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Energy efficiency enhancement in heterogeneous networks: a joint resource allocation approach

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Abstract

To support the drastic growth of wireless multimedia services and the requirements of ubiquitous access, numerous wireless infrastructures which consume enormous energy, such as macrocell, small cell, distributed antenna systems and wireless sensor networks, have been deployed. Under the background of environmental protection, improving the energy efficiency (EE) in wireless networks is becoming more and more important. In this paper, an EE enhancement scheme in heterogeneous networks (HetNets) by using a joint resource allocation approach is proposed. The HetNets consists of a mix of macrocell and small cells. Firstly, we model this strategic coexistence as a multi-agent system in which decentralized resource management inspired from Reinforcement Learning are devised. Secondly, a *Q*-learning based joint resource allocation algorithm is designed. Meanwhile, with the consideration of the time-varying channel characteristics, we take the long-term learning reward into account. At last, simulation results show that the proposed decentralized algorithm can approximate to centralized algorithm with low-complexity and obtain high spectral efficiency (SE) in the meantime.

Keywords heterogeneous networks, energy efficiency, reinforcement learning, decentralized resource allocation, joint resource allocation approach

1 Introduction

Since the forecasted explosion of data traffic and the radio link is approaching the theoretical performance limits, the concept of HetNet is proposed in the framework of long-term evolution-advanced (LTE-Advanced) to increase the SE. In HetNets, small cells, such as picocells, femtocells and relays, with radius of about 30~200 m are deployed within a macrocell. It has been proved that the deployment of small cells around the cell-edge of the macrocell can improve the area SE of the network [1–2]. However, driven by the growing awareness of environmental protection and the high energy consumption expenditure, the power consumption in wireless communication has attracted great attentions.

Although the power consumption of the small cell base stations (SBSs) is relatively low compared to the macrocell base station (MBS), it is necessary to reduce the total power consumption of the SBSs because of their dense deployment in the network. In Ref. [3], the author analyzes the optimal partial spectrum reuse (PSR) factor in HetNets, and a closed-form limit of the optimal PSR factor is derived as the radio of the user rate requirement over the whole system spectrum bandwidth is approaching zero, based on which a threshold of the MBS energy cost is also derived to determine which type of base stations (BSs) is more preferable. Besides, an optimal fractional frequency reuse and power control scheme that can effectively mitigate the interference between macrocell and low power nodes in HetNets is proposed in Ref. [4]. In addition, Ref. [5] investigates the design and the associated tradeoffs of energy efficient cellular networks through the deployment of sleeping strategies and small cells. Moreover, the success probability and EE in HetNets under different sleeping policies are derived by using a stochastic geometry based model. In Ref. [6], the optimal BS density for HetNets to minimize network energy cost is analyzed, and the best type of BSs to be deployed for capacity extension, or to be switched off for energy saving

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is given.

To sum up, most of the existing studies focus on the relationship between the deployment density of small cells and EE of HetNets. As we all know, severe inter-tier interference in HetNets is detrimental to the network performance, in this paper we use the joint resource allocation approach to enhance the network EE. Number of works about the joint resource allocation have been done recently. In Ref. [7], Xiong et al. studied the EE resource allocation in both downlink and uplink orthogonal frequency division multiple access (OFDMA) networks. For each scenario, an optimal EE resource allocation approach and a low-complexity suboptimal algorithm are proposed. In Ref. [8], the joint power and subcarrier allocation problem is formulated for maximizing the EE in a multi-relay aided multi-user OFMDA cellular network. To the author's best knowledge, using joint resource allocation to optimize the EE in HetNets has not been investigated so far.

In this paper, we focus on the EE improvement by using a joint resource allocation method in HetNets. Generally, the centralized and distributed methods are adopted. The centralized method is impractical to implement and the complexity is high, especially when small cells are randomly and densely deployed. We design a distributed resource allocation scheme based on the *Q*-learning algorithm which has superior convergence performances. Therein, an improved bisection-based power adaptation (IBPA) algorithm is designed to solve the power allocation problem for given resource block (RB) allocation, which is regarded as the reward of the actions of *Q*-learning. The simulation results confirm that our proposed algorithm can highly improve the network EE with low complexity.

