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# Cell Selection Game in Heterogeneous Macro-Small Cell Networks

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**Abstract**—Heterogeneous networks (HetNets) which include macrocells with short range small cells proved a better coverage and higher user data rates compared to classical networks. Using the same spectrum as the macrocells, small cells would allow increased spatial reuse of bandwidth. In industrialized countries, the deployment of new small cells by another actor (tier) to cover the outage improves the service with a lower cost. In this paper, we investigate cell association issue in heterogeneous networks composed of small and macrocells operating in the same spectrum. In contrast to the related work, we consider that the small cells are a cellular network belonging to another tier. Hence, there is competitiveness between the two tiers in order to selfishly maximize the gain while respecting the User Equipment (UE) Quality of Service (QoS) requirements. We propose a model based on game theory in order to get the best distribution of user equipments among small and macro base stations.

## I. INTRODUCTION

The increasing number of mobile subscribers and the growth to unprecedented levels of exchanged wireless data require more and more resources. To deal with this growing demand, the Mobile Network Operators (MNOs) investigate many tracks such as small cells deployment to offload the macrocells and to improve the quality of service at cell edge where the performance can substantially degrade. In order to reduce the cost of deployments, MNOs investigate to reuse existing infrastructure belonging to other industrial tiers (i.e urban furniture such as bus stop shelters or street lights). These tiers, contribute in the enhancement of the traditional network infrastructure by providing resources like sites, power, etc. This new business model raises an open issue on how to distribute traffic between macrocells and these small cells, in order to reduce costs and possibly share revenues.

The deployment of small cells, by some of these tiers, characterized with a reduced transmission range is also being considered as an important option for MNOs. We get a two-tier network with high power macrocells in combination with low-power small cells deployed in white outed zones and at the edge of the macrocell coverage (Figure 1).

The deployment of small cell networks in a given area is a very promising technique as it would provide a huge capacity gain and bring small base stations (S-BS) closer to mobile devices.

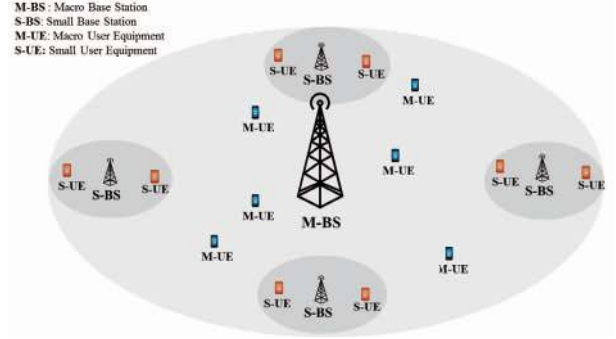


Fig. 1. Small-Macro cells heterogeneous network architecture

One challenge for small cells, though, is that due to their weaker signals (lower transmission powers, antennas with smaller antenna gains), the coverage area tends to be significantly reduced and the incremental benefit of deploying each small cell is limited.

The power heterogeneity increases the complexity of the network planning since the cell selection is usually based on received signal strength and the UE is associated to the Base Station (BS) that provides the highest signal [1]. This selection scheme based on Reference Signal Received Power (RSRP) is used in Long Term Evolution (LTE) single-tier networks [2]. However, in HetNets, this criterion is no longer applicable due to the disproportion of transmission power. The max Signal to Interference plus Noise Ratio (SINR) based cell association strategy in the case of HetNets affects the load balancing and does not guarantee the required performance in terms of spectral efficiency.

We propose in this paper a cell selection scheme based on traffic transfer strategy in order to get an uniform distribution through different cells while maintaining the QoS level required by users and maximizes the spectral efficiency. We use game theory as a mathematical tool to study the cell selection issue. We consider a non cooperative game and we investigate the Nash Equilibrium to analyze the interaction of users, small cells and macrocells. The objective is to maximize the Quality of Experience (QoE) of users on one hand thanks to small

cells, and to control the distribution between macrocells and small cells for MNOs.

The remainder of this paper is organized as follows: we present in Section II some related works, then describe the network architecture, the game formulation model and its solution in Section III. Section IV is dedicated to the simulation results. Finally, we conclude the paper and give some perspectives of this work in Section V.

## II. RELATED WORK

There are many research works that highlight the cell selection issue in HetNets.

