LTE-A SHARING RELATIONSHIP IN MACROCELL AND FEMTOCELLS FOR SPECTRUM

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Abstract: Heterogeneous networks (HetNets) are likely to provide a ubiquitous access to the mobile broadband services as they involve various small cells, each targeting a different environment in the network. However, the application of the advanced resource allocation techniques is highly needed in order to handle the inter-cell interference and fully exploit the benefits of such networks. 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. It is formulated as 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 neighboring femtocells. By demonstrating the 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.

Key words: HetNet, picocells, long term evolution (LTE)

1 INTRODUCTION

1.1 Background

In order to further improve the performance of long term evolution (LTE)-Advanced system, 3rd Generation Partnership Project (3GPP) has recently introduced an advanced network topology based on Heterogeneous Networks (HetNet) [1]. A HetNet, also known as small cell network, is a network that involves a diverse set of short-range and low-power base stations, such as microcells, picocells, relays or femtocells, all distributed inside a macrocell. This new network topology has the advantage of providing a flexible deployment pattern in a cost-effective way. In fact, the different nodes are economical and have various capabilities as they target different environments in the network. Operators no longer need to deploy additional macrocells usually hard to install in more and denser urban areas [1]. Consequently, the system radio capacity as well as the network coverage can be largely improved thanks to the emerging HetNets. Subscribers can in the future benefit from ubiquitous access to mobile broadband services. However, an inevitable increase of inter-tier and intra-tier interferences is expected, and the application of new methods for interference coordination and radio resource allocation between the different entities is much needed. In this paper, we consider a HetNet including a macrocell with a centric macro-eNodeB (MeNB) coexisting with different femtocells which are deployed to ensure a reliable coverage inside buildings and enhance the data rates for users in indoor environments. Each femtocells is covered by a Home-eNodeB (HeNB). Since both MeNB and HeNB can operate on the same frequency bandwidth, significant inter-tier interference may occur. Especially, macro-users, who are served by the MeNB and are in the vicinity of the HeNBs, experience strong downlink interference from these HeNBs.

1.2 Related work

In order to mitigate the inter-tier interference between the MeNB and the HeNBs many frequency-domain approaches have brought solutions based on fractional frequency reuse. In [4], the authors proposed an adaptive fractional frequency reuse scheme between the MeNB and the HeNBs using the formation of an interference graph. In [5], a dynamic resource partitioning has also been proposed, in which HeNBs are denied access to frequencies that are assigned to nearby macro-users. In this way, the interference to the macrocells is effectively controlled, although this results in certain degradation in femtocell capacity. In fact, these solutions, based on a non-overlapping bandwidth sharing, may reduce t he available spectrum for both MeNB and HeNBs. Indeed, an instrument is used to better study the complex interactions among independent players (or entities) in order to optimize the setting of various elements of the network . As HetNet's network topology is better prepared for a hierarchical game, the aforementioned studies have formulated their approaches as Stackelberg games where the leader is the MeNB and the followers are the HeNBs. Stackelberg game was intensively used to address the power control problem In [6], the authors also proposed a price-based power control scheme using Stackelberg game. The leader manages to minimise the sum of interference generated by the HeNBs by pricing for their power consumptions while respecting the quality of service requirements of the femto-users. The authors demonstrate that an optimal price can be found and is unique, whereas, the optimal transmit powers of the HeNBs are obtained through iterative water-filling. In [7], the authors observes operator first determines spectrum allocations and pricings of femtocell and macrocell services, then heterogeneous users choose between the two services and the amount of resource to request. In [8], the authors proposed a spectrum leasing framework. The femtocell service provider (FSP) expects to rent spectrum from the coexisting macrocell service provider (MSP) in order to serve its femto-users, and the FSP may allow hybrid access to the macro-users. The authors sought to motivate both MSP and FSP by solving the optimal spectrum leasing and open access ratios. In [9], the authors proposed a reimbursement mechanism where the wireless service provider (WSP) provides certain refunding to motivate HeNBs to open their resource to macro-users. HeNBs decide the resource allocation among femto and macro-users according to the amount of refunding WSP offers. It should also be pointed out that other kinds of games theoretic were proposed to deal with power control or bandwidth sharing for HetNets in the presence of femtocell.In this paper, we propose a Stackelberg game as it better exploits the hierarchical architecture of this type of network.

