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MINIMIZING INTERFERENCE BY SHARING SPECTRUM IN LTE-A USING GAME THEORY

S.INDHUMATHI[1], R.SELVARAJ[2] AND V.ELAVARASI[3]

[1]*Department of ECE, E.G.S.Pillai Engineering College, Nagapattinam*
[2]*Department of ECE, Bharathiyar College of Engineering and Technology*
[3]*Department of ECE, E.G.S.Pillai Engineering College, Nagapattinam*

Abstract— Improving capacity and coverage is one of the main issues in next-generation wireless communication. Heterogeneous networks (HetNets), which is currently investigated in LTE-Advanced standard, is a promising solution to enhance capacity and eliminate coverage holes in a cost-efficient manner. A HetNet is composed of existing macrocells and various types of small cells. By deploying small cells into the existing network, operators enhance the users' quality of service which are suffering from severe signal degradation at cell edges or coverage holes. Nevertheless, there are numerous challenges in integrating small cells into the existing cellular network due to the characteristics: unplanned deployment, intercell interference, economic potential, etc. Recently, game theory has been shown to be a powerful tool for investigating the challenges in HetNets. Several game-theoretic approaches have been proposed to model the distributed deployment and self-organization feature of HetNets. In this chapter, the authors first give an overview of the challenges in HetNets. Subsequently, the authors illustrate how game theory can be applied to solve issues related to HetNets. In this study, the authors address the spectrum sharing problem in a HetNet composed of a macrocell and several femtocells. They propose a new approach in which macrocell and femtocells can simultaneously share the available bandwidth, while avoiding the intra-tier interference and helping the macrocell to offload by expanding the cell range of some femtocells. The author's approach is formulated ass a Stackelberg game, in which the macrocell is selling bandwidths to femtocells in exchange of some victim macro-users to serve, mainly the macro-users who undergo severe interference from the neighbouring femtocells. They demonstrated that their game theoretic reaches a stable state called Stackelberg equilibrium analytically and by simulations. More importantly, they show that overall network performance is improved in terms of total femtocells' throughputs and spectral efficiency of the macro-users who are in the vicinity of the femtocells.

Keywords— HetNets, LTE-A, Macrocells, Stackelberg Game, Interference

I. INTRODUCTION

High system capacity is one of the fundamental requirements to access current wireless communication. While most advanced signal and transmission techniques potentially enhance the performance of wireless systems (Parkvall, Furuskar, & Dahlman, 2011), they eventually reach the theoretical limitation due to the physical laws: the signal quality. Most of next generation wireless networks are planned to operate in high frequency spectrum. In such spectrum, the signals will degrade significantly in long distance and indoor environments. This suggests that more areas will experience weak signal receptions unless the network deployment is densified.

In order to boost network capacity in a flexible and cost-efficient manner, the concept of Heterogeneous Networks (HetNets) has been introduced in LTE-A standard (Lopez-Perez et al., 2011). A heterogeneous network consists of macrocells, which are deployed for serving large coverage areas, and low-power and low-cost nodes such as picocells, femtocells, relay nodes, or remote radio heads (RRHs), which provide services in areas with dedicated capacity. The wireless signal quality can be greatly enhanced through the assistance from the low-power nodes when they are properly deployed in the coverage holes in the macrocells. Additionally, these newly deployed small cells can be served for offloading purposes for help reducing the heavy loading in macrocells. The extra capacity offered by these cells can be used to handle more demands in the cellular network, or even redirect them directly to home and company's intranet or the Internet. Lastly, these low-cost nodes are more economically attractive as they usually require lower-cost infrastructure (pico and relay nodes) and lower requirements in terms of backhaul connections (femtocell).

