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A Stackelberg game-based spectrum allocation scheme in macro/femtocell hierarchical networks

Peng Xu [a,b,*], Xuming Fang [b], Meirong Chen [c], Yang Xu [a]

[a] School of Mathematics, Southwest Jiaotong University, Chengdu 610031, China
[b] Key Lab of Information Coding and Transmission, Southwest Jiaotong University, Chengdu 610031, China
[c] Electronic Information and Electric Engineering Department, Chengdu Textile College, Chengdu 611731, China

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ABSTRACT

Femtocells widely deployed in a macrocell form hierarchical cell networks, which can improve indoor coverage and network capacity, and have been regarded as one of the most promising approaches. However owing to the absence of coordination between the macro and femtocells, and among femtocells, decentralized spectrum allocation between macro and femtocell users become technically challenging. In this paper, a dynamic spectrum allocation scheme based on Stackelberg game is proposed, in which macrocell base stations as leaders and femtocell base stations as followers are players, and the same spectrum is the resource that players will choose assigning to users for minimizing the affected interference among each other. The Stackelberg equilibrium is defined and proved to be existed, which is also the optimal spectrum allocation manner. Simulations were conducted to study the impact of femtocells on the macrocells regarding throughput, outage probability and spectrum efficiency. And the comparison results show that the proposed scheme might be a solution for efficiently allocating the spectrum in hierarchical cell networks, as the improvement in terms of throughput, outage probability and spectrum efficiency had been achieved.

1. Introduction

The recent development of hierarchical macro/femtocell networks is a realistic way of providing better quality of service to indoor mobile users [1]. Femto cell systems, known as access point base stations or small cellular home base stations, provide service providers with extension of indoor service coverage and also with expansion of link capacity by drastically reducing the infrastructure costs [2]. Another advantage of the femtocells is that cellular terminals can incorporate the functionality of femto base stations (BS) without specific or dual mode user devices [3,4].

The placement of femtocells has a critical effect on the performance of a pre-existing macrocell network, and there are many complicated issues to be overcome for successful deployment of femtocells. One of the main issues yet not to be solved is that femto and macrocells could suffer severe co-channel interference from each other if spectrum management is not appropriately considered [5]. Since femtocells will be placed by end consumers, the ad hoc locations of femtocells will render centralized frequency planning difficulty. Decentralized spectrum allocation between macro and femto users may adopt two manners. One is that all macro and femtocell users are orthogonal through bandwidth splitting; the other is that macro and femtocell assign their users with shared bandwidth (i.e. frequency reuse) [3,6].

Generally it has been considered more feasible to introduce femtocells on orthogonal frequency than macrocells due to coexistence problems by reducing the mutual interference. However that will lead low spectrum efficiency, and recent studies have shown that deploying co-channel femtocells with minor impact on the macrocell performance is possible [7]. One conventional approach to improving spectrum efficiency in static manner is to reuse the frequency band in multiple geographical areas or cells. However inter-cell interference will be inevitably incurred, when in adjacent cells share the same spectrum [8–10]. In Ref. [8], frequency reuse with reuse factor three, and two manners of fraction frequency reuse (FFR) are discussed in multi-cell networks. But it is not well suitable because the femtocells in hierarchical networks are designed to work in plug and play and be deployed by end user. In Refs. [9,10], fractional frequency reuse was discussed in detail to reduce hierarchical interference, including conventional and modified FFR. However preplanned frequency assignments cannot realtimely satisfy the variety of femtocells deployed in ad hoc manner. So the methods of dynamic spectrum allocation are needed [11]. The decentralized resource allocation scheme in terms of resource

* Corresponding author at: School of Mathematics, Southwest Jiaotong University, No.111, Erhuanlu Beiyiduan, Chengdu 610031, China. Tel.: +86 1355 039 4586.
E-mail address: pengxup@gmail.com (P. Xu).

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blocks with time and frequency is discussed to achieve inter-cell interference avoidance [12]. In Ref. [13], an autonomous spectrum sharing algorithms is proposed to reduce co-channel interference. In the meantime, game theory as a mathematical tool has been widely used in radio resource allocation, such as in Refs. [14–16]. A potential game is modeled among femtocells in Ref. [14] to allocate the resource blocks and set power levels. However macrocells has not been taken into account. Unlike in Ref. [14] both macrocells and femtocells are considered in Refs. [15] and [16], in which Stackelberg game was modeled. Stackelberg game as a specific branch of game theory has been applied in the context of cognitive radios, where the desirability of outcomes depends not only on their own actions but also on other cognitive radios [15]. Stackelberg is based on a leader–follower approach where the leader plays his strategy before the follower and then enforces it [17]. Especially in Ref. [15] spectrum sharing and learning scheme are discussed, except for specific method of spectrum allocation. The bi-level hierarchical Stackelberg game based on the spectrum allocation between macrocells and femtocells was given and proved particularly in Ref. [16], but in fact the spectrum allocation analyzed only among macrocells or among femocells was not essential to reduce cross-tier interference.