Two kinds of small cells can be considered. In most of the cases, small cells behave exactly in the same way than macrocells, but have lower transmission power; both belong to MNOs; a special care on interference management has to be taken because they operate on shared coverage but it is achieved by MNOs. In the context of shared infrastructure, small cells are femtocells [3] that belong to tiers partners; special mechanisms for auto-configuration are embedded there, but end-users are still authenticated in the MNOs core network in order to integrate smoothly tiered-party resources in MNOs networks. Authors in [4] classified access strategies in the femtocells networks into: (i) *Closed access*: Only registered users to a small cell have access to it, (ii) *Open access*: Users do not need an extra authorization to get access to small cells, (iii) *Hybrid access*: Small cells are mainly destined to their subscribers but normal users can have access under some conditions. This article discussed the problems and solutions of every mechanism. The major problem of closed access is cross-tier interference whereas the issue of open access is the large number of handovers. Therefore, it proposed the hybrid access to get the advantages of the closed and open access and get rid of their problems.

[5] investigated the spectrum allocation and the access issue in two-tiers networks. This study proved that in sparse networks, joint sub-channel allocation provides the highest throughput with both closed and open access schemes. Whereas in dense femtocells networks, the first scheme's throughput is higher when it is used with disjoint sub-channel allocation but the latter provides the best throughput with the joint allocation.

[6] classified selection schemes into *Strategies based on channel borrowing from lightly-loaded cells* and *Strategies based on traffic transfer to lightly loaded cells*. They proposed a load-aware scheme based on traffic transfer. They proved, through a distributed algorithm which converges to a beforehand defined theoretical upper bound on performance, that simple per-tier biasing factors introduced to small BSs in accordance to their transmit powers reach the optimal load-aware performance.

[7] studied Cognitive Radio Resource Management (CRRM) and game theory in order to mitigate respectively cross-tier and intra-tier interference in femtocell networks. [8] also used game theory based algorithm to reduce the power consumption by the Cognitive Users.

[9] performed a qualitative comparison among different distributed selection schemes namely Reference Signal Received Power (RSRP) [2], (Reference Signal Received Quality)RSRQ [2], Bias-Based Cell Range Expansion (CRE) [10], [6], and Association Based on Almost Blank Sub-frame (ABS) Ratio [11].

The comparison takes in consideration the instantaneous knowledge of the available channel, the interference and the traffic load, the available resource and the users' priority. It shows that the standard cell association schemes (RSRP, RSRQ) are not resource, priority and traffic load-aware. CRE is better than RSRP and RSRQ as it considers the load balancing and the most efficient scheme among those listed above is the ABS Ratio. Its objective is to maximize the rate and balance the traffic load in the network.

Most of these cited works consider macrocell networks overlaid by femtocells that belong to the MNOs. In the proposed approach, we consider that the small cells are a cellular network belonging to another tier. Hence, there is competitiveness between the two network tiers in order to selfishly maximize the gain while respecting the UE QoS requirements.

We consider the open access strategy. The small cell is considered as a macrocell with lower power by users. Small cells' range is higher than femtocells so that we avoid the problem of handovers. The cross-tier interference is also mitigated with the disjoint sub-channel allocation between small and macrocells. The disjoint allocation is only used between small and macrocells but users within the same cell share the available spectrum.

## III. NETWORK ARCHITECTURE AND MODEL DESCRIPTIONS

We present in this Section the small-macro cells network architecture that we considered during the simulation and we explain the theoretical modal based on Game Theory and Nash Equilibrium used to study the interactions between the network tiers.

### A. Network architecture

The network architecture we consider in this work is illustrated in Figure 2. We consider the downlink of an heterogeneous network where multiple small cells are added in the edge of every macrocell of the conventional macro radio access network.