The deployment of HetNets, however, is a serious challenge to the service operators. The deployment scheme depends on the purpose of the service provider. In case of traffic offloading, the deployment should be directly handled by the service provider according to the statistic or predicted demands in certain areas. In such a case, the problem is similar to the traditional cell planning except that the small cell deployment could be dynamic according to the current demands. On the other hand, when it comes to the cell quality enhancement, the traditional cell planning and deployment solution is impractical to HetNets, especially for the femtocells. This is due to the significant larger number of cell sites and uncertainty in coverage holes. Additionally, the coverage holes are also difficult to be found without the assistance and demands from end-users. This poses a strong link between the deployment of femtocells and the demands from users. These users, who should be considered rational, determine the deployment of femtocells by either sending requests to the service provider or installing low-power nodes by themselves. Unlike the service provider, who concerns the overall system performance, these rational users care about their own benefits only? Additionally, heterogeneous components (pico/femtocells, macrocells, UEs) in HetNet may have different objectives (Khan, Tembine, & Vasilakos, 2012) and preferences on the network configurations. This increases the difficulty to have a proper organization among all these components. The conflict of interests between the service provider and end users may lead to inefficient deployment of HetNets if not carefully addressed. Therefore, it is important to understand how these rational users interact with the service provider in the deployment and configuration of HetNets. Game theory, a powerful tool for analyzing a distributed system with rational users, is a natural choice for studying above scenarios in HetNets.

II. BACKGROUND

Game theory is a study on the mathematical models of the strategic interactions between individual players in a game. The outcome of the game depends on the interactions among participated players. The players are considered rational and have certain valuations on the outcome of the game. Since the game outcome depends on the interaction, a player will be aware of the (expected) actions of other player and will make her decisions accordingly in order to reach her most desired outcome. Most researchers are interested in predicting the final outcome of a game, in which various types of equilibrium concept, such as Nash equilibrium, correlated equilibrium, core ...etc, can be applied. Nevertheless, it is possible that the expected outcome is an inefficient one since players are involved in multiple individual interests on the outcome. In such cases, some researchers study on tuning the final outcome by refining the game rule or structure in order to improve the system performance.

A typical HetNet in LTE-A is composed of lower-power base stations (BSs) underlying in the existing macrocell system. These small BSs are intended to increase the signal strength, offload the macrocells, and enhance the spectrum utilization. The deployment of HetNets can be planned and conducted by the service provider in advance, or requested and deployed by users themselves. The service area and operating spectrum of the small cells is usually partly or fully overlapping with the macrocell. Heterogeneous small cell base stations have been introduced in HetNets (Lopez-Perez et al., 2011). The authors briefly state as follows:

- Picocells are low-power (23 to 30dBm) cell towers providing similar features as macrocells except smaller coverage (hundreds of meters) and user load (tens of users). They use the same backhaul as the macrocells and are deployed by the service provider.
- Relays are small stations that deliver the data between macrocells and MSs in a multi-hop over-the-air scheme. They are mostly deployed by the service provider in order to extend the coverage

of existing networks. A relay requires over-the-air backhaul capacity between macrocell BS and uses a similar transmit power as picocells.

- RRHs are radio control units that are connected directly to the macrocells through fibers but deployed with a distance from the macrocell BS. The macrocell has full control on the RRHs and operate them as its own wireless interface.
- Femtocells are also known as Home eNode Bs (HeNBs) in LTE systems. A femtocell BS can be regarded as a simple, low-transmission power (i.e. 23 dBm or less) base station installed by users in an unplanned manner. Through the deployment of femtocells, subscribers are able to access to networks via broadband backhaul. That is, femtocells may utilize Internet protocol (IP) and flat base station architectures. Femtocells may operate in open-access, closed-subscribed group (CSG), or hybrid-access scheme, depending on the choice of the cell owner.

In these possible choices of small cells, the femtocell has the following advantages: It increases indoor signal coverage and system capacity on demands, providing higher link quality with lower transmission power, and utilizes the existing broadband connection as its backhaul. Nevertheless, the femtocell system faces several challenges. In what follows, the authors will focus on the challenges in HetNets using femtocells.

