International Journal of Innovative
Computing, Information and Control
Volume **14**, Number **1**, February **2018**

ICIC International ©2018 ISSN 1349-4198
pp. **99–109**

SUB-CHANNEL AND POWER ALLOCATION IN FEMTOCELL NETWORKS USING OVERLAPPING COALITION FORMATION GAMES

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Received June 2017; revised October 2017

Abstract. *Resource allocation and interference mitigation are mainly challenge in the plug-and-play femtocell networks. Most of the previous work on resource allocation principally focuses on the non-cooperative way, while this paper further investigates the cooperative way in femtocell networks, in order to further optimize networks' data rate. Additionally, in the cooperative ideas, the transmission power control is rarely considered. Based on the above, we propose a new overlapping coalition formation game framework with power control, where more efficient and flexible resource allocation is performed in a femtocell network. The key idea here is to cast femtocell base stations as an overlapping coalition formation game coupled with power allocation. On the basis of switching order and independent order, the femtocell base stations or resource units are spontaneously driven to less interfered coalitions. Within each coalition, we design a multi-objective optimal power control method and leverage the weighted sum method to solve it; thus the optimal unequal power is achieved. Simulations present that our algorithm can improve the system data rate by 14.93% for the number of 32 femtocell base stations, compared to the prior art.*

Keywords: Femtocell networks, Cooperative games, Resource allocation, Power control

1. **Introduction.** Femtocell networks have emerged as a cellular technology and are significantly attractive to mobile operators since they are able to improve coverage and capacity, especially indoor environments. Moreover, femtocell networks are critical enabler for offloading mobile data traffic from existing macro cells [1]. Particularly, in view of the unique features of femto base stations (FBSs), such as plug-and-play, low-power and low-cost, FBS devices have been drawn great attention in recent years [2-5].

However, like all other emerging technologies, some problems come along with the introduction and development of femtocell networks. Among these problems, resource allocation and interference mitigation are considered to be the critical factor of the successful implementation [6-8]. There is comparatively rich literature on the applications of the centralized way, i.e., a non-cooperative way, to the study of the above problems. For instance, in [7], the authors investigated a self-organization strategy for physical resource block allocation to avoid the interference. In [8], the authors studied the joint sub-channel and power allocation and the fair resource sharing solution for end-users. In [9], the authors proposed the power minimization based resource allocation for mitigating interference. Nevertheless, as for the non-cooperative way, each FBS is concerned only with its own quality of service (QoS), neglecting the co-tier interference generated by the FBS itself to other FBSs. As far as we know, the co-tier interference always causes the reduction of the system data rate.

To solve the problem, the cooperative way among FBSs has been proposed in prior literature [10-14]. In [10], the authors formulated the spectrum sharing problem as a coalition formation game in partition form for femtocell networks. In [11], the authors proposed a distributed algorithm for femtocells sub-channel allocation problem and then femtocells were able to autonomously cooperate into a partition. The formed partitions were composed of disjoint coalitions. This method was a classic for coalition formation game. In [12], the authors further formulated the small cell base stations' cooperation problem as a coalition formation game with overlapping, i.e., each small cell base station was able to join more than one coalition for mitigating interference. In [13,14], the authors presented the bargaining cooperative game theoretic framework to overcome the interference and save energy.

However, the authors assume that each FBS transmits the equal power to its every femtocell user equipment (FUE), which implies that each FUE obtains the equal transmission power, wherever the FUE is. The restriction on the transmission power of the SBSs limits the data rate that can be achieved by the SBSs.

Specifically, the main contributions of this paper are as follows.

- We leverage the framework of overlapping cooperative to model FBSs cooperation characteristics with the goal of building a more rational and effective resource allocation system and maximizing the system data rate.
- To make the power allocation more reasonable and flexible than the equal power control situations, we design an optimizing scheme which simultaneously makes the maximum total transmit rate of each coalition and the minimum total transmission power of each coalition in the downlink communication over fading channels.
- We design two preferences, i.e., switching order and independent order, for solving the problem of overlapping cooperative formation. On the basis of two preferences, we propose the overlapping coalition formation with power control (OCF-PC) for mitigating the co-tier interference and improving the system transmit data rate.
- The effectiveness of the proposed OCF-PC algorithm was verified via a series of system level simulations. These simulations show that the proposed approach largely improves the system throughput in comparison with existing schemes and non-cooperative case.

The remainder of this paper is arranged as follows. In Section 2, we present the system model. In Section 3, we formulate the FBSs' cooperative problem as an overlapping coalition formation game with power control. In Section 4, we analyze the simulation results, followed by the conclusions and future work in Section 5.

2. **System Model.** In this paper, we consider the downlink transmission of the orthogonal frequency division multiple access (OFDMA) femtocell network. In a femtocell network, there are F FBSs in an enterprise.