We consider that it is a two-tier OFDMA-based network with a two frequency reuse models for the macrocells and the small cells. We assume that there is a prior convention between the two tiers: we divide the entire available spectrum into sub-bands. Each sub-band is assigned to a BS to mitigate the cross-tiers interference. The convention allows the small cells network to use openly the spectrum but it limits the maximum users number that can be associated to each S-BS in order to guarantee the required quality of service. The income of the small cell network depends on the total number of user equipments that it serves and in the total number of

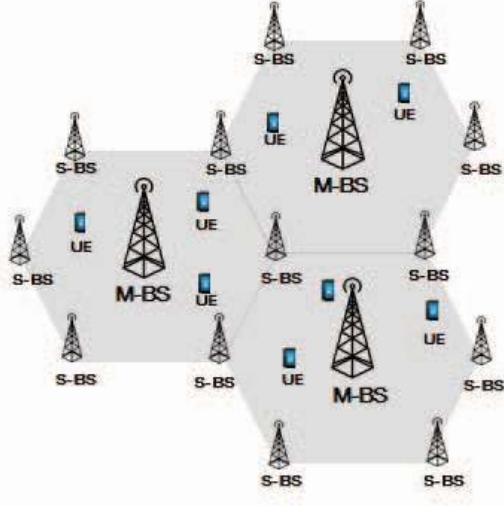


Fig. 2. Hexagonal Network Layout

user equipments associated to the whole network. The gain of the tier network will reach its maximum in the load time where the number of communicating UEs increases.

### B. Cell selection game model

This Section is dedicated to the theoretical model that we proposed to find a suitable selection scheme in the small-macro network. Game theory is widely used in wireless communications and networking [12]. It is a suitable mathematical tool to study the interactions between different tiers in heterogeneous networks.

1) *Game formulation:* We consider that a UE at the time  $t$  is close enough to a S-BS but it receives a good SINR from the closest M-BS as well. We assume that there is a QoS threshold defined beforehand that lets the S-BS delegates the UE to the best closet M-BS even if that reduces its income.

Therefore, we consider a non cooperative game with two players: the User Equipment UE and the BS. Each player has two different strategies. It selfishly chooses the strategy that ensures him the higher payoff while respecting the QoS conditions.

Thus, we assume two utility functions: (i) The BS's utility function that depends on the price of a served user at a time  $t$ . This price varies according to the variation of the total number of served users, and (ii) The utility function of an UE is based on the capacity of the link with its selected BS.

The two pure strategies of the UE player are:

- 1) *Strategy 1:* Select S-BS.
- 2) *Strategy 2:* Select M-BS.

And the two pure strategies of the BS player are:

- 1) *Strategy 1:* The S-BS serves the UE. The UE associated to the small cell is called Small UE (S-UE).
- 2) *Strategy 2:* The M-BS serves the UE. The UE associated to the macrocell is called macro UE (M-UE).

TABLE I  
MATRIX GAME

BS \ UE	S-BS serves the UE	M-BS serves the UE	
Select S-BS	$(X_{11}, Y_{11})$	$(X_{12}, Y_{12})$	p
Select M-BS	$(X_{21}, Y_{21})$	$(X_{22}, Y_{22})$	1-p
	q	1-q	

The matrix game is presented in the following Table I.

If a M-BS decides that the S-BS serves the UE, then it will maximize the income of this latter, and it will increase the price of the next UE that it will serve. But it will deprive the UE of selecting the M-BS that has a higher SINR. That may endure a quicker handover and an eventual degradation in the Quality of the Communication.

Payoffs of different strategies of the two players are listed below:

- $X_{11} = C_S(t) + G_{US}(t)$
- $Y_{11} = P_S(t)$
- $X_{12} = C_M(t)$
- $Y_{12} = \frac{P_M(t)}{2}$
- $X_{21} = C_S(t)$
- $Y_{21} = \frac{P_S(t)}{2}$
- $X_{22} = C_M(t) + G_{UM}(t)$
- $Y_{22} = P_M(t)$

where we have:

- $C_S(t)$  is the normalized link capacity when the UE is associated to the small cell.

$$C_S(t) = \frac{W_S(t) \log_2(1 + SINR_S)}{\max(C_S(t))}$$

where  $W_S(t)$  is the used bandwidth and  $SINR_S$  is SINR of the S-BS,

- $C_M(t)$  is the normalized link capacity when the UE is associated to the macrocell.

$$C_M(t) = \frac{W_M(t) \log_2(1 + SINR_M)}{\max(C_M(t))}$$

where  $W_M(t)$  is the used bandwidth and  $SINR_M$  is SINR of the S-BS,

- $G_{US}(t)$  is the UE's gain when it selects the S-BS.