III. CHALLENGES IN FEMTOCELLS

There are numerous challenges that have been identified in femtocells. In this chapter, the authors focus on self-organization, intercell interference, and economic potentials. These challenges cover two fundamental but different perspectives, technologic and economic, of the femtocells.

3.1. Self-Organization

Self-organization is a key component of heterogeneous networks. As the authors mentioned previously, the deployment of femtocells in HetNets is likely to be conducted by users themselves without planning. Additionally, the ability for the service provider to organize and control the deployed cells may be limited by 1) the scalability in network size, and 2) the low QoS provided by the backhaul connection. An improperly deployed and configured femtocell may eventually lead to poor performance due to severe intercell interference and load unbalance among cells.

3.2. Intercell Interference

Intercell interference takes place when femtocells operate in a licensed spectrum and their coverage overlaps with other base stations in the same spectrum, as shown in Fig. 1. Intercell interference poses a great technical challenge to the deployment of co-channel femtocells. This issue becomes more challenging than in traditional cellular networks because 1) unplanned deployment and limited control from the service provider makes the centralized-optimization solution in traditional networks impractical, 2) self-organization feature provided by the femtocells may tend to optimize their own performance instead of the overall network performance, such as always operating in CSG mode even it still has unused resource for other MSs, and 3) dynamic deployment from the users make the environment and network deployment changes more frequently and therefore a fast-response mechanism is required to dynamically conduct the interference mitigation.

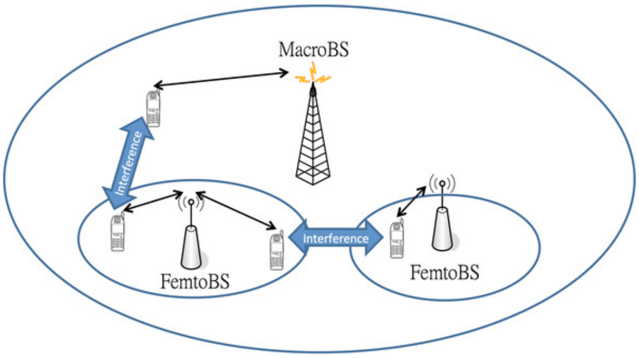

Figure 1. An illustration of various interference scenarios in heterogeneous networks

3.3. Economic Potentials

One of the main reasons to introduce femtocell is to reduce the deployment cost of the service provider when implementing the next-generation wireless networks. Therefore, it is necessary to analyze if femtocells indeed are profitable to the service provider by considering both the deployment cost and the added value to the service. The value addition of femtocells mainly comes from the enhanced service quality, such as higher throughput, lower delay, and less congestions and blocking probability. These performance improvements under the femtocell technique should be evaluated in advance before introducing such techniques. Additionally, these objective metrics need to be translated into the subjective valuation from users. Users may be heterogeneous with different environments, preferences, and requirements for the wireless service. How these users will behave is an important topic to investigate.

IV. GAME THEORY

Game theory is a powerful tool applied to model and to analyze the outcome of interactions among multiple decision-makers. A traditional game consists of three basic elements: players, strategies, and utilities. Players are the participants and decision makers in the game. They can take some predefined actions to affect the interaction with other players and make influence on the final game result. Players are individual decision makers - given specified information (game rules, state of the system, applied actions of other players, etc) of the game, they apply strategies to decide the actions (reactions) taken in the game. Given a strategy profile which describes the strategies applied by each player, the game will produce a corresponding outcome.

Utility functions, as quantified evaluations to the outcomes of a game, map the outcomes into real-value spaces. A player's evaluation of the outcome is given by a utility function. Since different game strategies may bring out different outcomes, the authors can see the element of utility as a function of a strategy evaluation.