The set $\mathbf{F} = \{1, \dots, F\}$ collects all FBSs indices and F denotes the number of FBSs in the network. Each FBS $f \in \mathbf{F}$ serves u_f FUEs and $U_f = \{1, \dots, u_f\}$ collects all FUEs which are served by the according FBS $f \in \mathbf{F}$. The set $\mathbf{N} = \{1, \dots, N\}$ collects all available orthogonal frequency sub-channels indices and N denotes the number of sub-channels in the network. Each FBS $f \in \mathbf{F}$ randomly selects N_f orthogonal frequency sub-channels serving u_f FUEs in a frequency division duplexing (FDD) access mode. In here, we have $N_f \in \mathbf{N}$.

As mentioned, all the FBSs are considered to be deployed indoors, e.g., an enterprise. In this case, we consider the practical fading effects, including path loss, penetration loss and Rayleigh fading. For a given sub-channel $n \in N_f$, the channel gain experienced over the link of FUEs $n \in N_f$ served by FBS $f \in \mathbf{F}$ can be given by:

$$G_{f,u_f}^{(n)} = PL_{f,u_f} D_{f,u_f}^{-\alpha} RF_{f,u_f}^{(n)}, \tag{1}$$

where PL_{f,u_f} and D_{f,u_f} respectively denote the path loss coefficient and the distance from FBS f to one of its FUEs u_f. α is the path loss exponent. $RF_{f,u_f}^{(n)}$ denotes the Rayleigh fading from FBS f to one of its FUEs u_f on the sub-channel n.

Furthermore, for a given sub-channel $n \in N_f$, the interfering sub-channels gain experienced over the link of FUEs $u_f \in U_f$ served by FBS $f \in \mathbf{F}$ can be given by:

$$G_{d,u_f}^{(n)} = PL_{d,u_f} D_{d,u_f}^{-\alpha} W_{d,u_f}^{-1} RF_{d,u_f}^{(n)}, \tag{2}$$

where W_{d,u_f}^{-1} denotes the internal wall penetration loss.

Thus, the downlink rate achieved by the FUE associated with FBS f on the sub-channel n under the non-cooperative case can be given by:

$$R_{f,u_f}^{(n)} = \sum_{n \in N_f} \sum_{u_f \in U_f} \log_2 \left(1 + \frac{P_{f,u_f}^{(n)} G_{f,u_f}^{(n)}}{\delta^2 + I_{\text{co-tier}}} \right), \tag{3}$$

where δ^2 is the variance of the Gaussian noise. $P_{f,u_f}^{(n)}$ is the downlink transmission power between FBS f and its FUEs u_f on the sub-channel n. $I_{\text{co-tier}}$ is the received total co-tier interference by the FUE u_f from other FBSs on the serving sub-channel n:

$$I_{\text{co-tier}} = \sum_{d \in \mathbf{F}, d \neq f} P_{d,u_f}^{(n)} G_{d,u_f}^{(n)}. \tag{4}$$

It should be noted that, especially in a hyper dense deployment of FBSs, the co-tier interference is an extremely serious problem which can greatly decrease the system performance. Therefore, in this work, we tackle resource allocation and co-tier interference problem by proposing an overlapping cooperative framework.

3. **Overlapping Cooperative Framework for Resource Allocation in Femtocell Networks.** In this section, we propose a new overlapping cooperative game theoretic framework which is conducive to build a more rational and effective resource allocation system. First, we introduce some basic definitions of overlapping coalition formation games in order to obtain stable and satisfying overlapping coalition structures.

3.1. **Overlapping coalition formation among FBSs.** Let $\mathbf{F} = \{1, \ldots, F\}$, i.e., all FBSs, denote a set of players. A vector $\mathbf{c} = \{c_1, \ldots, c_F\}$ is called a partial coalition (coalition for short), where c_f denotes the portion of the player f's sub-channel resources allocated to the coalition $\mathbf{c}$. Obviously, if $c_f = 0$, the player f does not belong to the coalition $\mathbf{c}$. Next, we introduce some basic concepts in overlapping coalition formation games (OCF-games) [12,15,16].

Definition 3.1. *The resource pool of the coalition* $\mathbf{c}$ *is defined as follows:*

$$rp_{\mathbf{c}} = \underset{f \in supp(\mathbf{c})}{\cup} \omega_{f,\mathbf{c}} N_f, \tag{5}$$

where $supp(\mathbf{c}) = \{f \in \mathbf{F} | c_f \neq 0\}$ *represents the support of the coalition* $\mathbf{c}$*, i.e., the player set formed the coalition* $\mathbf{c}$*.* $\omega_{f,\mathbf{c}}$ *is that the fraction of sub-channel resource of the FBS* f *contributes to the coalition* $\mathbf{c}$*. Clearly, the value of* $\omega_{f,\mathbf{c}}$ *is* $0 \leq \omega_{f,\mathbf{c}} \leq 1$.

