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Utility-driven relay for hybrid access femtocells based on cognitive radio spectrum auction

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ABSTRACT

Femtocells promisingly improve coverage and spectrum efficiency at the edge of macrocell. However, macro users may suffer dead-zone trouble due to strong interference coming from closed access femtocell, or compete spectrum resource with femto users in the open access model. In this paper, we propose a novel utility-driven relay scheme adopted by hybrid access femtocell (HAF) to address the above two issues, wherein the macrocell maximizes the usage of its idle spectrum bands, bided by femtocells, via cognitive radio spectrum auction; and recompense relay expense to stimulate selfish femtocells undertaking HAFs to relay the signal to the vicinal macro user, meanwhile avoiding two-tier interference. Spectrum competition among femtocells is formulated as a static Cournot game provided with global information; then necessarily considered as a dynamic Cournot game of the strategy adapting distributively according to the players previous actions. Furthermore, we introduce a protocol and propose refund factor, spectrum price dynamic adjustment algorithms to achieve the Stackelberg equilibrium, i.e., the solution of the non-cooperative game between macrocell and femtocells. We also prove the existence of equilibrium and the convergence of algorithms. Extensive simulation results show the details of games, which indicate they can match the win-win hybrid access mechanism, benefiting cell-edge macro users for better QoS and higher access opportunities for femto users.

1. Introduction

Femtocells have strong competence with Distributed Antenna System and WiFi, in providing low-cost low-power coverage to satisfy indoor beyond 66% of voice plus 9/10 of data traffic needs [1]. Because the receiving signal-to-interference-plus-noise ratio (SINR) is improved, as a result of the femtocell base station (FBS) approaching close to femtocell user (FUE) [2]. Femtocell was formerly designed as closed access point, merely serving authorized FUEs, i.e., sealed subscriber group defined by 3GPP, which may bring about serious cross-tier interference to macrocell user (MUE), given randomly deploying the femtocells. Although, all subscribers of the operator are allowed to leverage the femtocell in an open access manner, not having above interference, the management of handover, security and signaling interaction become more complex. So HAF being a trade-off between open and closed approaches is suggested [1]. The HAF opens a limited amount of time-frequency resources for MUEs, while reserve the rest for femto users exclusive use. However, femtocells tend to be selfish and generally have no motive to run in hybrid access, even the open access model. Thus, a rational incentive mechanism to stimulate femtocells choosing hybrid access mode, meantime to profit the macrocell base station (MBS) and MUEs is urgently desired. In this paper, A novel game model aims to maximize the idle spectrum usage of the FBSs and transform harmful

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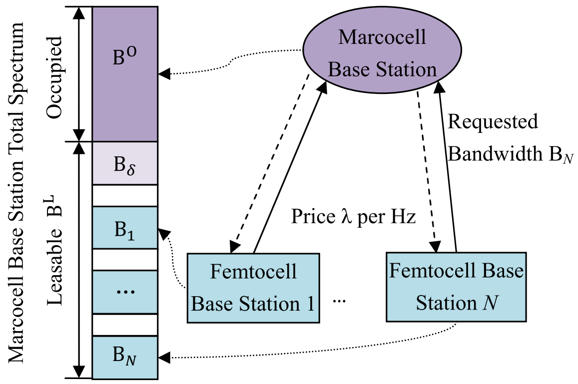

Fig. 1. Macrocell base station spectrum planning and spectrum auction.

interference (FBS to MUE) to cooperative relay transmission, is proposed.

