A Coalitional Game for Femtocell Clustering in OFDMA Macro-femtocell Networks

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***Abstract*—In this paper, we tackle the problem of resource management in macro-femtocell networks. Dense deployment of femtocells imposes several challenges for a cluster-based resource allocation. Some of those challenges are the trade-off between the level of offloaded traffic from macrocell and bandwidth allocated to femto-tier, the fair distribution of resources, and the mitigation of inter-cluster interference. To overcome these limitations, we propose a coalitional game to form clusters of femtocells that can reduce the resource allocation complexity. Stable clusters are formed based on the core model. Our proposal mainly consists of three components. Namely, a femtocell selection for public users, a coalitional game where cooperative femtocells are rewarded, and a Weighted Water Filling algorithm to allocate resources. Our solution is performed under a rewarding model, which is based on an ideal spectral efficiency and on an effective spectral efficiency. We compare the results of our rewarding model with a non-cooperative model, where femtocells work in closed access mode. Simulation results demonstrate that our proposal improves the femto-tier throughput and the satisfaction of femtocells subscribers.**

I. Introduction

As data traffic demand increases due to new applications and ubiquitous mobile devices, the cellular network looks for solutions to cope with these challenges. Among the possible solutions, femtocells (FCs) have been deployed in the macrocell coverage to accommodate the vast demands.

In a macro-femtocell network, the mobile users are classified as public users (PU) and FC subscribers (SU). Public users can be served by macrocell or femtocells with open or hybrid access policies. FC subscribers should be connected to their own FCs when they are located in their coverage area. Femtocell subscribers have prioriy over the public users. FC access policies offer new ways to connect PUs to the network in order to improve their spectral efficiency and reduce the co-tier interference in a two-tier network. Femtocells can work under three types of access policies: closed, open and hybrid [1]. Femtocells in closed access mode have a fixed number of SUs, which are provided with privacy and full benefits from their FC owner. Open access policy allows femtocells to provide service to nearby PUs. However, although the macrocell load is reduced with the open access policy, there must be a rigorous control of resources in order to satisfy the FC subscribers. Thus, hybrid access policy is proposed to keep some reserved resources for SUs and reserved resources for nearby PUs [2]. As a result so far, hybrid access policy deals with closed and open access challenges since subscribers resources are guaranteed and interference caused by nearby PUs is reduced.

In the literature, several cooperation mechanisms have been investigated to improve the macro-femtocell network performance. In [3], a Stackelberg game is formulated between macrocell and femtocells to jointly study the utility maximization of the macro base station (MBS) and femtocell users. Authors propose a price-based resource allocation scheme for femtocell users, in which its transmit power is controlled by the MBS. The work in [4] proposes a distributed algorithm for coalition formation among femtocells and for intra-tier interference control. Authors in [5] formulate a coalition formation game to solve the subchannel allocation problem. They assume that FCs work in hybrid access scheme, and find the stability of the coalition structure using the recursive core. In [6], authors propose a centralized power control algorithm for dense femtocell networks based on predicted signal-to-interference-plus-noise ratio (SINR). In addition, the clustering of femtocells is considered in order to reduce the computational complexity by controlling the power per femtocell within each cluster. To the best of our knowledge, there is no existing work that encourages FCs to cooperate (i.e. granting access to public users and forming cluster) by rewarding them with extra resources from the macrocell.

In the context of resource allocation, some approaches tackle only the bandwidth optimization as in [7], or the power optimization depending on the air interface technology of the network [8]. The works in [9], [10] propose to jointly optimize the bandwidth and power only in the femtocell network by maximizing the femtocells throughput. In [11], authors propose a resource allocation model taking into account users demand and location. The model jointly allocates bandwidth and power together with base station selection considering noises. However, the main drawback of this model is the high running time required to find the optimal solution. In [12], a genetic algorithm is proposed to speed up the optimization process of resource allocation under realistic scenarios with user mobility and resource reservation.