In this paper, we propose a new deal between the MeNB and the HeNBs. As the HeNBs seek to enhance the femto-users' data rates, they are expected to demand more and more bandwidth to share with the MeNB. However, the transmission on the same frequency bandwidth will cause a harmful interference to the macro-users in the vicinity of these HeNBs (referred to throughout this paper as victim macro-users). In order to avoid the degradation of the service quality for these macro-users, the MeNB will ask the HeNBs to serve some of the victim macro-users by applying a cell range expansion (CRE).We also prove the convergence of the proposed Stackelberg game analytically and by means of simulations.

2 SYSTEM MODEL

We consider the downlink of an LTE-Advanced HetNet environment as illustrated in Fig. 1. The HetNet is composed of one MeNB centered in the cell area and which serves the whole macrocell as one sector, and F femtocells uniformly distributed in the macrocell area. Each femtocell is covered by one HeNB. We assume that the macrocell is integrated in a network of 19 hexagonal macrocells. The macrocell and the femtocell have a coverage radius of RM and RF, respectively, (RF < < RM). Similarly, the MeNB and the HeNBs have a total transmit power PM and PF, respectively, (PF < < PM).

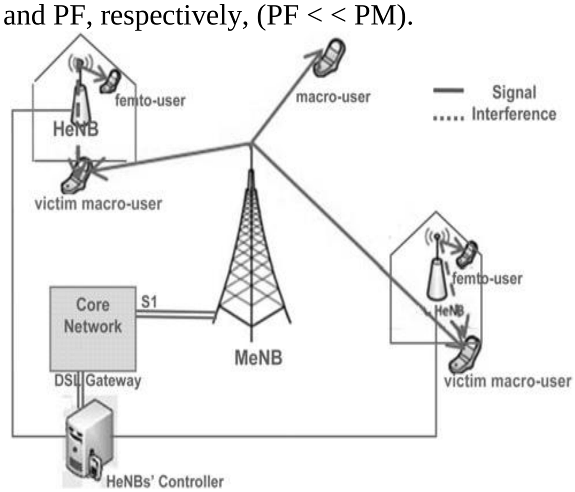

Fig. 1 System layout

We also assume that the MeNB and the HeNB exchange their information on the S1 interface through the core network and a DSL Gateway as shown in Fig. 1. Another alternative, which consists of establishing a direct air interface between the MeNB and the HeNBs, could also be considered to ensure this exchange as suggested in [9]. Each HeNB i serves Ii femto-users uniformly distributed in the femtocell and operates in hybrid access mode (which enables it to serve some macro-users in its vicinity). All femtocells offer Continuous Bit Rate applications to their femto-users in order to fully utilise the allocated bandwidth. We assume that each femtocell i is surrounded by Mi macro-users. As shown in Fig. 1, these victim macro-users experience strong downlink inter-tier interference since the HeNBs partially share the spectrum with the MeNB. Another kind of inter-tier interference also exists in this system and consists of macrocell-to-femtocell interference. In fact, as the MeNB transmits higher power than the HeNB, the femto-user quality of service can also be damaged. In our paper, we deal with femtocell-to-macrocell interference problem, as we consider that the femtocells are deployed mainly to improve the indoor coverage of the system and to help offload the macrocell. On the other hand, intra-tier interference between the different femtocells can affect the quality of service of femto-users. In our work, the bandwidths are allocated to the HeNB in a non-overlapping way so that intra-tier interference between the femtocells is avoided.

