Collaborative Sub-channel Allocation with Power Control in Small Cell Networks

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Abstract

For enhancing the coverage of wireless networks and increasing the spectrum efficiency, small cell networks (SCNs) are considered to be one of the most prospective schemes. Most of the existing literature on resource allocation among non-cooperative small cell base stations (SBSs) has widely drawn close attention and there are only a small number of the cooperative ideas in SCNs. Based on the motivation, we further investigate the cooperative approach, which is formulated as a coalition formation game with power control algorithm (CFG-PC). First, we formulate the downlink sub-channel resource allocation problem in an SCN as a coalition formation game. Pareto order and utilitarian order are applied to form coalitions respectively. Second, to achieve more availability and efficiency power assignment, we expand and solve the power control using particle swarm optimization (PSO). Finally, with our proposed algorithm, each SBS can cooperatively work and eventually converge to a stable SBS partition. As far as the transmit rate of per SBS and the system rate are concerned respectively, simulation results indicate that our proposed CFG-PC has a significant advantage, relative to a classical coalition formation algorithm and the non-cooperative case.

Keywords: Small cell networks, coalition formation game, interference mitigation, sub-channel allocation, power control

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1. Introduction

Wireless communication is facing a new dilemma: low frequency spectrum is occupied by a large number of traditional applications such that operators have to transfer to high frequency spectrum. Given SBSs' unique characteristics, such as low-cost, low-power and plug-and-play, SCNs are considered to be one of the perspective techniques for solving the dilemma. Currently, SCNs have drawn intense concern in some standardization organizations [1-3]. Moreover, small cells have significant benefits for the macro cellular network: they are critical enabler for offloading data traffic [3-5].

The introduction of SCNs, however, is faced with some problems, such as programming, interference, service carrying. Above all, key factors of the successful implementation will ride on how to perform resource allocation and mitigate interference. For instance, in [6], the authors studied the resource allocation for SCNs and made resource optimization based interference management. In [7], the authors considered the power assignment by a new technique based on multi-objective optimization problem in OFDMA femtocell networks. In [8], considering the distributed nature of femtocell networks, the authors proposed that minimizing downlink transmit power to give every user what it needed could cause the new scheduling opportunities and improve the network capacity. In [9], the authors presented a game model based on a cost function for the efficient power control and the interference management in two-tier femtocell networks. In [10], to mitigate interference and increases the average throughput, the authors studied the most recent sub-frame utilization of spectrum in LTE-Unlicensed under co-existence of macro and small cells.

Most existing researches focused more on decentralized interference mitigation methods in which SBSs perform the non-cooperative way, i.e., each SBS only considers quality of service for itself while neglecting the co-tier interference. Hence, it dramatically reduces data rate, especially pico-cells which are deployed outdoors. To solve this issue, ideas about cooperation are proposed, which call for collaboration among SBSs [11-15]. In [11], coalition game with a recursive core approach (RCA) was proposed, which was a cooperative model among femtocells that only searched the shareable sub-channel resources. In [12], by using coalitional structure generation with characteristic forms, the authors design a cooperative interference mitigation model for SCNs in which an SBS is able to cooperate with other SBSs and joins other coalitions depending on the associated utility. In [13], the authors proposed a cluster-based resource allocation scheme considering sub-channel and power assignment problem for downlink transmission in ultra dense SCNs. In [14], the authors proposed a self-organized coalition formation approach for intra-tier interference management in heterogeneous SCNs. In [15], a game theoretical approach was introduced for sub-channel allocation among femtocells' users. The above literature applied the cooperative game idea, but did not consider the real-time power allocation which is a key aspect for improving the network throughput. Moreover, in the previous studies, the orthogonal frequency allocation scheme was applied in SCNs, which obviously decreased the spectrum utilization.

Based on the motivation of further improving the spectrum utilization and mitigating the interference, we formulate the cooperative sub-channel allocation problem among SBSs as a coalitional game [16], and propose CFG-PC algorithm. Namely, we study resource allocation including the sub-channel and power for a two-tier SCN based on coalition formation games. Moreover, Pareto order and utilitarian order are separately applied to evaluate the data rate from two aspects: individual utility and system utility. To the best of our knowledge, solving resource allocation based on coalition formation games from the above comprehensive perspective has been rarely investigated in prior literature. Specifically, the main contributions of this paper include the following:

- We expand and design the power control on the basis of a coalitional game, which enables each SBS to adjust its transmission power adapting to the interference environment. Therefore, we advance a new idea by means of PSO algorithm for making transmit power more efficient and flexible.
- We formulate the sub-channel allocation of an SCN as a coalition formation game. By leveraging the definitions of Pareto order and utilitarian order, we evaluate the data rate from two perspectives: individual utility (the data rate of per SBS) and system utility (the system data rate in an SCN).
- To further improve the spectrum utilization, we apply the co-channel assignment approach rather than the orthogonal sub-channel allocation approach used in [11].