In most cases, the authors assume that all players are rational. Thus, they tend to adopt strategy that can maximize their utility. In such games, every player is trying to maximize their own utility. If the players refuse to collude with each other, the game can be modeled as a non-cooperative game, and players compete with each other's directly. For the case that players may cooperate with each other, the authors model it as a cooperative game, where players may form groups (coalitions) in order to gain advantages in the competition. A cooperative game is suitable for describing specific application such as admission control and cluster formation, where coalitions naturally forms in such systems. Nevertheless, due to space limitation, the authors focus on non-cooperative game approaches in this chapter as it is popularly applied in HetNet issues.

In most game models, the purpose of the theoretic analysis is to find out the equilibrium, namely, the most likely produced outcome of a steady state in the system. Under the framework of a game theory, the behavior and interactions of players can be properly modeled. For researchers in communication areas, game theory is very useful to analyze problems involving interactions among elements in the system, the resource allocation problem particularly.

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4.1. Interference Mitigation

Intercell interference is one of the most challenging issue in HetNets. Without a proper interference mitigation technique, the service quality of macrocells in HetNets will be harmed by the interference from pico/femtocells, as illustrated in Fig. 1. Due to the limitation on the control ability of the service provider on the femtocells and the scalability issue, self-organized and distributed interference mitigation techniques are required. The interference mitigation is a classic issue and has been studied by researchers using various game-theoretic approaches, such as strategic game (Chandrasekhar, Andrews, Muharemovic, Shen & Gatherer, 2009), potential game (Mustika,Yamamoto, Murata, & Yoshida, 2011), Bayesian game (He, Debbah & Altman, 2010), and Stackelberg game (Guruacharya, Niyato, Kim & Hossain, 2013). The authors will introduce each of them in the following paragraphs.

4.2. Strategic Game

Strategic game is a type of games that all players behave simultaneously with perfect knowledge on other players' possible actions. Specifically, suppose that there is a game that involves two or more players, in which each player is assumed to know the actions of the other players. All players choose their actions simultaneously, and then the outcome of the game is also settled. In such a case, a rational player should predict what actions other players will choose before she chooses her action.The expected outcome of the game can be found through finding the Nash equilibrium. Let's assume that there exists an action profile that after each player has chosen her action accordingly, no player can increase her utility from changing her action when other players' actions remain unchanged. If such an action profile is applied, no players have the incentive to deviate from the applied action since the deviation gives her equal or less utility. When the above conditions are met, the action profile constitutes a Nash equilibrium.

Femtocells can be considered as the players in the strategic game, while their actions are their applied transmission power, occupied resources, or other operations that will potentially influence the service quality of other cells. Then, a femtocell's utility can be defined as the service quality, such as the throughput or delay time, experienced by UEs in the cell. An example is illustrated in Fig. 2, where multiple femtoBSs are determining their transmission power. Given other femtocell's transmission power, a femtocell may have her optimal transmission power that maximizes her utility. In such an approach, the authors would like to identify the stable outcome of the game, that is, the Nash equilibrium in the HetNet. Strategic game approach is straight forwarding, but the results may not be appealing: the Nash equilibrium can be an inefficient outcome comparing to the optimal solution due to the competitive effect in strategic game. Some regulation designs, such as penalties on the femtocells, may be necessary to improve the system performance.