3 PROBLEM FORMULATION

The aim of our study is to provide a high data rate for the femto-users inside a given femtocell without harming the macro-users' quality of service in the vicinity of this femtocell. On the contrary, we attempt to guarantee better data traffic to the macro-users who suffer from high inter-tier interference. In fact, the MeNB will take full advantage of the presence of additional 4G transmitters, the HeNBs, to offload and handoff some victim macro-users to the nearby HeNB which will apply a CRE. To achieve this aim, we formulate our approach as a Stackelberg game. Stackelberg game is a strategic game that consists of a leader and a follower competing with each other on certain quantities qL and qF (respectively, for the leader and the follower) [5]. The leader moves first and the follower moves sequentially. The leader imposes a price per unit on the follower. Then, the followers update their strategies to maximise their net utility based on the leader's price. Both players compete on their quantities in order to maximise their profits. The profit of each player is expressed as the player's revenue minus the cost [5]. Revenue can be the product of price and quantity and cost is given by the player's loss or expense [5]. In our proposed Stackelberg game, the leader is the MeNB and the HeNBs are the followers. The MeNB sells a portion of bandwidth to the HeNB in exchange of some victim macro-users to serve. More precisely, a HeNB i is allowed to transmit on some part of the total available bandwidth simultaneously with the MeNB in order to improve its serving femto-users data rates. In return, this HeNB will apply a CRE and serve some victim macro-users in its surrounding area. Both MeNB and HeNBs' objectives lie in maximising their utilities under the constraint of interference level in the system, especially the inter-tier interference. In fact, as we consider a non-overlapping bandwidth allocation between the HeNBs, the intra-tier interference is avoided. Let bi be the allocated bandwidth to the HeNB i, and Ni the number of the nearby victim macro-users that will be served by this HeNB i when applying a CRE (Ni <Mi). The parameters bi and Ni are the respective quantities qF and qL of the followers HeNB and the leader MeNB to compete on. This price is proportional to the allocated bandwidth bi and inversely proportional to the number Ni of victim macro-users that can be served by the HeNB i. The more bandwidth the HeNB requires to fulfil its femto-users applications' needs, the higher the price is (as it will cause higher inter-tier interference). Conversely, the more victim macro-users a HeNB i can serve to help avoid inter-tier interference and enhance their quality of service, the lower the price is. On the other hand, the term Cbwi i represents the cost that the MeNB endures. In fact, each allocated portion bi of the total available bandwidth at the MeNB to a given HeNB i will cause a certain inter-tier interference to the macro-users within the macrocell. The factor wi differs from one HeNB to another as the impact (in terms of inter-tier interference) varies according to the corresponding HeNB I position and the propagation conditions. Then, the optimisation problem for the MeNB can be formulated as max UMeNB (6) Consequently, the higher the bandwidth bi allocated to the

HeBN i is, the higher the total femto-users' throughput within this femtocell can be achieved, with respect to a given cost. The latter is equal to ((Abi)/(1 + Ni))bi for each HeNB i. In other words, it is equal to the price that the follower HeNB should pay to the leader MeNB multiplied by the follower's quantity which is the bandwidth allocated to this HeNB. Note that the constraint given in the (7) reflects the condition that no overlapping bandwidth allocation is permitted to femtocells, in order to avoid intra-tier interference. Therefore the maximisation problem of each HeNB i is given by max Ui (8) subject to _F i=1bi ≤ B 4 SE for the proposed game 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.

4 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 ri 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 bi, Ni and λi are also initialised in this step. In the second step, we update the Lagrange multiplier λi, 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 [17]. Finally, the system performance metrics are deduced in order to evaluate our proposed Stackelberg game.

5 NUMERICAL RESULTS

5.1 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)

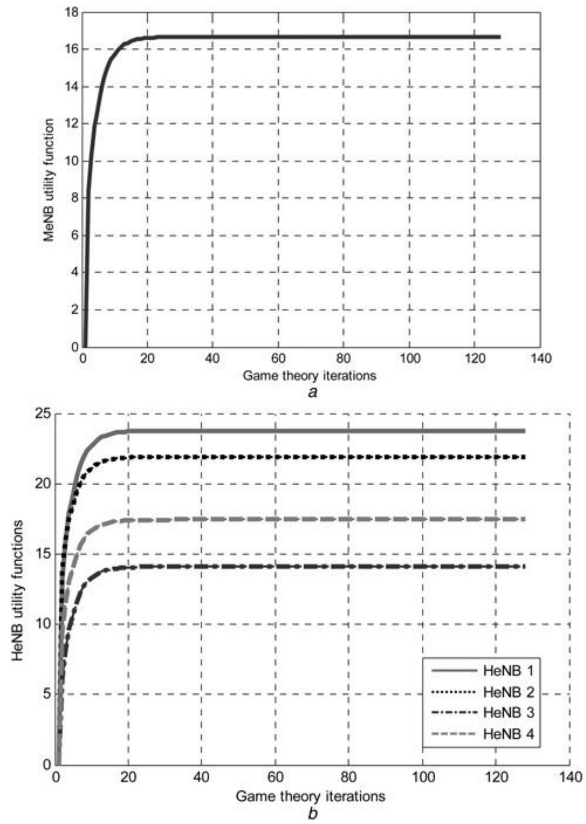

Fig. 3 MeNB's and HeNBs' utility functions convergence
a MeNB utility function against game theoretic iterations
b HeNBs' utility functions against game theoretic iterations