Clustering techniques are considered to alleviate the resource allocation problem by allocating resources per cluster, and to reduce the co-tier interference. For example, in [13], a cluster-based resource management that considers quality of service (QoS) requirements is proposed. This work establishes priorities between macrocell and femtocell users, where femtocell subscribers have higher priority than the macrocell users close to FCs. In [14], authors propose a semi-distributed clustering algorithm to manage interference and resource allocation. A femto gateway is responsible for the clustering while the cluster head allocates resources within each cluster. Authors in [15] formulate a femtocell clustering algorithm by rewarding cooperative femtocells. Although, authors consider the available capacity of FC clusters (in terms of number of users and resources) for the clustering formation, clusters stability is not addressed. In [16], a frequency allocation scheme along with interference management is proposed for macro-femtocell and micro-femtocell network. The network is partitioned into clusters, each cluster is allocated with a macrocell or several microcells, namely a macro-femtocell cluster and a micro-femtocell cluster. Unlike these works, we tackle the resource allocation problem by forming stable femtocells' clusters based on a rewarding method and on the core model of the game theory.

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In this paper, we propose a model based on coalitional game theory that consists of: (i) a femtocell selection for public users, (ii) a femtocell cluster formation algorithm and (iii) a resource allocation algorithm. In order to encourage FCs to cooperate, we propose a model to reward cooperative FCs, assuming an ideal spectral efficiency (ISE-RM) or an effective spectral efficiency (ESE-RM). Furthermore, we apply a core model to determine the stability of the resulting coalitions.

The rest of this paper is organized as follows: in Section II we describe the system model, the proposed coalitional game along with the core of the game, and the resource allocation algorithm. Simulation results are described in Section III. Finally, Section IV concludes the paper.

II. FC Clustering Model based on Coalitional Game

A. System Model

We consider a macro-femtocell network where femtocells and public users are deployed within the coverage area of the macrocell. We assume that stand-alone femtocells (SA-FCs) serve to one subscriber, while FCs in coalition grant service to PUs, as shown in Fig. 1. The set of available subcarriers is denoted as SC and is split among the femto-tier and macro-tier to avoid cross-tier interference. When FCs act in a non-cooperative mode, they use the closed access policy without granting service to PUs. SA-FCs may suffer interference due to other femtocells that attempt to access the same resources.

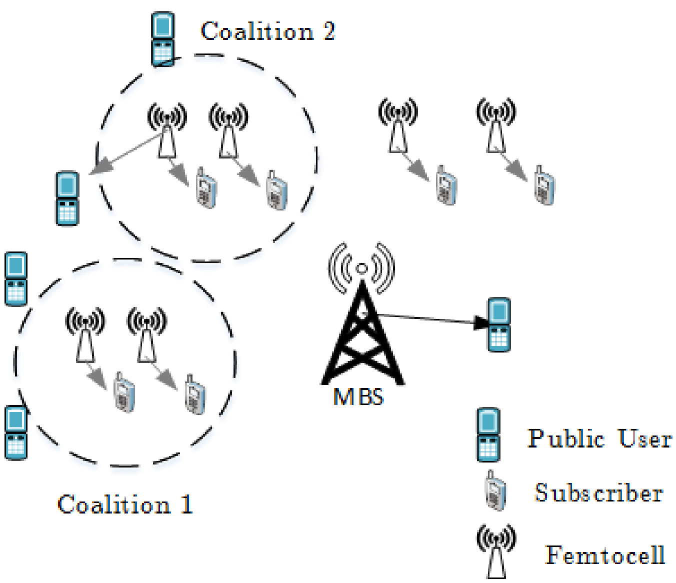

Fig. 1. Illustrative example of coalitions on a cellular network with femtocells and one subscriber per femtocell.