$$G_{US}(t) = \frac{W_A}{W_T} + \frac{W_S(t) \log_2(1 + SINR_S)}{\max(C_S(t))}$$

while  $W_A$  is the available sub-band,  $W_T$  is the total sub-band and  $SINR_S$  is the SINR of the S-BS,

- $G_{UM}(t)$  is the user gain when it selects the M-BS.

$$G_{UM}(t) = \frac{W_A}{W_T} + \frac{W_S(t) \log_2(1 + SINR_M)}{\max(C_M(t))}$$

while  $SINR_M$  is the SINR of the M-BS,

- $P_S(t)$  is the price of the service provided by the S-BS to a UE at time  $t$ .

$$P_S(t) = \frac{P_{US} \times N_{US}}{N_T}$$

such as  $P_{US}$  is the unit price fixed for the S-BS,  $N_{US}$  is the total number of users served by the small cells network and  $N_T$  is the total number of users served by the whole network,

- $P_M(t)$  is the price of the service provided by the macro BS to a UE at time  $t$ .

$$P_M(t) = \frac{P_{UM} \times N_{UM}}{N_T}$$

such as  $P_{UM}$  is the unit price,  $N_{UM}$  is the total number of users served by the macrocells network and  $N_T$  is the total number of users served by the whole network.

2) *Equilibrium Determination*: Nash Equilibrium represents the solution for all players in non-cooperative games. The equilibrium strategy of a player ensures the best payoff. Hence, in the equilibrium, no player has interest to change its strategy. We have the following strategy combinations:

- *Connect to the S-BS & S-BS serves the UE*: In this strategy combination, the UE is very close to the S-BS and the signal of the S-BS is stronger than the nearest M-BS. At the same time, the S-BS strategy is to serve this UE because of the limited number of UEs that it can serve is not reached. In this case the UE and the BS have the same strategy. Hence, the UE benefits from a gain GUS,
- *Connect to the S-BS & M-BS serves the UE*: The UE in this case is close to the S-BS, but this latter cannot serve it because the permitted UEs number that it is allowed to serve is reached. The S-BS receives the request of the UE but redirects it to the closet M-BS that offers the best service,
- *Connect to the M-BS & S-BS serves the UE*: In this case the UE selects the M-BS as it provides the best signal strength, but this latter cannot serve it because the maximum number of UEs that it can serve is reached, or because there is a close S-BS that can serve it. So, the M-BS redirects it to the S-BS in order to balance the load and provide a better QoS to the served UEs. This use-case can occur in load time,
- *Connect to the M-BS & M-BS serves the UE*: In this strategy combination, the UE selects the M-BS. The M-BS strategy is to serve because it is load off time or there is not an available small cell around that can serve it. In this case the UE and the BS have the same strategy hence the UE has a gain  $G_{UM}$ .

A mixed strategy Nash equilibrium is based on probability distribution over the set of available player's actions. For

example, if we have  $n$  available actions for each player  $i$ , then its mixed strategy will be  $n$  dimensional vector  $(p_{i1}, p_{i2}, \dots, p_{in})$  such as  $p_{ik} \geq 0$  and  $\sum_{k=1}^n p_{ik} = 1$ .

In our situation, we have  $n = 2$ . According to Nash equilibrium theory, there is a mixed strategy where *player1* (*strategy1*,  $p^*$ ) and *player2* (*strategy1*,  $q^*$ ) do not have interest to change their actions. We are looking for this equilibrium state where the UE and the BS keep the same strategies.

### Theorem

There is a mixed strategy Nash Equilibrium *UE* (*connects to S-BS*,  $p^*$ ), *BS* (*S-BS serves the UE*,  $q^*$ ) where the UE selects the S-BS if the probability  $p > p^*$  and the BS's action is S-BS serves the UE if  $q > q^*$ .

### Proof

The mixed strategy of the UE is defined as  $Q = (q, 1 - q)$  and the payoffs of the BS are

- 1)  $P_{BS}(\text{S-BS serves the UE}) = p \times Y_{11} + (1 - p) \times Y_{21}$
- 2)  $P_{BS}(\text{M-BS serves the UE}) = p \times Y_{12} + (1 - p) \times Y_{22}$

The BS will choose the strategy *S-BS serves the UE* when  $P_{BS}(\text{S-BS serves the UE})$  is greater than  $P_{BS}(\text{M-BS serves the UE}) \Rightarrow p > p^*$ .

$$p^* = \frac{2 \times P_M(t) - P_S(t)}{P_M(t) + P_S(t)}$$

such as  $0 < p^* \leq 1$ .