This so-called "overlapping" is that each player or FBS f might simultaneously join the different coalitions, which corresponds to dividing the sub-channel of each FBS f into several parts or units and each part or unit belongs to the different coalitions. Based on this, the definition of the sub-channel resource unit or FBS unit is given below.

Definition 3.2. *A sub-channel resource unit, denoted as $\varphi_{f,m}$, is the minimum frequency resource of each FBS f and there are a total of units M for each FBS f. That is, each FBS f divides its initial orthogonal frequency sub-channels N_f into M single sub-channel parts. Therefore, we have $\sum_{m=1}^{M} \varphi_{f,m} = N_f$. We can also call a sub-channel resource unit $\varphi_{f,m}$ its corresponding FBS f unit without losing the practical significance.*

Definition 3.3. *An OCF-game $G = (\mathbf{F}, v)$ is defined as a player set $\mathbf{F} = \{1, \ldots, F\}$ and a function v. The function v maps each coalition $\mathbf{c}$ to the corresponding utility or payoff.*

Definition 3.4. *An overlapping coalition structure on the player set $\mathbf{F} = \{1, \ldots, F\}$ is defined as a finite list of vectors $\mathbf{OCS} = \{\mathbf{c}^1, \ldots, \mathbf{c}^l, \ldots, \mathbf{c}^L\}$ where L is the size of the overlapping coalition structure $\mathbf{OCS}$, i.e., $|\mathbf{OCS}| = L$.*

In particular, the coalition $\mathbf{c}$ mentioned above is the general description and has the same physical meaning with $\mathbf{c}^l$ from the set $\mathbf{OCS}$. Therefore, we have $supp(\mathbf{c}^l) \subseteq \mathbf{F}$ for all $l = \{1, \ldots, L\}$.

According to these definitions, we can get the utility $U(\mathbf{c}^l, \mathbf{OCS})$ of any coalition from the set $\mathbf{OCS}$ by rewriting (3) as follows:

$$U\left(\mathbf{c}^l, \mathbf{OCS}\right) = \sum_{f \in supp\left(\mathbf{c}^l\right)} \sum_{n \in rp_{\mathbf{c}^l}} \sum_{u_f \in U_f} \log_2 \left(1 + \frac{P_{f,u_f}^{(n)} G_{f,u_f}^{(n)}}{\delta^2 + I_{\text{co-tier}}}\right), \tag{6}$$

where the co-tier interference term $I_{\text{co-tier}}$ can be rewritten as follows:

$$I_{\text{co-tier}} = \sum_{\overline{\mathbf{c}^l} \in \mathbf{OCS} \backslash c^l} \sum_{d \in supp\left(\overline{\mathbf{c}^l}\right), d \neq f} P_{d,u_f}^{(n)} G_{d,u_f}^{(n)}. \tag{7}$$

Moreover, for forming the considered coalitions among FBSs, they need to exchange information. Therefore, each FBS has to pay the price for exchange information in accordance with transmission power. We can define the total price with the following equation [17]:

$$P_{tot} = \sum_{f=1}^{\left|\mathbf{c}^l\right|} P_{f,f^*}, \tag{8}$$

where f, f^* belong to the same coalition $\mathbf{c}^l$. f needs to transmit the information to the farthest FBS f^*. On the process of information transmit, P_{f,f^*} denotes the power consumption from the FBS f to the FBS f^*. And the presupposition of forming the coalition $\mathbf{c}^l$ is that the total power consumption is not larger than the maximum tolerable power consumption $P_{\max}$, so we have:

$$P_{tot} \leq P_{\max}. \tag{9}$$

Based on the above constraint, the value of the coalition $\mathbf{c}^l$ can be given by:

$$v\left(\mathbf{c}^l, \mathbf{OCS}\right) = U\left(\mathbf{c}^l, \mathbf{OCS}\right). \tag{10}$$

Subsequently, the function v in the OCF-game $G = (\mathbf{F}, v)$, i.e., the system utility, is given by:

$$v\left(\mathbf{OCS}\right) = \sum_{l=1}^{\mathrm{L}} v\left(\mathbf{c}^{l}, \mathbf{OCS}\right). \tag{11}$$

Furthermore, according to Definition 3.1 and (10), the utility of each FBS f belonged to the coalition $\mathbf{c}^{l}$, i.e., the individual utility, is given by:

$$\mu_f\left(\mathbf{c}^{l}, \mathbf{OCS}\right) = \omega_{f,\mathbf{c}} v\left(\mathbf{c}^{l}, \mathbf{OCS}\right). \tag{12}$$

Then, the total individual utility for each FBS f is given by:

$$\mu_f(\mathbf{OCS}) = \sum_{l=1}^{\mathrm{L}} \mu_f\left(\mathbf{c}^{l}, \mathbf{OCS}\right). \tag{13}$$

It is well-known that each FBS can select any coalitions for participating. However, the major challenge is how to select coalitions for making resource allocation more reasonable. Given this, we introduce the definitions of preference orders from two aspects [12].