To improve the subscribers satisfaction and reduce the resource allocation complexity, we propose to form cooperative groups among FCs based on a coalitional game. Besides, we present a model to reward cooperative FCs. With the rewarding model each FC within a coalition receives extra-resources (i.e. extra-subcarriers). We consider that a cooperative femtocell is granting access to nearby PUs and forming clusters, while guaranteeing the satisfaction of their own SUs. In this regard, we assume that each FC is aware of their surrounding public users and the data rate they demand.

When resources are allocated to FCs within a coalition based on the ISE-RM model, femtocells are aware of the ideal spectral efficiency achieved by their subscribers. However, this spectral efficiency can improve towards an effective spectral efficiency by allocating extra-resources to cooperative FCs (i.e. using the ESE-RM model). Our FC clustering model based on coalitional game consists of three components: (i) femtocell selection for public users, (ii) coalition formation, and (iii) resource allocation for every FC within a coalition. These components are described below.

B. FC selection for Public User

The objective is to select the FC that can grant service to nearby PUs. All PUs near FCs are sorted in descending order based on their demanded data rate and their proximity towards the FCs. As FCs serve a maximum number of users, the allocation of PUs is made until the maximum capacity (in terms of number of connected users) per FC is achieved.

C. FC Coalition Formation Game

We formulate the coalitional game with transferable utility. This means that the revenue obtained per coalition can be distributed in an arbitrary manner to the members of the coalition. We propose an equal distribution method to allocate the payoffs to the coalition members. This method is based on the value of the coalition and on the size of each coalition, thus each coalition member receives the same amount of extra-resources.

Definition 1 - Game: A coalitional game with transferable utility is defined by a pair of $(\mathcal{N}, v)$ where $\mathcal{N} = \{FC\}$ is the set of players, which is basically the subset of available femtocells. Function v is defined for each coalition $C \subseteq \mathcal{N}, v(C)$, as a real number representing the utility that coalition C receives.

In order to determine the value of the coalition, we set a bandwidth for the coalitons as $BW_C = b \times B_S \times N_S$, where b is a value between $[0, 1]$ that indicates the portion of the available subcarriers used for the femto-tier. N_S and B_S represent the number of subcarriers available and the bandwidth per subcarrier, respectively. The value function is based on the bandwidth and size of the coalition if the demanded data rate per coalition is higher than the allocated bandwidth per coalition, otherwise is equal to the required bandwidth. The value function is defined as

$$v(C) = \begin{cases} \frac{|C| \times BW_C}{|\mathbb{C}| \times B_S} & ; \quad D_C > \frac{\gamma_f \times |C| \times BW_C}{|\mathbb{C}|} \\ \frac{D_C}{\gamma_f \times B_S} & ; \quad otherwise \end{cases} \tag{1}$$

where $|C|$ is the size of the coalition, $|\mathbb{C}|$ indicates the maximum size of the formed coalitions, D_C is the demanded data rate per coalition, and γ_f is the spectral efficiency for femtocells. We characterize the individual payoff of a cooperative FC as the equal distribution of the value of the coalition among the members of the coalition, as shown in Equation (2). Basically, the payoffs are the extra-subcarriers that FCs receive to improve the performance of their subscribers. The payoff for each femtocell is defined as

$$x_i(C) = \frac{v(C)}{(|C|)} \quad ; i \in C \tag{2}$$

The coalition formation algorithm finds the best coalitions of femtocells that grant service to PUs and increase their SUs satisfaction. First, disjoint coalitions are built with cooperative femtocells, once the PUs have been allocated to them. Then, the core concept is used to