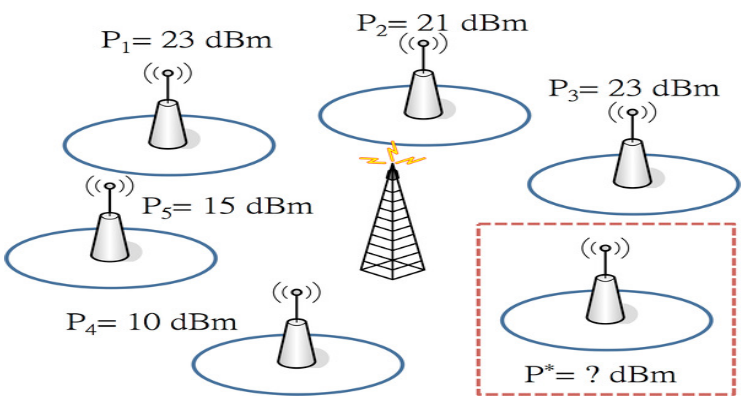


Figure 2. A strategic game approach to heterogeneous networks

4.2.1 Potential Game

Potential game is another popular game model, especially in power control problem. It is a special type of strategic game: In such a game, the incentive of any player in the game to change their actions can be expressed in a global function called the potential function. Specifically, there exists a function taking the applied actions of all players in the game as inputs. Whenever a player changes her actions and has some utility increase/decrease, the output of the function increase/decreases in the same direction or with the same amount. It has been proved that the set of pure Nash equilibrium in a potential game can be found by simply locating the local optima of the potential function. Additionally, a distributed iterative update algorithm in a potential game always converges to a Nash equilibrium. This reduces the complexity to implement the Nash equilibrium. Potential game is one of the ideal approaches to HetNets since it guarantees a distributed iterative update algorithm will always converge to a stable Nash equilibrium, which is desirable for self-organized femtocells. Nevertheless, it requires a global potential function, which may not exist in a general HetNets. The convergence speed is also a concern when the deployment is dynamic.

4.3. Bayesian Game

Bayesian game is a game model with uncertainty in the type of players. In a typical Bayesian game, at least one player is unsure of the type (and so the payoff function) of another player. Players have initial beliefs about the type of each player and can update their beliefs according to Bayes' Rule in the game. When the information of the system is incomplete, i.e., the channel gains of femtocell users are unknown, an appropriate choice of game models is Bayesian game, in which a belief on the unknown information is introduced. Notice that the performance of the system does not necessary degrade in Bayesian game comparing to complete information game. Incomplete information sometimes results in less fierce competition and therefore prevent performance degradation. Nevertheless, the challenges in Bayesian game is correctly identifying and learning the distribution of the unknown information, such as the channel quality distributions. An incorrectly constructed distribution usually leads to the sub-optimal operations in the system.

4.4. Stackelberg Game

Stackelberg game is a sequential game specifically for the systems with hierarchical structure. In a Stackelberg game, two types of players, leaders and followers, are defined. In the game process, the leader should apply or announce her action first. Then, the followers response to the leader's action accordingly. Since all players are rational, the followers should choose their actions that maximize their own utility. By using this insight, the leader can predict the rational responses of the followers if she chooses certain actions. The leader then can choose her action that maximize her own utility based on her analysis on the rational response of the followers.

Stackelberg game is ideal for HetNets consists of both macrocell and femtocells. The leaders, which should be macrocells in HetNets, have the advantages to apply their actions wisely before the followers, which are the femtocells in HetNets (Fig. 3). By strategically determining their applied action, the macrocells can lead the game to their desired outcome when they have enough information to predict the response of the femtocells in HetNets. This reflects the control ability of macrocells on the operations of femtcoells, such as the penalty on undesired interference. Nevertheless, the requirements to fully understand the response of femtocells given any possible action of macrocell in Stackelberg game may be impractical when the HetNet is complex. In such a case, learning techniques, such as reinforcement learning, could be applied to help macrocell find her best strategy in the Stackelberg game.