The remainder of the paper is organized as follows. Section 2 describes the system model. Section 3 formulates the coalition formation, sub-channel allocation and power control problem. Simulation results are discussed in Section 4. Section 5 concludes the paper.

2. System Description

In this paper, we consider the downlink transmission of the Orthogonal Frequency Division Multiple Access (OFDMA) based SCNs. An SCN is composed of a MBS to serve K macro cell user equipment (MUEs) and F SBSs. SBSs are deployed hotspot indoors. In such scenario, due to the short distance and the lack of wall settings, the co-tier interference is quite severe. However, MBS is deployed outdoors with the long distance and wall settings, so the cross-tier interference is weak. Hence, in this paper, we mainly solve the downlink co-tier interference.

In an SCN, let $\mathbb{F}=\{1,...,F\}$ be the set of all SBSs, where F is the total number of SBSs, $\mathbb{U}=\{1,...,U_f\}$ be the set of all small cell user equipment (SUEs), which $U_f=\{u_1,...,u_f\}$ is the set of SUEs served by the $f-th$ SBS, i.e., each SBS serves $|U_f|$ SUEs ($|\bullet|$ is the cardinality of a set), and $\mathbb{N}=\{1,...,N_f\}$ be the set of all sub-channels, which $N_f=\{1,...,n\}$ is the initial sub-channel resource set of each SBS $f\in\mathbb{F}$. We assume each SBS operates in closed access mode [2, 17] and each SBS randomly selects a sub-channel set N_f including $|N_f|$ orthogonal frequency sub-channels in a frequency division duplexing access way and serves $|U_f|$ SUEs.

When SBSs carry out non-cooperative case, each SBS $f\in\mathbb{F}$ transmits data to its SUEs U_f on its own sub-channels N_f. Each sub-channel $n\in N_f$ from the initial sub-channels resource set N_f of each SBS $f\in\mathbb{F}$ only serves one SUE which uses the full time duration of the sub-channel n, i.e., $\Gamma_{f,u_f}^{(n)}=1$, so the co-tier interference emerges. Meanwhile, MBS also transmits its data through the same sub-channel n, so there also exists the cross-tier interference. Nevertheless, when SBSs carry out cooperative case, one SUE only occupies a part of each sub-channel $n\in N_f$, i.e., the fraction of the super-frame transmit time, so $\Gamma_{f,u_f}^{(n)}<1$. The latter case obviously helps improve the spectrum efficiency. The reason is that the co-tier interference inside of a coalition is efficiently mitigated. The scheduling scheme refers to [18].

Considered the non-cooperative case first, the total interference I can be represented as:

$$\begin{aligned} I &= \sigma^2 + I_{CrTI} + I_{CoTI} \\ &= \sigma^2 + p_{M,u_f}^{(n)} g_{M,u_f}^{(n)} + \sum_{j\in\mathbb{F}, j\neq f} p_{j,u_f}^{(n)} g_{j,u_f}^{(n)} \end{aligned} \quad (1)$$

where I_{CrTI} is cross-tier interference and I_{CoTI} is co-tier interference. $p_{j/M,u_f}^{(n)}$ is downlink transmit power from SBS j or MBS M to SUE u_f on the sub-channel n. $g_{j/M,u_f}^{(n)}$ is channel gain between SBS j or MBS M and SUE u_f on the sub-channel n. σ^2 is noise power which is set to -174 dBm. Then the transmit rate of SUE u_f served by SBS f through the sub-channel n is expressed as:

$$R_{f,u_f}^{(n)} = \sum_{n\in\mathbb{N}} \sum_{u_f\in\mathbb{U}} \Gamma_{f,u_f}^{(n)} \log_2\left(1 + \frac{p_{f,u_f}^{(n)} g_{f,u_f}^{(n)}}{I}\right) \quad (2)$$

where $\Gamma_{f,u_f}^{(n)} \in (0,1]$ is the fraction of the super-frame transmit time.