Algorithm 1: COALITION FORMATION ALGORITHM

begin
  Initial state
  The network is partitioned by $\pi_n = 1, ..., N$ with non-cooperative FCs. All femtocells are in stand-alone mode, thus SA = FC. The available bandwidth for coalitions is BW_C.
  Coalition formation algorithm
  Neighbor discovery
  for *each* $f \in SA$ **do**
    Discover its close femtocells, based on proximity information.
    Make a list of neighboring FCs with the obtained information, $Neighbor^f$.
  end
  Coalition Formation
  for *each* $f \in SA$ **do**
    for *all the interfering* f *in the list* $Neighbor^f$ **do**
      Join each f with their neighboring femtocells into coalitions.
      Determine the value of each coalition using the Equation (1), and the payoff using the equal distribution method, as in (2).
      Each f joins into a final coalition that ensures the maximum payoff.
      The final coalitions are included in the core until converge to a stable coalition, $S_{coalitions}$.
    end
  end
  Resource Allocation
  for *each* f *in* $S_{coalitions}$ **do**
    Determine the set of users per coalition, public users and subscribers.
    Run the WWF algorithm for all the mobile users in the coalition.
  end
end

find stable coalitions, where FCs obtain the highest payoff. Algorithm 1 represents the coalition formation algorithm.

In order to obtain stable coalitions, we use the solution concept of game theory known as *core*. According to [17], the core is the strongest solution concept in cooperative game theory. It represents a set of payoff vectors where no subset of players could improve their current payoff by deviating and forming other coalitions.

Definition 2 - Core: A payoff vector x is in the core of a coalitional game (N,v) if and only if:

$$\sum_{i \in C} x_i \geq v(C), \forall C \in N$$

where x_i represents the payoff for each femtocell. If the core is nonempty, stable coalitions can be formed, since that no femtocell has an incentive to leave its current coalition and join another in order to obtain more resources.

We demonstrate the stability of the coalitions through a numerical example. Table I shows a number of possible coalitions, in which each coalition has a common member, namely the $FC1$. In order to analyze which coalition gives the highest benefit to $FC1$, let us consider the following situations:

- *Stand-alone femtocells*. The coalition $Cp1$ has a unique member, the $FC1$. In our proposal, only femtocells that decide to cooperate by forming coalitions are rewarded with extra-resources. Thus, the coalition $Cp1$ has a value of 0 subcarriers, and as a consequence $FC1$ is not rewarded.
- *Cooperative femtocells*. When $FC1$ cooperates, several coalitions can be formed, i.e. $Cp2$, $Cp3$, $Cp4$, and $Cp5$, as shown in Table I. However, according to our coalition formation algorithm, a femtocell joins to a coalition in which it obtains the highest benefit. Clearly, the best decision for $FC1$ is to join the coalition $Cp2$ as it gets a payoff of 21 subcarriers compared with a payoff of 0 subcarriers when it acts alone. Besides, $FC1$ receives a gain of 8 subcarriers.

TABLE I
NUMERICAL EXAMPLE

Possible coalitions	Value (SC)	FCs demand (SC)	FCs payoff (SC)
$Cp1$={FC1}	0	[13]	[0]
$Cp2$={FC1,FC2}	38	[13,13]	[21,21]
$Cp3$={FC1,FC3,FC8}	57	[13,12,9]	[20,20,20]
$Cp4$={FC1,FC6,FC7}	57	[13,17,13]	[20,20,20]
$Cp5$={FC1,FC7,FC8}	57	[13,13,13]	[20,20,20]

A coalition lies in the core of the game if the total payoff received by their members is higher or equal than its value. In our example, the total payoff for FCs within the coalition $C1$ is 42 subcarriers, which results from the sum of SUs payoffs and PUs payoffs, while the value of the coalition $C1$ is 38 (in terms of subcarriers). Accordingly, the sum of the payoffs is higher than the value of the coalition. This is the case for all the resulting coalitions of our proposal, thus demonstrating the stability of the coalitions, as shown in Table II.

