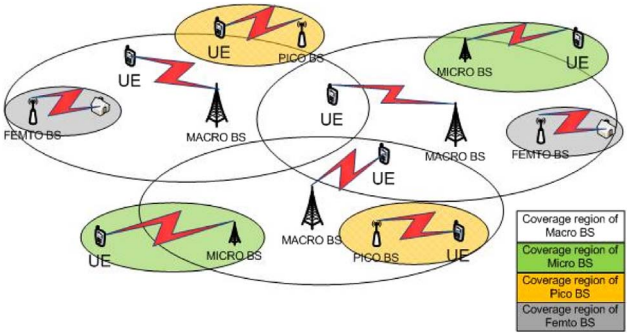

Fig. 1. System model.