Definition 3.5. *Switching order: given an FBS unit* $\varphi_{f,m} \subseteq f \in \mathbf{c}^{l}$ *and two overlapping coalition structures:* $\mathbf{OCS} = \{\mathbf{c}^{1}, \ldots, \mathbf{c}^{l}, \ldots, \mathbf{c}^{L}\}$ *and* $\mathbf{OCS}' = \{\mathbf{c}^{1'}, \ldots, \mathbf{c}^{l'}, \ldots, \mathbf{c}^{L'}\}$*, the* $\mathbf{OCS}$ *switches into the* $\mathbf{OCS}'$*, if the following conditions are satisfied: (a) total individual utility:* $u_f(\mathbf{c}^{l}) > u_f(\mathbf{c}^{l'})$*; (b) system utility:* $v(\mathbf{OCS}) > v(\mathbf{OCS}')$*; (c) utility of new coalition* $\mathbf{c}^{l'}$*:* $\sum\limits_{\varphi_{f',m} \subseteq f \in \mathbf{c}^{l'}} \mu_{f'}(\mathbf{c}^{l}) \geq \sum\limits_{\varphi_{f',m} \subseteq f \in \mathbf{c}^{l'}} \mu_{f'}(\mathbf{c}^{l'})$*.*

Definition 3.6. *Independent order: given an FBS unit* $\varphi_{f,m} \subseteq f \in \mathbf{c}^{l}$ *and two overlapping coalition structures:* $\mathbf{OCS} = \{\mathbf{c}^{1}, \ldots, \mathbf{c}^{l}, \ldots, \mathbf{c}^{L}\}$ *and* $\mathbf{OCS}' = \{\mathbf{c}^{1'}, \ldots, \mathbf{c}^{l'}, \ldots, \mathbf{c}^{L'}\}$ *from the coalition* $\mathbf{c}^{l}$ *turns into the independent coalition* $\{\{\varphi_{f,m}\}\}$*, if the following conditions are satisfied: (a) the total individual utility:* $u_f(\mathbf{c}^{l}) > u_f(\mathbf{c}^{l'})$*; (b) system utility:* $v(\mathbf{OCS}) > v(\mathbf{OCS}')$*.*

Through the above two definitions, each FBS alone can decide to change its units into different coalitions in terms of the total individual utility of each FBS, the coalitional system utility and the utility of the new coalition respectively.

3.2. **Power control within FBSs overlapping coalitions.** Compared with the existing literature, we introduce power control to the FBSs overlapping coalition formation games. The goal here is to improve the system throughout by obtaining the reasonable and flexible power. Therefore, in the process of forming overlapping coalitions, the power allocation method is designed by simultaneously making the maximum total transmit rate of each coalition and the minimum total transmission power of each coalition in the downlink transmission. Mathematically, the achievement of this goal needs to solve the following multi-objective optimization problem:

$$\begin{array}{l} \max\limits_{P_{f,u_f}^{(n)}} \sum\limits_{f \in \mathbf{c}^{l}} \sum\limits_{u_f \in U_f} \log_2\left(1 + \frac{P_{f,u_f}^{(n)} g_{f,u_f}^{(n)}}{\delta^2 + I_{\text{co-tier}}}\right) \\ \min\limits_{P_{f,u_f}^{(n)}} \sum\limits_{f \in \mathbf{c}^{l}} \sum\limits_{u_f \in U_f} P_{f,u_f}^{(n)} \\ \text{s.t. } C1: \sum\limits_{u_f \in U_f} \frac{P_{f,u_f}^{(n)}}{\left|\mathbf{c}^{l}\right|} \leq P_{\max} \\ \qquad C2: P_{f,u_f}^{(n)} \geq 0 \end{array}, \tag{14}$$

where $\frac{1}{|\mathbf{c}^l|}$ is the transmit time for FUE u_f on its own normalized slot, constraint $C1$ illustrates that the total power of each FBS f to serve its all FUEs should be no larger than the given maximum transmission power.