To form coalitions among SBSs, cooperative SBSs need to exchange their information, but the exchanging process causes transmit power cost. The required power cost for exchanging information between an SBS and its most distant SBS is given by (2) from [19], so the total cost for forming coalition is:

$$P_{tot} = \sum_{i=1}^{|S|} P_{i,j} \quad (3)$$

The total transmit power can be larger due to SBSs' position and the formed coalition size, thus the maximum tolerable transmit power cost is limited to $P_{\lim}$, i.e., $P_{tot} \le P_{\lim}$.

3. Coalition Formation for Resource Allocation

3.1 Coalition Formation among SBSs

In this sub-section, we formulate the sub-channel allocation problem as a coalition formation game to maximize data rate in a two-tier SCN. We propose an algorithm to obtain satisfying coalition structures by using some basic concepts of coalition formation games [16, 20].

Definition 1. A coalition formation game $G = (\mathbb{F}, V)$ with transferable utility (TU) is defined by a set of players, i.e., the set of SBSs $\mathbb{F} = \{1,\dots,F\}$, and a mapping V: for every coalition $S_l \subseteq \mathbb{F}$, $V(S_l,\pi)$ is utility vectors which players in the coalition S_l can obtain. Here, $\pi = \{S_1,\dots S_L\}$ is the set of coalitional structure or coalition partition. $S_l \subseteq \mathbb{F}$ are disjoint coalitions, such that $\bigcup_{l=1}^{L} S_l = \mathbb{F}$ and $\bigcap_{l=1}^{L} S_l = \varnothing$ for any $\forall l \in \{1,\dots,L\}$.

In accordance with the above definition, the mapping V is given by:

$$V(S_l,\pi) = \begin{cases} \mathbf{R}(S_l,\pi), & \text{if } P_{tot} \le P_{\lim}; \\ 0, & \text{otherwise.} \end{cases} \quad (4)$$

where $\mathbf{R}(S_l,\pi)$ is the utility of coalition $S_l \in \pi$, then we give its expression as per (2):

$$\mathbf{R}(S_l,\pi) = \sum_{f\in S_l} \sum_{n\in T_{S_l}} \sum_{u_f\in U_f} \Gamma_{f,u_f}^{(n)} \log_2\left(1 + \frac{p_{f,u_f}^{(n)} g_{f,u_f}^{(n)}}{I}\right) \quad (5)$$

where T_{S_l} is the sub-channel resource pool which is possessed by the coalition S_l. Currently, the co-tier interference I_{CoTI} should be rewritten:

$$I_{CoTI} = \sum_{S^* \in \pi \setminus S_l} \sum_{j \in S^*, j \neq f} p_{j,u_f}^{(n)} g_{j,u_f}^{(n)} \tag{6}$$

Furthermore, the average utility of per SBS f in the coalition S_l is defined by:

$$\mathbf{R}_f = \frac{1}{|S_l|} \mathbf{R}(S_l, \pi) \tag{7}$$

The utility of the coalition structure $\pi = \{S_1, ..., S_L\}$, i.e., the system utility, is defined by:

$$V(\pi, \Pi) = \sum_{l=1}^{L} V(S_l, \pi) \tag{8}$$

where Π is the set of all possible coalition partitions of SBSs set $\mathbb{F}$, clearly, $\pi \in \Pi$.

Whether a coalition is formed or not is determined by players' preferences when players attend the potential coalitions. Preferences are based on the following concepts [16, 20].

Definition 2. Given two coalitions $S_1 = \{x_1, ..., x_L\}$ and $S_2 = \{y_1, ..., y_L\}$ for same players, a player prefers to incorporate itself into S_1 instead of S_2 by Pareto order:

$$\begin{aligned} &\{x_1, ..., x_L\} \succ_{Pareto} \{y_1, ..., y_L\} \quad iff \\ &\forall\, l \in \{1, ..., L\}, x_l \geq y_l \;\; and \;\; \exists\, l \in \{1, ..., L\}, x_l > y_l \end{aligned} \tag{9}$$

where Pareto order or relation $\succ_{Pareto}$ is transitive, irreflexive, monotonic and linear.

Definition 2 shows that Pareto order depends on the preference of each player's utility and is independent on the value of the coalition. Once one player's utility increases in S_1, which does not lead to reduce in other players' utility, the player prefers S_1.