TABLE II
RESULTING STABLE COALITIONS

Stable coalitions	Value (SC)	FCs demand (SC)	FCs payoff (SC)
$C1$={FC1,FC2}	38	[13,13]	[21,21]
$C2$={FC4,FC9}	38	[14,14]	[21,21]
$C3$={FC5,FC10}	38	[12,12]	[21,21]
$C4$={FC7,FC8}	38	[13,13]	[21,21]

D. WWF based Resource Allocation

In our proposal, we first obtain the available subcarriers for the femto-tier based on the demanded data rate per SU. The available subcarriers for femto-tier is defined as N_{s_f}, and the subcarriers for the macro-tier as $N_{s\_m} = N_s - N_{s\_f}$. According to our model a specific amount of the macrocell bandwidth (i.e. BW_C) is dedicated to the clusters formation, as metioned in the subsection II-C. Consequently, the total number of available subcarriers (N_s) is divided into macro-tier subcarriers (N_s_PU), and femto-tier subcarriers (BW_C and N_s_SU).

When the clusters are established, FCs receive information about their corresponding allocated bandwidth for public users (SC_PUf) and subscribers (SC_SUf). Specifically, SC_PUf are the subcarriers allocated to PUS served by FCs in coalition, and SC_PUf represent the extra-subcarriers received by FC subscribers, as shown in Fig. 2.

Finally, the WWF algorithm uses this distribution of the bandwidth to assign bandwidth (B_{MS}^f) and power (P_{MS}^f) to mobile users (MS). WWF algorithm is based on the bandwidth required per user ($b_i^{required}$) and their weighted demand (w_i^f). Note that, users may not reach the required demand, because the spectral efficiency taken into account in the coalitional game is not the effective one. However, if there is remaining resources, the users receive more subcarriers until the required demand is achieved, and the user satisfaction is improved. The WWF algorithm is presented in Algorithm 2.

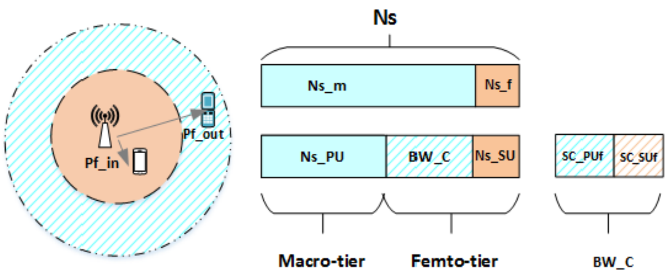

Fig. 2. Subcarriers allocation for PU and SU in coalition.

Algorithm 2: WWF ALGORITHM

Data: Bandwidth assigned to femto-tier (BW_C),
Set of users assigned to femtocell within a coalition (MS^C)
Result: Data Rate allocated per user (T_i^c). Bandwidth and power allocated per user (B_{MS}^f, P_{MS}^f).
begin
  Sort MS^f according to the bandwidth required divided by the total required bandwidth;
  while $i \in MS^C$ **do**
    $b_i^{wwf} \leftarrow \min\left(\frac{b_i^{required} - b_i^{k-1}}{w_i^f}, \frac{BW_C - \sum_{k=1}^{i-1}\sum_{j=k}^{MS^f} b_j}{\sum_{j=i}^{MS^f} w_j^f}\right);$
    for $j = i \rightarrow |MS^f|$ **do**
      while b_i *is not satisfied* **do**
        $b_j^k \leftarrow b_j^{k-1} + w_j^f b_i^{wwf};$
      end
    end
    $p_i^f \leftarrow \min\left(SNR_{th}^f N_0 PL_i^f, \max(P_{f\_in}, P_{f\_out})\right);$
  end
  Calculate the data rate using Shannon Law's Capaciy, T_i^c
end