2 System model and problem formulation

In this paper, we consider the downlink operation of a two-tier HetNets that comprises MBS and SBSs. The total available spectrum bandwidth is B Hz which is partitioned into N RBs, each RB occupies a bandwidth of $W = B/N$ Hz. Macrocell and small cells operate in the same frequency band and have the same amount of available RBs.

2.1 System model

For the simplicity of analysis, we consider the HetNets consisting of one macrocell and L small cells. Let $\mathcal{L} = \{1, 2, ..., L\}$ be the set of small cells. For the macrocell and small cells, users are randomly distributed inside their regions. We suppose M macrocell users (MUE) are served by the MBS and K small cell users (SUE) in each small cell. Assuming that each RB is exclusively assigned to at most one UE each time to avoid interference among different UEs in the same station. The downlink transmit power of MBS and SBS l in the nth RB for MUE m and SUE k is respectively denoted as $p^0_{m,n}$ and $p^l_{k,n}$. Then the signal to interference and noise ratio (SINR) of MUE m and SUE k in SBS l on the nth RB are:

$$\gamma^0_{m,n} = \frac{p^0_{m,n} h^{\mathrm{M}}_{m,n}}{\sum_{l=1}^{L}\sum_{k=1}^{K} p^l_{k,n} h^{\mathrm{SM}}_{l,m,n} + N_0 W} \tag{1}$$

$$\gamma^l_{k,n} = \frac{p^l_{k,n} h^{\mathrm{S}}_{l,k,n}}{\sum_{m=1}^{M} p^0_{m,n} h^{\mathrm{MS}}_{l,k,n} + \sum_{\substack{u=1\\u\neq l}}^{L}\sum_{j=1}^{K} p^u_{j,n} h^{\mathrm{SS}}_{u,l,k,n} + N_0 W} \tag{2}$$

The first summation in the denominator of Eq. (1) and Eq. (2) represents the inter-tier interference between the MBS and SBS, while the second summation in the denominator of Eq. (2) is the intra-tier interference from the other SBSs. And $h^{\mathrm{M}}_{m,n}$ is the channel gain from MBS to MUE m. $h^{\mathrm{SM}}_{l,m,n}$ indicates the link gain from SBS l to MUE m. $h^{\mathrm{S}}_{l,k,n}$ is the link gain from SBS l to its SUE k. $h^{\mathrm{MS}}_{l,k,n}$ is the link gain from MBS to SUE k of SBS l. $h^{\mathrm{SS}}_{u,l,k,n}$ is the link gain from SBS $u(u \in \mathcal{L}, u \neq l)$ to SUE k of SBS l. N_0 is the noise spectral density. Then the Shannon rate of MUE m on the nth RB is accordingly

$$r^0_{m,n} = W\,\mathrm{lb}\left(1 + \gamma^0_{m,n}\right) \tag{3}$$

Similarly the maximum achievable data rate of SUE k in SBS l on RB n is

$$r^l_{k,n} = W\,\mathrm{lb}\left(1 + \gamma^l_{k,n}\right) \tag{4}$$

We use a feasible RB assignment indicator matrix $\boldsymbol{\rho}^0 = \left[\rho^0_{m,n}\right]_{M\times N}$, where $\rho^0_{m,n} \in \{0,1\}$ indicates whether the nth RB is allocated to user m.

The matrix satisfies [7]

$$\boldsymbol{\rho}^0 = \left\{\left[\rho^0_{m,n}\right]_{M\times N} \middle| \sum_{m=1}^{M}\rho^0_{m,n} \leqslant 1, \forall n \in \mathcal{N}; \rho^0_{m,n} \in \{0,1\}, \forall m \in \mathcal{M}, \forall n \in \mathcal{N}\right\}$$

, where $\mathcal{N} = \{1, 2, ...N\}$ and $\mathcal{M} = \{1, 2, ...M\}$ denote the sets of all RBs and all MUEs.

Hence, the total throughput of MBS and SBS l can be