In order to find the optimal solution of (14) in the corresponding sub-channel n, the weighted sum method is used to solve the multi-objective optimization [18]. Therefore, the problem (14) can be rewritten as:

$$\begin{aligned}&\max_{P_{f,u_f}^{(n)}}\left[\varepsilon\left(\sum_{f\in\mathbf{c}^l}\sum_{u_f\in U_f}\log_2\left(1+\frac{P_{f,u_f}^{(n)}g_{f,u_f}^{(n)}}{\delta^2+I_{\text{co-tier}}}\right)\right)-(1-\varepsilon)\left(\sum_{f\in\mathbf{c}^l}\sum_{u_f\in U_f}P_{f,u_f}^{(n)}\right)\right], \\ &\text{s.t. } C1 \text{ and } C2\end{aligned} \tag{15}$$

where ε is the weighting coefficient representing the significance of the two different objectives.

The optimal transmission power is given by the following proposition.

Proposition 3.1. *The optimal power allocation solution of (14) is as follows:*

$$P_{f,u_f}^{(n)*}=\frac{\delta^2+I_{\text{co-tier}}}{\sum_{f\in\mathbf{c}^l}\sum_{u_f\in U_f}g_{f,u_f}^{(n)}}-\frac{\delta^2+I_{\text{co-tier}}}{g_{f,u_f}^{(n)}}+\left|\mathbf{c}^l\right|P_{\max},\quad\forall f,\ u_f. \tag{16}$$

Proof: Obviously, (15) is a classical convex optimization problem. Therefore, its optimal solution should satisfy Karush-Kuhn-Tucker (KKT) conditions. Its Lagrange function is given by:

$$\begin{aligned}L\left(P,\alpha,\beta\right)\ =\ &\left[\varepsilon\left(\sum_{f\in\mathbf{c}^l}\sum_{u_f\in U_f}\log_2\left(1+\frac{P_{f,u_f}^{(n)}g_{f,u_f}^{(n)}}{\delta^2+I_{\text{co-tier}}}\right)\right)-(1-\varepsilon)\left(\sum_{f\in\mathbf{c}^l}\sum_{u_f\in U_f}P_{f,u_f}^{(n)}\right)\right]\\ &-\alpha\left(\sum_{u_f\in U_f}\frac{P_{f,u_f}^{(n)}}{|\mathbf{c}^l|}-P_{\max}\right)+\beta_{f,u_f}^{(n)}P_{f,u_f}^{(n)},\end{aligned} \tag{17}$$

where α and $\beta_{f,u_f}^{(n)}$ are non-negative variables associated with the constraints $C1$ and $C2$.

As the length limits, the completed KKT conditions do not be listed in detail. Then, we can get the derivative of (17) associated with $P_{f,u_f}^{(n)}$. Setting the derivative equal to 0 yields:

$$P_{f,u_f}^{(n)*}=\frac{\varepsilon}{\ln 2\left(1-\varepsilon+\frac{\alpha}{|\mathbf{c}^l|}+\beta_{f,u_f}^{(n)}\right)}-\frac{\delta^2+I_{\text{co-tier}}}{g_{f,u_f}^{(n)}}. \tag{18}$$

Using the proof by contradiction, $\beta_{f,u_f}^{(n)}=0$, $\forall f,u$ is supported. Using the KKT conditions and the proof by contradiction, $\sum\limits_{u_f\in U_f}\frac{P_{f,u_f}^{(n)}}{|\mathbf{c}^l|}-P_{\max}=0$ is supported. We thus have:

$$\alpha=\left|\mathbf{c}^l\right|\left(\varepsilon-1+\frac{\varepsilon}{\ln 2\left(\left|\mathbf{c}^l\right|P_{\max}+\frac{\delta^2+I_{\text{co-tier}}}{g_{f,u_f}^{(n)}}\right)}\right). \tag{19}$$

Substituting it and $\beta_{f,u_f}^{(n)}=0$ into (18), (16) is thus proved.

3.3. **Proposed algorithm for OCF-game with power control.** On the basis of switching order and independent order, the proposed OCF-PC algorithm is composed of four principal stages: initial state, neighborhood discovery, FBSs overlapping coalition structure formed and inner coalition scheduling.

Firstly, beginning with the completely disjoint situation (non-cooperative case): a partition where every coalition is composed of a single player f, that is, all FBSs are partitioned by F singleton coalitions. Secondly, each FBS $f \in \mathbf{F}$ investigates its neighborhood and tries to form a coalition. Thirdly, each FBS computes the price for exchange information according to (8) and make sure to meet the power constraint (9). Next, for each FBS unit, their FBS makes a decision on how to allocate the FBS's units according to the switching order and independent order. In the process of allocating, each FUE, which is served by the corresponding FBS unit or the sub-channel resource unit, receives the unequal transmission power in accordance with the real-time sub-channel status and the distance between the current FUE and the corresponding FBS unit. The unequal or optimal transmission power is computed by (16). Additionally, the history visiting set H of each FBS unit, which will be further explained below, should be considered. Once the allocation is done, the system utility is increased. If there are no other re-allocations, the third stage is completed. Fourthly, inside of every coalition schedules its transmission according to the method of [20]. In short, the proposed OCF-PC makes SBSs into an overlapping coalition structure and achieves more reasonable and flexible power allocation, which improves the system data rate in the network.