Definition 3. Given two coalitions $S_1 = \{x_1, ..., x_L\}$ and $S_2 = \{y_1, ..., y_M\}$, for a group of players, the coalition S_1 is preferred over the coalition S_2 by utilitarian order:

$$S_1 \succ_{utili} S_2 \quad iff \;\; \sum_{l=1}^{L} x_l > \sum_{m=1}^{M} y_m \tag{10}$$

where utilitarian order or relation $\succ_{utili}$ is complete, reflexive, and transitive. To clearly quantify the system utility's preference, the latter part of (13) is expanded as:

$$W_{\pi_1}(\Pi) = \sum_{S_l \in \pi_1} \sum_{l \in S_l} x_l,\; S_l = \{1, ..l., L\} \;\; and \;\; W_{\pi_2}(\Pi) = \sum_{S_m \in \pi_2} \sum_{m \in S_m} x_m,\; S_m = \{1, ..m., M\} \tag{11}$$

$$W_{\pi_1}(\Pi) = \begin{cases} V(\pi_1, \Pi), & if\, (R_l(S) \geq R_l(S \setminus \{m\}), so\ that\ V(\pi_1, \Pi) \geq V(\pi_2, \Pi), \\ & \forall l \in S \setminus \{m\}\, and\ H_l(S) \leq TH_l), \\ -\infty, & otherwise \end{cases} \tag{12}$$

where W_{π_1} and W_{π_2} are the total utility of two systems $\pi_1 = \{S_1, ..., S_L\}$ and $\pi_2 = \{S_1, ..., S_M\}$, respectively. $V(\pi_1, \Pi)$ is the utility received by the system coalition π_1 in the set Π as per (8). $R_l(S)$ is the average utility of per SBS l in the coalition S as per (7). $H_l(S)$ is the number of times that SBS l has taken part in the coalition S and then leaves this coalition. TH_l is the man-made threshold parameter to set a limit to SBS l back to the once joined coalition, which is set to 5.

Definition 3 shows that utilitarian order depends on the preference of the system utility and has no direct relationship with the preference of the individual player. Namely, utilitarian order only needs to meet the total utility of the coalition strictly bigger than the total utility of the coalition .The threshold parameter ensures that SBS l is to join the new coalition which has never been visited.

3.2 Power Control within SBSs Coalition

Compared with the previous literature, the main improvement of the proposed CFG-PC is that power control is introduced. It is to ensure that each SUE can obtain the flexible un-equal power according to its own location and its coalition position. Hence, the power allocation method is needed to maximize the data rate of the coalition S_l .

In the process of forming coalitions, by maximizing the following proposed utility function, we can obtain this optimal transmission power. First, the proposed utility function is mathematically formulated as:

$$\begin{aligned} \max U_{f,u_f}(P_{f,u_f}^{(n)}) &= R(P_{f,u_f}^{(n)}) - C(P_{f,u_f}^{(n)}) \\ &= \sum_{n\in T_{S_l}} \sum_{u_f \in U_f} \Gamma_{f,u_f}^{(n)} \log_2\left(1+\frac{p_{f,u_f}^{(n)} g_{f,u_f}^{(n)}}{I}\right) - \sum_{j\in F, j\neq f} \alpha e^{\beta \sum_{n\in T_{S_l}} \Gamma_{j,u_f}^{(n)} P_{j,u_f}^{(n)}} \\ s.t.\ \ 0 \le P_{f,u_f}^{(n)} &\le P_{\max} \end{aligned} \tag{13}$$

where α is price coefficient, β is scaling factor. By try-and-error method in subsequent experiments, α, β are respectively set to 121 and 1.5. The constraint shows that each SUE's transmit power should be no larger than SUE's maximum transmit power.

As shown in (13), the utility function is composed of the reward term $R(P_{f,u_f}^{(n)})$ and the penalty term $C(P_{f,u_f}^{(n)})$. The former denotes the date rate of SUEs U_f using the resource pool T_{S_l} and the latter is the co-tier interference degree to SUEs U_f. The reason we select the exponential function for the penalty term is because for an SUE with high data rate, its power should be cut down, otherwise power should be improved.

To prove the existence of the solution to the optimization problem (13), we give the following conditions [21]: (i) $P_{f,u_f}^{(n)}$ is a compact, convex, non-empty subset of Euclidean space; (ii) $U_{f,u_f}(P_{f,u_f}^{(n)})$ is continuous and concave for $P_{f,u_f}^{(n)}$.

Theorem 1: The optimal solution of (13) exists.