III. SIMULATION RESULTS

Simulations were conducted under a macrocell area with a radius of 500 m within which 10 FCs are deployed. FCs are located in such a way that the distance among them is not greater than twice their radius. OFDMA physical layer assumptions are based on [18], while path loss is determined according to the 3GPP specifications [19]. System parameters configuration are described in Table III. We assume that a femtocell serves a maximum number of users, MS^f, by using the hybrid access policy since it can grant service to PUs and their own SUs. Two transmitted power levels are defined for users inside (P_{f_in}) and outside (P_{f_out}) the FC coverage, as shown in Fig. 2. The resulting coalitions are: $C_1 = \{FC1, FC2\}$, $C_2 = \{FC4, FC9\}$, $C_3 = \{FC5, FC10\}$, and $C_4 = \{FC7, FC8\}$, where each FC serves to one SU and a random number of nearby PUs. $FC3$ and $FC6$ decided not to join a coalition.

The performance of our proposal is shown in terms of throughput, interference, and satisfaction. The latter is the relation between the obtained data rate and the demanded data rate of a user. Furthermore, the results were obtained under two models: the non-cooperative (SA-FCs) model, and the cooperative model (ISE-RM, ESE-RM). The ISE-RM model intends to improve users satisfaction based on the required bandwidth, i.e. achieve the ideal spectral efficiency, while the ESE-RM model allocates more resources than the required ones until achieve an effective spectral efficiency.

TABLE III
SYSTEM PARAMETERS

Parameter	Description	Value
N_S	Number of Subcarriers	256
B_S	Bandwidth per Subcarrier	15 kHz
P_m^{Total}	Transmitted power per MC	60 dBm
P_f^{Total}	Transmitted power per FC	10 dBm
R_m, R_f	Macrocell and femtocell radius	500 m, 20 m
θ_f, θ_m	Attenuation factor of indoor and outdoor	3, 3.7
γ_m, γ_f	Spectral efficiency for MC and FC	(2, 4), 6
W_l	Wall loss penetration	-3 dB
f_c	Carrier frequency	2300 MHz
N_0	Noise	-174 dBm/Hz

A. Subscribers performance

In this subsection, we show the performance of subscribers in terms of allocated resources, satisfaction and throughput.

In Table IV, one can observe that the number of allocated subcarriers for SUs using SA-FCs and ISE-RM model is the same. This is owing to the fact that the allocated resources using the ISE-RM model is based on the ideal spectral efficiency. While, we notice that ESE-RM model allocates more resources to SUs than the ISE-RM model. In Table V, we see that the ESE-RM model improves the SUs satisfaction to an average of 100 %, which is due to the extra-resources allocated to FC subscribers.

TABLE IV
ALLOCATED SUBCARRIERS FOR SUBSCRIBERS (SC)

Coalition	SUs	SA-FCs	ISE-RM	ESE-RM
$C1$	SU1	5	5	10
	SU2	5	5	10
$C2$	SU4	5	5	9
	SU9	5	5	9
$C3$	SU5	5	5	10
	SU10	5	5	10
$C4$	SU7	5	5	10
	SU8	5	5	10

TABLE V
SATISFACTION PER SUBSCRIBER (%)

Coalition	SUs	SA-FCs	ISE-RM	ESE-RM
$C1$	SU1	65.65	72.42	100
	SU2	49.07	68.55	100
$C2$	SU4	39.74	62.83	97.93
	SU9	50.77	56.38	99.42
$C3$	SU5	66.49	71.98	100
	SU10	46.62	84.46	100
$C4$	SU7	62.88	79.62	100
	SU8	52.67	65.24	100

In Fig. 3, we present the throughput per SU. The throughput per SU improves for FCs in coalition using the models ISE-RM and ESE-RM. However, femtocell subscribers achieve twice the throughput with the ESE-RM model compared with the ISE-RM model, which is due to the extra-resources received by users until achieve an effective spectral efficiency.