In addition, the convergence and stability of the formed overlapping coalitions are explained in the following.

Proposition 3.2. *Given switching order, independent order and the threshold parameter* TH *of the history visiting set* H*, the convergence and stability of the proposed OCF-PC algorithm can be guaranteed. In here, the history visiting set* H *represents the times that an FBS unit* $\varphi_{f,m}$ *has joined a coalition and then leaves the coalition.* TH *is the man-made threshold parameter to set a limit to the FBS unit* $\varphi_{f,m}$ *back to the once joined coalitions, which is set to 5.*

Proof: The convergence is mainly based on two aspects. Firstly, the number of FBSs, the number of sub-channels and the number of FBSs' units are finite, so the total number of the potential overlapping coalitions is finite (given by the bell number [21]). Secondly, the parameter TH limits the times that any FBS unit revisits the coalitions which have been visited. Based on the convergence and the two orders, the stability is obvious.

4. **Simulation Results and Analysis.**

In this section, based on Matlab simulations are conducted to evaluate the proposed OCF-PC. The evaluated femtocell network is a square area of 500 × 500 m^2, where there are N available orthogonal frequency sub-channels and the bandwidth of each sub-channel is 180 kHz. Assuming that the F FBSs obey a random uniform distribution in the given area [11,12]. Without loss of generality, we also assume that each FBS f randomly selects $N_f = 4$ sub-channels to separately serve $u_f = 4$ FUEs. The 4 FUEs are randomly distributed in their corresponding FBS and the radiation radius of each FBS is set 100 m. We assume that the thermal noise density is set to -174 dBm/Hz and the maximum transmission power of each FBS is set to 30 dBm. The equal transmission power of each FBS is set to 20 dBm, which is used to the three comparison schemes: non-cooperative case, the non-overlapping coalition formation using a recursive core approach (RCA) [11] and the coalitional games with overlapping coalitions for interference management (CGIM) [12]. The path loss exponent is set to 3.7 and the internal wall penetration loss is set 4 dB [19].

Figure 1 shows a snapshot of a femtocell network which causes from the proposed OCF-PC algorithm with the number of FBSs $F = 4$, the fixed number of available sub-channels $N = 10$ and 4 FUEs per FBS. As we can see from Figure 1, the overlapping coalition structure is composed of three overlapping coalitions, that is, $\mathbf{OCS} = \{\mathbf{c}^1, \mathbf{c}^2, \mathbf{c}^3\}$, of which every coalition member and the allocation of every FBS unit respectively are:

$$\begin{aligned} &\mathbf{c}^1 = \{FBS1\} = \{\varphi_{FBS1,1}, \varphi_{FBS1,2}, \varphi_{FBS1,3}, \varphi_{FBS1,4}\} \\ &\mathbf{c}^2 = \{FBS2, FBS3\} = \{\varphi_{FBS2,1}, \varphi_{FBS2,2}, \varphi_{FBS2,3}, \varphi_{FBS2,4}, \varphi_{FBS3,4}\} \\ &\mathbf{c}^3 = \{FBS3, FBS4\} = \{\varphi_{FBS3,1}, \varphi_{FBS3,2}, \varphi_{FBS3,3}, \varphi_{FBS4,1}, \varphi_{FBS4,2}, \varphi_{FBS4,3}, \varphi_{FBS4,4}\}. \end{aligned} \tag{20}$$

Obviously, $FBS3$ is an overlapping FBS since its sub-channel units are divided into two parts allocated to the two different coalitions, $\mathbf{c}^2$ and $\mathbf{c}^3$. However, $FBS1$ has no cooperation with other players since its spectral occupation is orthogonal to other coalitions. Figure 1 shows that by using the proposed OCF-PC algorithm, FBSs can form a stable coalitional situation.