Figs. 3a and b depict the evolution n 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 The allocated bandwidth to the HeNBs not only depends on the constraint expressed in (7) but also depends on the bandwidths' price that HeNBs pay to the MeNB in terms of serving a certain number of victim macro-users. In fact, each HeNB attempts to increase its allocated bandwidth in order to enhance the total achieved throughput of its attached femto-users. However, to be able to do so, it has to serve an important number of victim macrocells in its vicinity; otherwise the price of the shared bandwidth will be high. However, if the cost measured at the MeNB in terms of inter-cell interference level is important, and the HeNB is not able to serve the victim macro-users, the MeNB had better not share a large bandwidth with the HeNB. Table 2 shows the number of victim macro-users served by each HeNB at the end of the proposed Stackelberg game thanks to the CRE procedure.

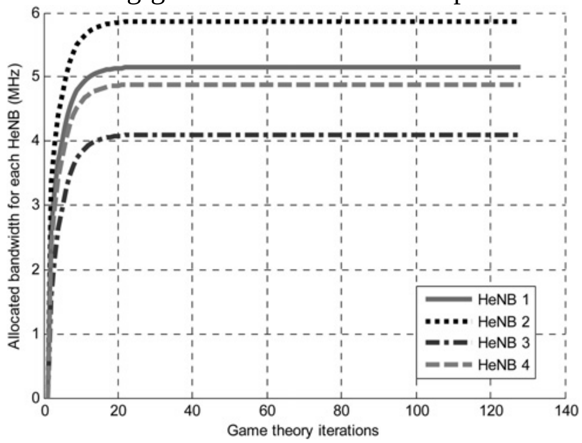

Fig. 4 HeNBs' allocated bandwidth convergence

It shows that the HeNB number 2, which was allocated the largest bandwidth (Fig. 4), is serving five victim macro-users. On the other hand, HeNB number 3 shares the lowest bandwidth with the MeNB and serves two victim macro-users only. Note also that, although HeNBs number 1 and 2 serve five victim macro-users, HeNB number 1 obtains less bandwidth than HeNB number 2. This is owing to the inter-tier interference constraint caused in the network.

5.2 Impact on the system performance

In this section, we consider the same snapshot of the previous section. We evaluate the effectiveness of our proposed Stackelberg game in terms of achieved total femto-users throughputs and spectral efficiency of the victim macro-users served by the nearby HeNBs. More precisely, this total achieved throughput only includes the achieved throughput of all former femto-users within each HeNB (i.e. the victim macro-users newly served by a given HeNB are not considered). Average spectral efficiency of the victim macro-users arround each HeNB throughput in the case a bandwidth of 1 MHz is allocated to each HeNB, to the case we apply the proposed Stackelberg game. As the HeNBs can improve their allocated bandwidth with regard to an equal bandwidth allocation scheme, these HeNBs can noticeably enhance their total achieved throughput (from 53 to 120%) assuming that this bandwidth is uniformly distributed among the serving femto-users.