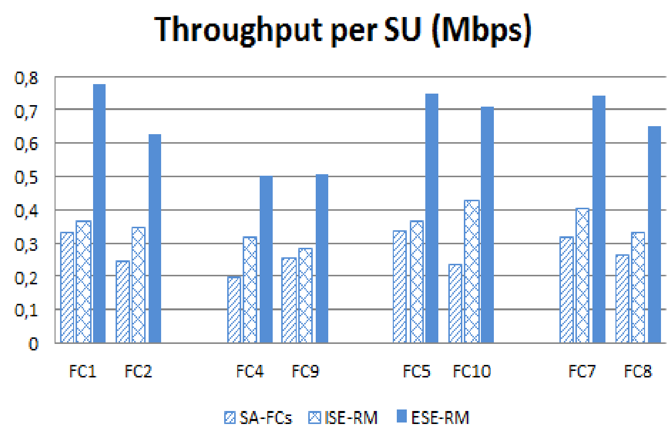

Fig. 3. Throughput per subscriber.

B. Public users performance

Table VI presents the allocated subcarriers for public users served by FCs in coalition. PUs receive a higher number of resources when the rewarding model is based on the effective spectral efficiency. As well, the maximum satisfaction for PUs is achieved with the ESE-RM model. On average, public users increase their satisfaction by 20 % with the ESE-RM model compared with the ISE-RM model, as can be seen in Table VII.

TABLE VI
ALLOCATED SUBCARRIERS FOR PUBLIC USERS (SC)

Coalition	PUs	ISE-RM	ESE-RM
$C1$	PU_FC1	7	12
	PU_FC2	7	8
$C2$	PU_FC4	5	8
	PU_FC9	8	9
$C3$	PU_FC5	5	6
	PU_FC10	6	9
$C4$	PU_FC7	7	8
	PU_FC8	1	9

TABLE VII
SATISFACTION PER PUBLIC USER (%)

Coalition	PUs	ISE-RM	ESE-RM
$C1$	PU_FC1	35.73	67.30
	PU_FC2	56.85	57.73
$C2$	PU_FC4	62.83	76.96
	PU_FC9	56.38	62.71
$C3$	PU_FC5	71.98	51.12
	PU_FC10	84.46	83.33
$C4$	PU_FC7	79.62	39.20
	PU_FC8	65.24	100

C. Femtocell performance

In Table VIII, we display the amount of allocated subcarriers for non-cooperative FCs and cooperative FCs. We notice that using the ISE-RM model, FCs receive twice the resources compared with the stand-alone mode. While, with the ESE-RM model, FCs receive four times more resources than acting alone. This is due to that ESE-RM model allocates resources until achieve the effective spectral efficiency.

TABLE VIII
ALLOCATED SUBCARRIERS PER FEMTOCELL (SC)

Coalition	FC	SA-FCs	ISE-RM	ESE-RM
$C1$	FC1	5	12	22
	FC2	5	12	18
$C2$	FC4	5	10	17
	FC9	5	13	18
$C3$	FC5	5	10	16
	FC10	5	11	19
$C4$	FC7	5	12	18
	FC8	5	6	19

In Fig. 4, it can be noticed that the throughput per FC is enhanced due to the extra-resources allocated to serve both PUs and SUs. On average, with the ISE-RM model, FCs achieve a throughput of 0,7 Mbps, while FCs enhance their throughput to 1,2 Mbps using the ESE-RM model. Fig. 5 shows the interference per FC. We note that both models, ISE-RM and ESE-RM, give similar levels of interference. We propose to mitigate the inter-cluster interference as a future work, since it is out of the scope of this paper.