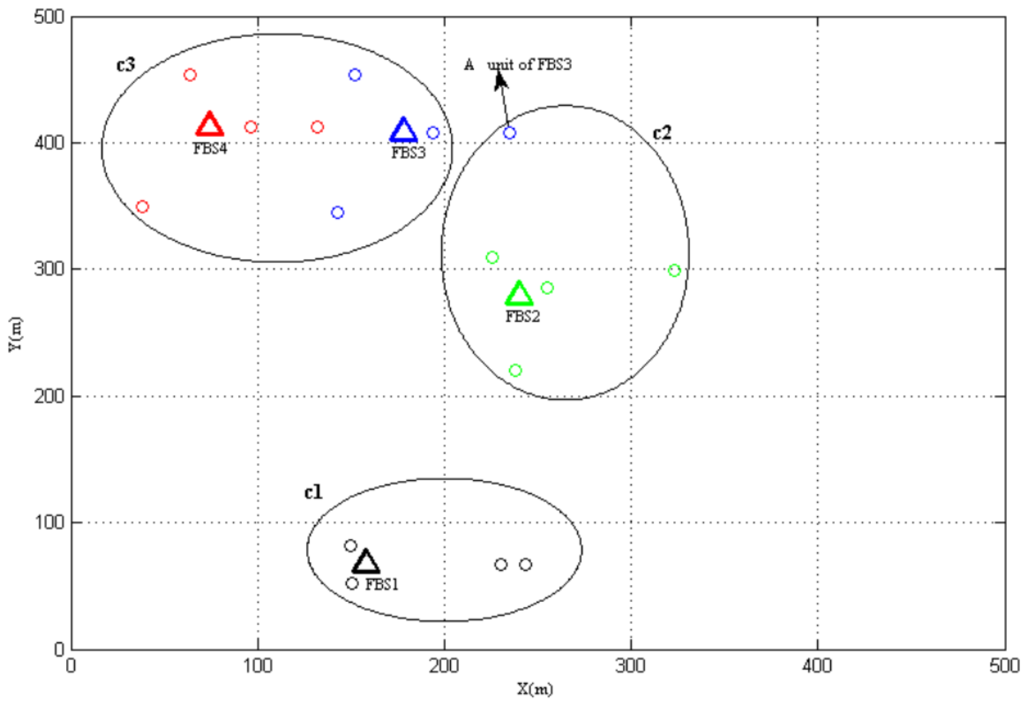

FIGURE 1. A snapshot of an overlapping coalition structure

The performance of the proposed method is compared with that of CGIM, RCA and non-cooperative case in Figure 2, where the result of system utility in terms of the data rate, versus the number of FBSs is shown. In the simulation, the number of available sub-channels is fixed $N = 20$. On the whole, as the number of FBSs F increases, the system utility is on the rise. The simulation result shows that when $FBS \le 4$, the system utility achieved via all the methods looks similar. The reason for this phenomenon is that in a sparsely deployed femtocell network, there are very few or no cooperative options available for these resource units. The three cooperative cases have a slight improvement compared with the non-cooperative on the system utility. Nevertheless, with the increasing of the number of FBSs, that is, when the number of FBSs in the given area becomes relatively dense, our proposed OCF-PC performs much better than the other three cases. This is because that for the dense deployment environment, all FBSs among each other tend to cooperative. Especially, when the number of the FBSs is $F = 32$, our algorithm shows a