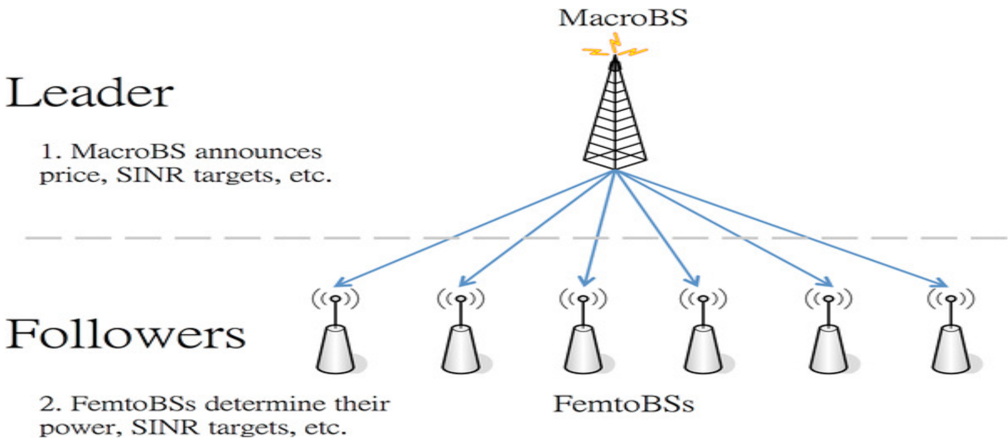


Figure 3. Stackelberg game approach to heterogeneous networks

Stackelberg game is popularly applied in hybrid-access system due to the natural leader–follower relation between macrocell and femtocell services. Yi et al. (2012) consider the case that two service providers construct a HetNet: one holds the traditional macrocell service, while the other is operating pico/femtocell service. They assume that the system is in split-spectrum mode and the macrocell service provider has the license of all operating spectrum. Therefore, the femtocell service provider needs to rent from the macrocell service provider in order to provide the service. They formulate the system as a three-stage Stackelberg game and show that under such a game structure, the equilibrium will be a win-win situation: the macrocell service provider will lease the spectrum to the femtocell service, while the femtocell service providers will run its service in hybrid-access mode.

V. SE FOR THE PROPOSED GAME

The SE is defined as the best response where a hierarchy of actions exists between players [5]. It is generally considered the same as a sub-game Nash equilibrium (NE) [6], which is defined as the outcome of the game in which no player has any incentive to deviate from his chosen strategy after considering the other players' choices. In our proposed game, it can easily be seen that the HeNBs strictly compete in a non-cooperative way. Therefore a non-cooperative bandwidth allocation sub-game can be formulated at the HeNBs' side. At the MeNB's side, since there is only one player, the best response of the MeNB is immediately obtained by solving the problem in max $U_{MeNB.}$

In our proposed Stackelberg game, to obtain both best responses, backward induction [10] is applied assuming that all players can reliably predict each other's behaviour. More precisely, for a given N_i, the problem in max U_i is solved first. Then, with the obtained best response function b_i* of the HeNBs, we solve the problem in max U_{MeNB} for the optimal value N∗ i . To solve the problem in max U_i ,we verify the NE existence of the sub-game at the HeNBs' side by proving the convexity of the utility function UHeNB on bi and N_i. Then, we deduce the optimal solution b_i* by solving the Karush–Kuhn–Tucker (KKT) conditions. Hence, we form the Lagrangian for the HeNBs as

$$L(N_i, b_i, \lambda_i) = r_i b_i - \frac{A b_i}{1+N_i} b_i - \lambda_i \left(\sum_{i=1}^{F} b_i - B \right) \qquad (1)$$

Where λ_i is the Lagrange multiplier. The second derivative of the former Lagrangian on both bi and N_i is given by

$$\begin{cases} \dfrac{\partial^2 L(N_i, b_i, \lambda_i)}{\partial b_i^2} = -\dfrac{2A}{1+N_i} < 0 \\ \dfrac{\partial^2 L(N_i, b_i, \lambda_i)}{\partial N_i^2} = -\dfrac{2A b_i^2 (1+N_i)}{(1+N_i)^4} < 0 \end{cases} \qquad (2)$$

This proves the convexity of the problem in (1) and thus, the existence of the NE for the sub-game at the HeNBs's side. For a convex optimisation problem, the optimal solution bi* must satisfy the KKT conditions. Therefore the optimal solution bi* is obtained as follows

$$b_i \frac{\partial L(N_i, b_i, \lambda_i)}{\partial b_i} = 0 \Leftrightarrow b_i\left(r_i - \frac{2Ab_i}{1+N_i} - \lambda_i\right) = 0$$

Thus, the best response of a given HeNB i is equal to

$$b_i^* = \left(\frac{(r_i - \lambda_i)(1+N_i)}{2A}\right)^+ \qquad \text{(3)}$$

where (x)+ = max{x,0}.