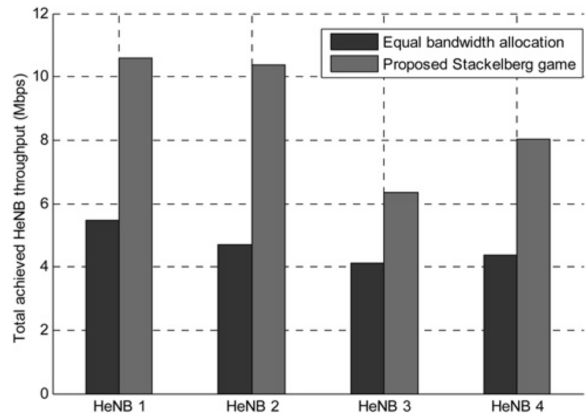

Fig. 5 Average spectral efficiency of the victim macro-users arround each HeNB

Besides, the spectral efficiency of victim macro-users who are served by the nearby HeNBs is considerably enhanced as compared with spectral efficiency when these macro-users are attached to the MeN. Each macro-user in this figure represents the victim macro-users in the vicinity of the corresponding HeNB. This spectral efficiency improvement (around ten times) is in fact owing to the closeness to these HeNBs as compared with the MeNB in the considered Impact of the HeNB position in the macrocell In this section, we examine the impact of the position of the HeNB on the performance of the proposed Stackelberg game. The achieved total throughput per HeNB is the sum of the achieved throughputs of initial femto-users inside the different femtocells.In fact, as we evaluate the impact of the proposed Stackelberg game on the HeNBs' performance, we compare this obtained performance metric to the one in case the HeNBs are commonly allocated equal bandwidth and do not apply any CRE. Fig. 8 shows that with an adaptive bandwidth allocation using the proposed Stackelbeg game, the HeNBs can achieve a better total femto-users' throughput. For instance, this improvement can reach 25% when ten HeNBs coexist in the macrocell. This is due to the fact that the HeNBs can negotiate the amount of the allocated bandwidth according to the inter-tier interference level. On Fig. 6 Total achieved femto-users' throughput for each HeNB Fig. 7 Average served victim macro-user and average allocated bandwidth per HeNB according to the HeNB positions Fig. 6 Average achieved throughput per HeNB against the number of HeNBs in the macrocell the other hand, it is clear that the more HeNBs in the macrocell, the less the average achieved total throughput per HeNB, as each HeNB obtains less bandwidth. Fig. 7 illustrates the average number of victim macro-users served per HeNB against the number of HeNBs in the macrocell of reference. We observe that the number of victim macro-users served per HeNB decreases with the number of HeNBs in the macrocell. This is indeed correlated to the bandwidth allocated to the HeNBs as shown previously. If the HeNB is allocated a large bandwidth, it can serve a high number of victim macro-users; otherwise, it has no interest in doing so.

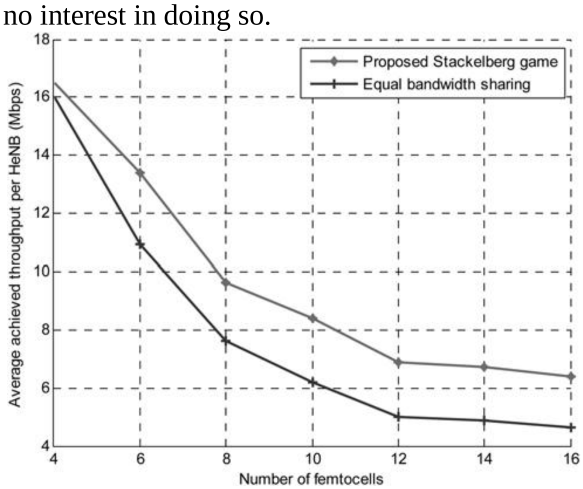

Fig. 6 Average achieved throughput per HeNB against the number of HeNBs in the macrocell

However, since the number of HeNBs rises, the allocated bandwidths obtains smaller as mentioned above. However, when the macrocell comprises many HeNBs, the MeNB can achieve a more macro-users' offloading.

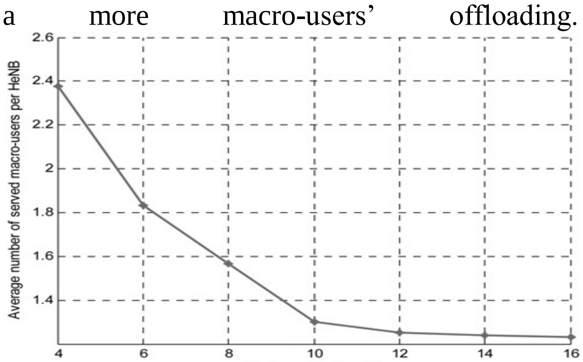

Fig. 7 Average number of served victim macro-user per HeNB against the number of HeNBs in the macrocell

In fact, according to the Fig. 7, HeNBs in the macrocell, the total number of served victim macro-users is about 12, whereas with 16 HeNBs, this number Therefore according to both Figs. 6 and 7, the proposed Stackelberg game reveals a win–win relationship between the MeNB and the HeNBs, which can reciprocally take advantage of this new spectrum sharing trade is around 20.

7 CONCLUSION

In this paper, we have proposed a new Stackelberg game for abetter 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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