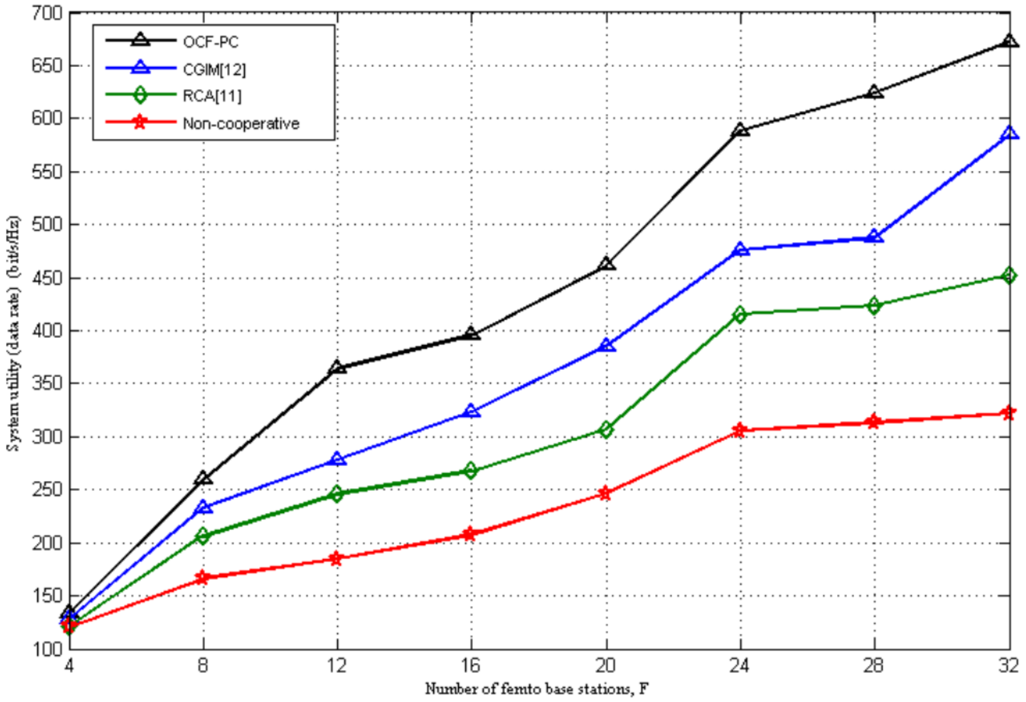

Figure 2. System utility versus the number of FBSs

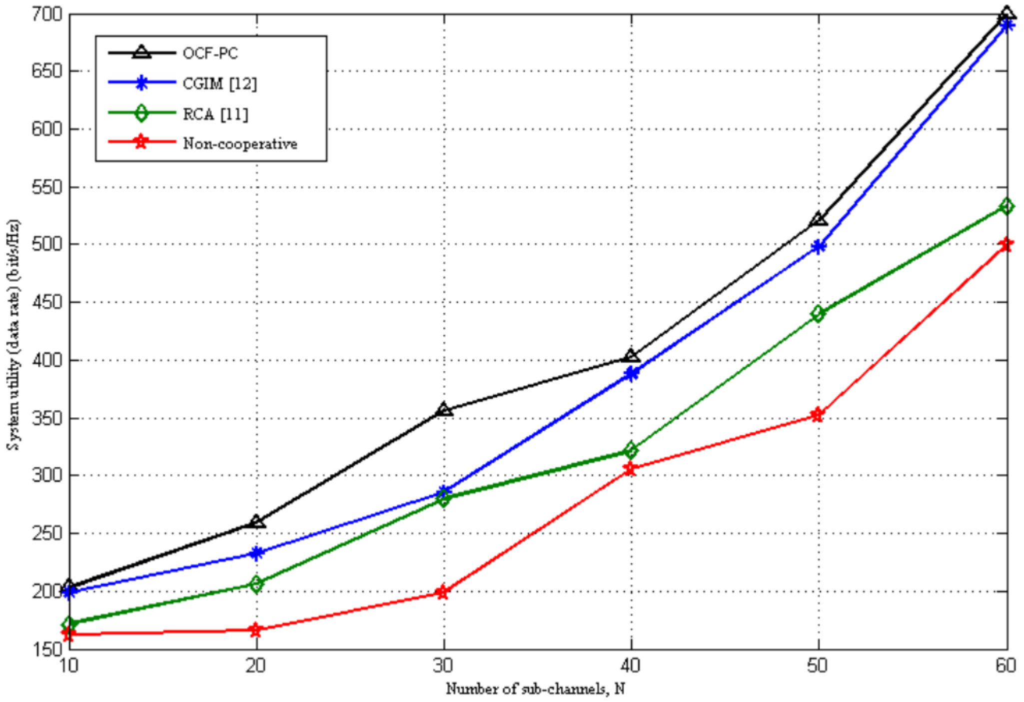

Figure 3. System utility versus the number of available sub-channels

performance improvement of 14.93%, 48.54% and 108.59% in terms of the system utility in comparison with CGIM, RCA and non-cooperative case, respectively. This is due to the fact that, by cooperation, the co-tier interference among densely deployed FBSs has been mitigated to some extent. More importantly, as the number of FBSs increases, the advantage of unequal transmission power, i.e., more reasonable and flexible transmission power, becomes more pronounced.

Next, through further comparative simulation of our proposed OCF-PC algorithm and CGIM, RCA as well as non-cooperative case, we present that the system utility versus the number of the available sub-channels in the femtocell network with the fixed number of 8 FBSs. As shown in Figure 3, the system utility is successively improved as the number of the available sub-channels increases. The main reason behind the result is that for ever-increasing the number of sub-channels, the possibility of each sub-channel simultaneously occupied by the same FUE is greatly reduced under all above four of schemes. Hence, as the number of available sub-channels increases, the co-tier interference in the femtocell network is also reduced and the system data transmit rate is improved. Furthermore, since that we apply the power allocation more reasonable and flexible than the equal power control situations. Figure 3 shows that as the number of available sub-channels increases, our proposed OCF-PC algorithm is superior to the other three schemes in terms of system utility.

5. **Conclusions and Future Work.** In this paper, we proposed an overlapping coalition game framework with power control which enables FBSs to form the stable coalitions and achieve the sub-channel allocation. Our algorithm obtains the optimal transmission power allocation for each FUE over the corresponding sub-channel, and the stability and convergence of the game framework are theoretically confirmed. Simulation results show that our algorithm is able to improve the network data rate by 14.93% in a femtocell network of 32 FBSs. For the future work, we will research the generalized scenario with the macro base stations outside. In the scenario, we will simultaneously concern how to solve the cross-interference in a two-tier cellular network.

Acknowledgment. This work was jointly supported by the Natural Science Foundation of China under Grant 61471222 and the Natural Science Foundation of Shandong Province under Grant ZR2015FM003.

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