In this paper a dynamic frequency allocation scheme based on Stackelberg game is proposed, due to the fact that Stackelberg concept naturally arises in some contexts of practical interest such as when base stations have allocated the spectrum to users in an asynchronous manner. A Stackelberg game also known as the leader–follower game, is an extension of non-cooperative dynamic game in which there are a group of players, called leaders that have the privilege of making the first move, while the remaining players, called the followers, make their move after the leaders. The leaders can anticipate and take into consideration, the behavior of the followers, before making their own moves [17]. And the reason that investigating a Stackelberg game in spectrum allocation scheme for hierarchical networks is motivated, by the fact that cross-tier interference by f-BSs deployed later than m-BSs has to be minimized while high priority is given to the m-BS. In the proposed scheme femto and macro BSs choose the optimal frequency in shared frequency to assign associated users, where the optimal object is defined as minimal interference introduced to users. The scheme indicates superior performance gain over the conventional method with high SINR.

The remaining part of this paper is organized as follows. In Section 2, the system model is given. The Stackelberg game formulation is described in Section 3. Section 4 gives the performance evaluation and comparison. At last in Section 5, the conclusion is given.

2. System model

In system deployment each base station has some options of frequency allocation, and BSs have the opportunity and some methods to deploy the femtocells in dedicated spectrum [18], as shown in Fig. 1. There are three methods to allocate spectrum, including orthogonal frequency, frequency reuse and fraction frequency reuse. At present there exist lots of traditional manners to avoid inter-cell interference have been proposed, which have been proved efficiently in Refs. [6,8]. However as the femtocells are largely deployed randomly by end consumers, the traditional way such as various frequency reuse methods in a preplanning/centralized manner would not work efficiently. And the macrocell base stations are currently deployed by operators. So the focus is concentrated in one macrocell with some femtocells randomly deployed, and some users are distributed among hierarchical networks, as shown in Fig. 2. Assume that the macro base station (m-BS) and all femto base stations(f-BSs) have the same spectrum

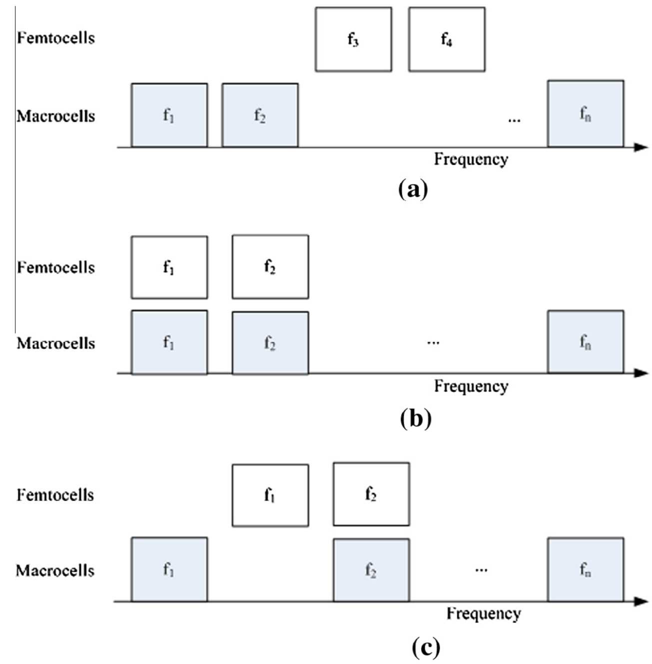

Fig. 1. Frequency assignment options.

resource. The ultimate target is to assign users with adequate frequency to minimize cross-tier interference, subject to guarantee existed users' quality of service (QoS) such as received signal to interference plus ratio (SINR).

The process of spectrum allocation between m-BS and f-BSs can be modeled as a dynamic game-Stackelberg game. In the Stackelberg game-based spectrum allocation scheme, the m-BS is the leader and the f-BSs are the followers, which is rational that the m-BS being the primary networks is preexisted whereas f-BSs are later deployed.

Then the Stackelberg game is defined as:

$$G = \{N, S, U\} \tag{1}$$

where $N = \{M,F\}$ denotes the set of players, $M = \{mBS\}$ and $F = \{fBS_l;\ l \in 1,2,\ldots,n\}$ denote the macro base station and some femto base stations in one macrocell, respectively. $S = \{f_1,f_2,\ldots,f_m\}$ denotes the frequency that mBS and fBS will be allocated, as the strategy set. $U = \{U_M,U_F\}$ represents the relevant utility set for the set M and F, which are defined as forenamed ultimate target. In this game the m-BS will firstly assign ith frequency with the anticipation the lth f-BS will choose kth frequency, then the lth f-BS assigned jth frequency with the knowledge of the m-BS's choice, and the utility can be described as:

$$U_M(mBS_i, fBS_k^l) = \{u_{i,k}^m(l) | i,k \in 1,2,\ldots,m;\ l \in 1,2,\ldots,n\} \tag{2}$$

$$U_F(fBS_j^l, mBS_i) = \{u_{j,i}^f(l) | i,j \in 1,2,\ldots,m;\ l \in 1,2,\ldots,n\} \tag{3}$$

If the anticipation on the kth assigned frequency does not accord with the jth frequency actually assigned, the m-BS and f-BS will dynamically adjust until the equilibrium appears.

3. Stackelberg game formulation

Assume that m-BS and all other co-existed femtocells have been adaptively assigned frequencies, and the suitable power control is adapted. To simplify the analysis, the scenario when a new femtocell is deployed with some new users distributed in macro and femtocell is adopted. Only the game of spectrum allocation