The mixed strategy of the BS is defined as:  $P = (p, 1 - p)$  and the payoffs of the UE with the related actions are:

- 1)  $P_{UE}(\text{Select S-BS}) = q \times X_{11} + (1 - q) \times X_{12}$
- 2)  $P_{UE}(\text{Select M-BS}) = q \times X_{21} + (1 - q) \times X_{22}$

The UE will select the S-BS when  $P_{UE}(\text{select S-BS})$  is greater than  $P_{UE}(\text{select M-BS}) \Rightarrow q > q^*$ .

$$q^* = \frac{G_{UM}(t)}{G_{UM}(t) + G_{US}(t)}$$

with  $0 < q^* \leq 1$ .

In conclusion, if  $p > p^*$  and  $q > q^*$ , UE and BS will not change their strategies.

## IV. SIMULATION RESULTS AND ANALYSIS

We evaluate the model performance via various scenarios using Matlab which is a powerful tool to analyze cellular networks. We consider an hexagonal network layout consisting of a serving M-BS with a transmission power  $P_t = 40W$  surrounded by 3 circles of M-BS. Each M-BS is overlaid by S-BS with a transmission power  $P_t = 2W$ . We consider a cluster size  $C = 3$  for macrocells and  $C = 2$  for small cells.

The simulation parameters are summarized in Table II.



TABLE II  
SIMULATION PARAMETERS

Number of M-BS	64
Number of S-BS per Macrocell	12
M-BS Range	5km
S-BS Range	0.4km
Reuse Factor for M-BS	1/3
Reuse Factor for S-BS	1/2
M-BS Transmission Power	40W
S-BS Transmission Power	2W
Frequency band	2.6 GHz

#### A. Probability convergence

In this section, we simulate with Matlab the performance of the proposed model and we investigate the evolution of  $(p^*, q^*)$  according to the variation of the UEs number. As indicated before,  $p^*$  represents the optimal probability of the BS when it decides that the S-BS serves the UE. Figure 3 shows the evolution of  $p^*$  within the increase of the total number of UEs associated to the network. We notice that  $p^*$  is increasing slightly until the network is half loaded. When the UEs number reaches the half of the capacity of the network,  $p^*$  exceeds 0.5 and it raises significantly until reaching its maximum (0.75) when the network is fully loaded. In load-off time, the M-BS accepts most of received requests as the required QoS can be respected. However, in the beginning of a load time, the BS player changes the strategy and decides that S-BS serves the new requests to balance the load.

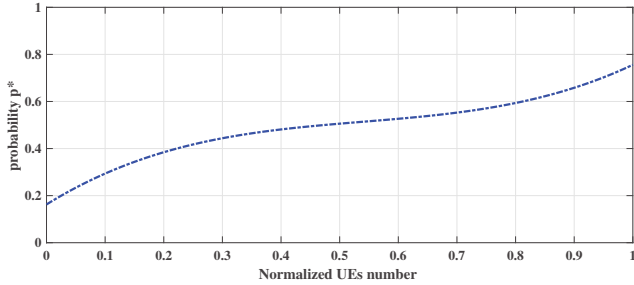


Fig. 3. Variation of  $p^*$  along with UEs number

On the other hand, Figure 4 shows the behavior of  $q^*$  within the raise of the requests on the network.  $q^*$  represents the optimal probability of *UE selects the S-BS* strategy. When the network is less than 20% charged,  $q^*$  is around 0.5. In this case, the S-BS as well as the M-BS offer the required QoS to the UE. In the simulation, we have supposed that the served UE is aware of the BS resources, it can use all the available spectrum in the S-BS and only a part of the M-BS available spectrum. So, in the load off time, it does not have preferences. But when the number of UEs associated to the S-BS raises,  $q^*$  decreases slightly until it reaches the minimum when the network is fully charged. As the UE looks forward to maximizing its throughput, when it notices that the number of UEs associated to its best S-BS, it tends to select the M-BS

in order to get a higher throughput.