Similarly and as we apply the backward induction, we compute the second derivative of the utility function UMeNB(N_i, b_i*) on N_i as follows

$$\frac{\partial^2 U_{\text{MeNB}}(N_i, b_i^*)}{\partial N_i^2} = -Cw_i(w_i - 1)\left(\frac{r_i - \lambda_i}{2A}\right)^2 \times \left(\frac{(r_i - \lambda_i)(1+N_i)}{2A}\right)^{w_i - 2} \qquad \text{(4)}$$

This second derivative being strictly negative, the utility function is thus convex on N_i and the NE of the sub-game at the MeNB side exists. The best response of the MeNB is therefore deduced by solving the following equation

$$\frac{\partial U_{\text{MeNB}}(N_i, b_i^*)}{\partial N_i} = 0 \qquad \text{(5)}$$

Hence, the best response of the MeNB is given by

$$N_i^* = \frac{2A}{(r_i - \lambda_i)} \sqrt[w_i - 1]{\frac{r_i - \lambda_i}{2Cw_i}} - 1 \qquad \text{(6)}$$

Now, the proposed Stackelberg game for the spectrum sharing between MeNB and HeNB is completely solved.

VI. ALGORITHM DESIGN

Based on the above analysis, we develop the bandwidth sharing algorithm as follows. In the first step, each HeNB i measures the total spectral efficiency r_i of the femto-users in its coverage area using (2), and estimates the degradation that may cause to the MeNB, specifically the factor wi. The parameters b_i, N_i and λ_i are also initialised in this step. In the second step, we update the Lagrange multiplier λ_i, the number Ni of the victim macro-users that can possibly be served by a HeNB i, and the allocated bandwidth bi to the HeNB i consecutively. Fig. 2 gives more details about the steps of the proposed algorithm. The convergence of such process is guaranteed as each iteration strictly increases the objective function, and because the Lagrange multiplier is associated to a sub-gradient method [11]. Finally, the system performance metrics are deduced in order to evaluate our proposed Stackelberg game.

Algorithm
For $i = 1, \ldots, F$
Initialisation
Initialise $r_i, w_i, b_i, N_i, \lambda_i$
$\varepsilon = 0;\ t = 2;\ \alpha = 0.02$
Updating of the parameters
while $b_i(t) - b_i(t-1) > \varepsilon$ **do**
Update the Lagrange multiplier λ_i

$$\lambda_i(t+1) = \max\left\{0, \lambda_i(t) + \alpha \frac{\partial L(N_i, b_i, \lambda_i)}{\partial \lambda_i}\right\} = \max\left\{0, \lambda_i(t) + \alpha\left[B - \sum_{i=1}^{F} b_i(t)\right]\right\}$$

Update N_i *at the MeNB*

$$N_i(t+1) = \frac{2A}{r_i - \lambda_i(t+1)} \sqrt[w_i-1]{\frac{r_i - \lambda_i(t+1)}{2Cw_i}} - 1$$

Update b_i *at the HeNB i*

$$b_i(t+1) = \left(\frac{(r_i - \lambda_i(t+1))(1 + N_i(t+1))}{2A}, 0\right)^{+}$$