The ultimate target is to handle two challenges in femtocells network, sharing spectrum competition and two-tier interference. The problem of all FBSs competing spectrum is tackled by auction game, which is efficient stimulating method to increase spectrum utilization, via minimizing underutilized spectrum bands [3]. We recommend the MBS fulfils centralized spectrum planning, where the MBS rents out the idle spectrum bands B^L to FBSs, as shown in Fig. 1, and the MBS auctioneer sells unit spectrum at price λ to FBSs. Then all FBSs bid, depending on their spectrum demand B_N. Dynamic spectrum sharing was viewed as reformative scheme to address the scarcity of the spectrum resource in cognitive radio networks [4]. The spectrum auction mechanism becomes a natural solution for spectrum competition, due to the spectrum leasing relationship [5]. In auction games, following certain rules, auctioneers determine resource allocation and prices according to bids [6]. To specifically describe the behavior of competitive FBSs, the Cournot game is employed. Under above spectrum splitting, two-tier interference is completely avoided thanks to non-overlapping channels between femtocells (B^L) and macrocell (B^O). Thereafter, dead-zone trouble of strong interference is vanished. However, cell-edge macro users may suffer the weak signal sent from the MBS and have inclined to handover to other MBS. So signal relay is necessary. We further exploit a Stackelberg game, where the MBS dynamically adjusts the spectrum price; and reward the FBSs for offering relay transmission to the cell-edge MUE to help reduce the churn rate. Under the incentive mechanism, HAFs improve QoS of cell-edge MUE and meet FUEs increasing spectrum demand, with a win-win situation. To the best of our knowledge, there is no existing work on HAFs relaying the signal to macro users.

The major contributions of this article are outlined below:

1. We propose a novel utility-driven relay framework to inspire femtocells to attempt HAFs supporting the MBS delivering reliable transmission to cell-edge macro users, meanwhile preventing two-tier interference.
2. We present a novel model which explores Cournot game to explain the competitive relationship among FBSs and adopts auction game, Stackelberg game to describe the cooperation and competition of the MBS and FBSs. Two algorithms of the MBS determining the proper refund factor and spectrum price are proposed.
3. We design a protocol to implement the framework and do extensive numerical simulations to evaluate the performance.

The succeeding sections are organized as follows. Section 2 reviews related works. Section 3 presents the system model and formulation. In Section 4, we describe the static and dynamic behavior of FBSs in the Cournot game. We propose two algorithms of seeking optimal refunding factor and spectrum price to achieve the Stackelberg equilibrium between the MBS and FBSs. We prove the existence of two equilibrium and the uniqueness of the Cournot-Nash equilibrium. The convergence of algorithms is also proved. We introduce a protocol for HAFs to relay MUE in Section 5. Extensive simulations and analytical results are displayed in Section 6, with the conclusion is drawn in Section 7.

2. Related work

In 1838, oligopolistic competition was initially investigated by Cournot, wherein a firm ought to consider the responses of its competitors to any intended action. On the other hand, in a monopolistic situation, you cannot find any competition. Sherali et al. [7] first expanded the classic Cournot games via introducing a Stackelberg organization who decides the production quantity by explicitly taking into account the other firms ("Cournot players") reaction. The follow-up can be found in these literature [8–10]. In [10], authors term a Stackelberg-Nash-Cournot equilibrium as Cournot-Nash players react to the Stackelberg player's profit-maximizing decisions.

Bandwidth auction game was utilized to organize spectrum sharing among licensed and unlicensed users, and a distributed bid updating algorithm to achieve Nash equilibrium was presented [11]. Three distributively auction-based spectrum allocation schemes for multimedia streaming over cognitive radio networks were studied [12]. Spectrum sharing concerning cognitive users was formulated as an oligopoly market competition (a Cournot game), static behavior and dynamic feature of the game together with the stability analysis were investigated [13]. A distributed Stackelberg game framework was used for relay selection and power control in cooperative communication networks [14]. Game analysis of an incentive mechanism to form hybrid access femtocell was proposed [15]. Yet relay transmission and spectrum competition among FBSs were not considered, and the SINR of FUE involved femto-femto interference $I_i(K)$, without attention to cope with the above two challenges.

If femtocells deployed densely, allowing more household customers to transmit, critical two-tier interference may weaken performance improvement [16]. Formulating the co-channel interference problem as either a coalition formation game or a game with a correlated equilibrium