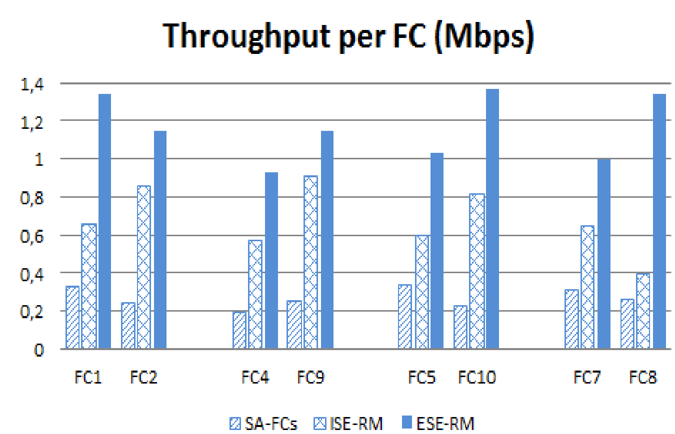

Fig. 4. Throughput per femtocell.

Table IX presents the performance of the stand-alone femtocells, in terms of SUs satisfaction, throughput and interference. We note that under a cooperative model the throughput for SA-FCs improves and the interference is reduced, which is due to the formation of coalitions. However, their subscribers do not achieve a 100 % of satisfaction because SA-FCs are not rewarded with extra-resources.

IV. CONCLUSION

We propose to encourage the cooperation among femtocells, in order to improve the subscriber satisfaction by granting access to public users and forming clusters. We model the clustering problem as a coalitional game for cooperative femtocells and an equal distribution method for the payoff allocation. Under

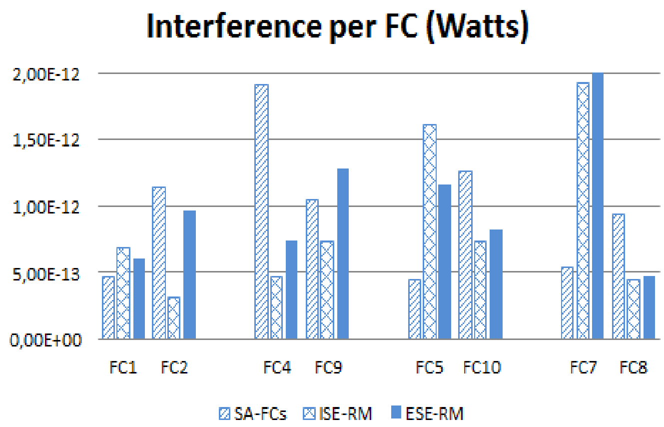

Fig. 5. Interference per femtocell.

TABLE IX
RESULTS FOR STAND-ALONE FEMTOCELLS

Model	SA FCs	SUs satisfaction (%)	Throughput (Mbps)	Interference (Watts)
Non-cooperative	FC3	38.28	0.19	1.72E-12
	FC6	82.46	0.42	1.93E-13
Cooperative	FC3	50.43	0.25	8.77E-13
	FC6	85.62	0.43	1.61E-13

the proposed algorithm, femtocells are able to join or leave a coalition, which depends on the payoff received by them, in terms of extra-subcarriers. Therefore, we analyzed the stability of coalitions and we demonstrated that the resulting coalitions lie in the core of the proposed game. Our results show an increase of 30 % in the satisfaction of SUs using the ESE-RM model over the ISE-RM model. With ESE-RM model, subscribers received twice the resources required since extra-resources allow them to achieve an effective spectral efficiency. While more FCs form coalitions, more PUs can improve their satisfaction by receiving part of the extra-resources allocated to cooperative FCs. With the ESE-RM model, PUs receive more resources than the required ones, and their satisfaction increases by 20 % compared with the ISE-RM model. Results have shown that the proposed coalition formation algorithm improves FCs performance, in terms of allocated subcarriers per femtocell, compared with the non-cooperative model. Both models, ISE-RM and ESE-RM, increase the throughput per FC by adding extra-resources from the macrocell.

As future work, we propose to mitigate the inter-cluster interference, as well as consider the Shapley value in order to make a fair allocation of resources. Furthermore, we propose to formulate a repeated game to analyze the behavior of femtocells. Some femtocells may have a misbehavior and not grant service to public users. Besides, misbehaving femtocells may use the received extra-resources only for the benefit of its own subscribers.

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