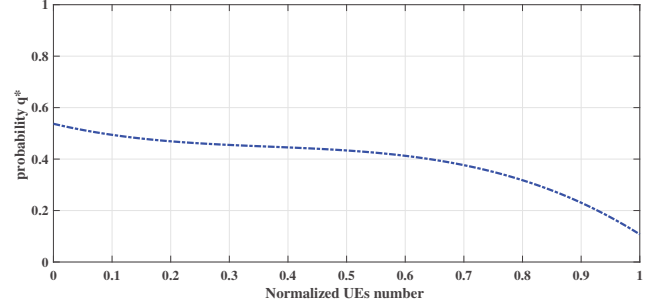


Fig. 4. Variation of  $q^*$  versus UEs number

#### B. User equipments distribution

Figure 5 presents the load of the S-BS network compared to the overall load. As mentioned in the previous section, in the loaded time, the global network strategy tends to associate UEs to the S-BS and in the off load time, the selection strategy that we describe in details in Section IV-C evenly distribute customers. That is what explains the load balancing in Figure 5 where we note that the percentage of S-BS UEs from the overall number of UEs associated to the network is proportional to the capacity of S-BS network compared to the whole network capacity.

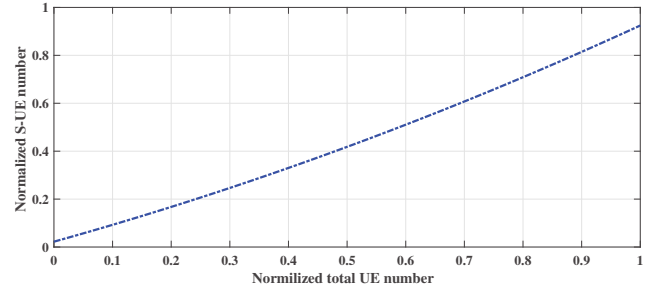


Fig. 5. Percentage of S-UE from the total UE number

#### C. Spectral efficiency

In this section, we study the average spectral efficiency. As mentioned before, we consider in this simulation that the UE attached to the S-BS benefits from the whole available spectrum and with the arrival of a new UE, its dedicated bandwidth will be shared instantly with the new customer. However, in the M-BS, it benefits from a percentage that varies within the requests rate. We suppose that the percentage of the available spectrum dedicated to a new UE decreases with the raise of the service requests, where the arrival rate is more important in order to mitigate the fluctuation and the sudden decrease of the throughput. We have implemented here two different association schemes and resources use between macrocells and small cells because M-BS has a more important

arrival rate compared to S-BS. In Figure 6, which shows the spectral efficiency per UE per cell for both macrocells and small cells, we notice that the spectral efficiency of the S-BS is higher than that of the M-UE when the network is not charged. In this phase, the UE of a S-BS has a higher throughput and the S-BS resources use is optimized. With the raise of the network load, the spectral efficiency of the M-BS approaches that of S-BS then exceeds it. In this phase the resources use of M-BS becomes optimum.

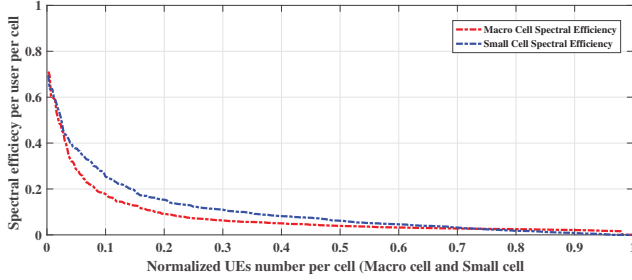


Fig. 6. M-UE and S-UE Spectral Efficiency

## V. CONCLUSION

In small-macro cell networks with disjoint spectrum subbands, we can avoid co-tiers interference but we encounter another problem which is the disproportion in transmission power and cell selection. We have proposed, in this paper, the game theory as a mathematical tool to obtain a spectrum aware selection scheme based on frequency reuse that realizes an equilibrium in the UEs distribution and maximizes the UE's throughput and the network's two tiers' gain. In future work we intend to test an hybrid solution, using frequency reuse and power control approach.

## ACKNOWLEDGMENT

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