$t = t+1$
end while
end for

VII. NUMERICAL RESULTS

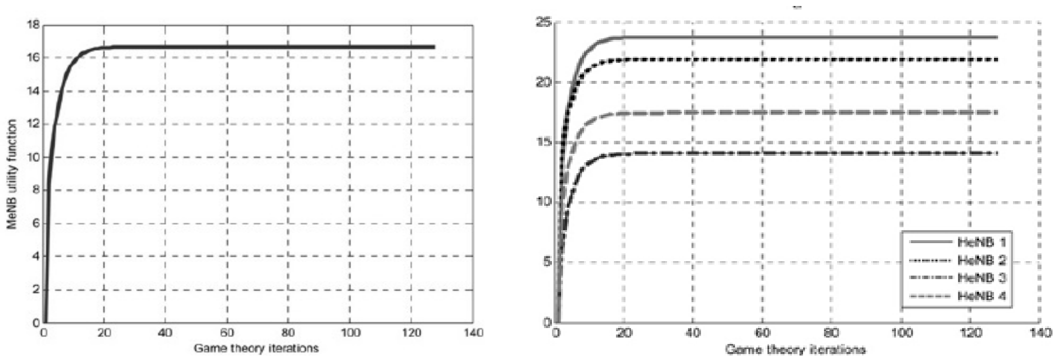
7.1 Convergence of the proposed Stackelberg game

In this section, we consider a snapshot in which a MeNB coexists with 4 HeNBs randomly distributed in the macrocell area. Each HeNB i serves three femto-users (Ii =3 for all i) and is surrounded by five macro-users (Mi = 5 for all i). Other system parameters are summarised in Table 1. Figs. 3a and b depict the evolution of MeNB's and all HeNBs' utility functions against the proposed Stackelberg game iterations, respectively. We observe that these utility functions converge to stable states after almost 20 iterations, which verifies the convergence to a SE. Similarly, during the game iterations, the total bandwidths allocated to all HeNBs increase until they reach the highest possible level as shown in Fig. 4. We note that the convergence is

Table 1 Simulation parameters [18]

Parameter	Value
total available bandwidth B, MHz	20
cell radius of the macrocell R_M, m	500
cell radius of the femtocell R_F, m	10
pathloss at the macrocell L_{macro}, dB	$137.4 + 37\log(d)$; d in kilometre
pathloss at the femtocell L_{femto}, dB	$38.5 + 20\log(d) + w_{ex}$; d in metre; $w_{ex} = 0$ for a femto-user and $w_{ex} =$ 15 dB for a served victim macro-user
total transmit power P_M at the MeNB, W	40
total transmit power P_F at the HeNB, mW	125
thermal noise level, dBm/Hz	−174

obtained after almost 20 iterations as in the previous figures. In practice, this convergence should be as quick as possible, so that bandwidth allocation decisions can be made within a scheduling time unit. We also verify that at the end of the proposed Stackelberg game, the total allocated bandwidth to all HeNBs is equal to the total available bandwidth B at the MeNB, which verifies the constraint expressed in (7).



(a) (b)

Fig. 3 MeNB's and HeNBs' utility functions convergence

(a) MeNB utility function against game theoretic iterations

(b) HeNBs' utility functions against game theoretic iterations

VIII. CONCLUSION

HetNets as a promising solution to increase capacity and coverage in next-generation wireless communications. Nevertheless, due to the unplanned deployment and distributed operating characteristics, several challenges exist in the deployment and configuration of HetNets. Game theory, which is a pothe authorsrful tool for studying distributed systems with self-interest players, has the potential to resolve most difficult challenges in HetNets. In this paper, we have proposed a new Stackelberg game for a better spectrum sharing between MeNB and HeNBs in a HetNet. We have proved that this game has built a win–win relationship between the two entities as each of them improves the quality of service of its attached users. In fact, with the proposed Stackelberg game, the MeNB can load off and switch some macro-users, who experience strong inter-tier interference, to the nearest HeNB which will apply a CRE. The spectral efficiency of these macro-users has increased considerably especially if they are far from the MeNB. Similarly, the HeNBs can share a large bandwidth with the MeNB and improve their total achieved throughputs, as long as they respect the inter-tier interference constraint and serve a large number of victim macro-users.

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