Proof: Just prove that the above two conditions can be satisfied. For the limitation of paper, the detailed proof is not discussed and we can reference the proof in [21].

Next, to find the specific optimal value of (13), we leverage PSO algorithm which is a useful and simple method for optimizing a wide range of functions [22]. Due to limited space, we only provide the pseudo code for the optimal power of (13).

Algorithm 1: SBSs transmit power optimization using PSO

Input: SUEs set, SBSs set, SBS's transmit power interval: $(0, P_{\max}]$, resource pool.

Output: Optimal power for each SUE $P_{f,u_f}^{(n)*}$.

Initialize: PP = 30, $c_1 = c_1 = 2$, it = 0, $iterations$ = 500,
for u = 1:u_f
    Compute $g_{f,u_f}^{(n)}$, I.

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for q = 1: PP
Compute $pbest_u$ and $gbest$.
end for
while $it < iterations$
Compute and update inertia weight $w(it) = w_{\max} - \frac{(w_{\max} - w_{\min}) * it}{iterations}$.
for q = 1: PP % particles loop
$P_{f,u_f}^{(n)\ *} = \arg\max_{P_{f,u_f}^{(n)\ q}} (U_{f,u_f}(P_{f,u_f}^{(n)}))$
According to formulas:
$$\begin{cases} v_{u,n}^q(it+1) = w(it)v_{u,n}^q(it) + c_1\xi(pbest_{u,n}^q(it) - x_{u,n}^q(it)) \\ \qquad\qquad + c_2\eta(gbest^q(it) - x_{u,n}^q(it)), \\ x_{u,n}^q(it+1) = x_{u,n}^q(it) + v_{u,n}^q(it+1) \end{cases}$$
Compute and update $P_{f,u_f}^{(n)\ q}(it+1)$, $v_{u,n}^q(it+1)$.
end for
end while
end for

3.3 Coalition Formation Game with Power Control

We assume that there exists a wireless backhaul to connect among SBSs, and our proposed CFG-PC is summarized in three major steps: initialization, coalition formation iteration and inner-coalition transmission. First, all SBSs in the network are partitioned F partitions. Namely, players perform the non-cooperative process. Second, a Nash-stable coalition structure is formed. In the process of forming coalitions, two types of orders control the coalition formation in terms of individual utility and system utility respectively. Third, as soon as coalitions are formed, inner-coalition control sub-channel transmission is performed according to the method of [18]. In summary, the proposed coalition formation game makes players to improve the data rate on the premise without hurting other members' utility.

In addition, SBS's utility obtaining algorithm is mainly composed of the non-cooperative and cooperative case. In the former case, each SUE receives the equal power from the corresponding SBS. In the latter case, for more efficient allocation power resource, each SUE receives the un-equal power from the corresponding SBS according to the real-time sub-channel status and the distance between the current SUE and the corresponding SBS. The calculation of un-equal power is based on Algorithm 1.

Next, we research the stability of formed coalitions according to the concept from [16].

Definition 4. A formed coalition structure or partition $\pi_1 = \{S_1, \ldots S_L\}$ is considered Nash-stable if the following condition is satisfied:

$$\forall f \in \mathbb{F}, f \in S_f, (S_f, \pi) \succ (S_l \cup \{f\}, \pi^*) \ \ for\ all\ S_l \in \pi \tag{14}$$

where $\pi^* = \{\pi \setminus \{S_f, S_l\} \cup \{S_f \setminus \{f\}\} \cup \{S_l \cup \{f\}\}$.

Namely, no player has the motivation to leave its current coalition for another coalition, and then the formed coalition structure or partition is considered Nash-stable.

Proposition 2. Given Pareto order, utilitarian order and the threshold parameter *TH* of the history variable *H*, the above formed coalition always can converge to a Nash-stable coalition structure.

Proof: Proposition 2 is mainly based on two aspects. First, the total number of potential coalition partitions of SBSs set $\mathbb{F}$ is finite (given by a bell number [23]); second, *TH* guarantees that any SBS does not revisit coalitions which have been visited.

Proposition 3. The complexity order of the proposed CFG-PC algorithm is of $O(Q_{ns})$, where Q_{ns} is the average number of neighboring SBSs causing co-tier interference.

Proof: The complexity of the proposed algorithm depends largely on the number of potential formed coalitions. As discussed in Section 3.1 that an SBS has a stronger incentive to form coalitions with the relatively large co-tier interferences in its neighbors, thus only a few SBSs or players, denoted as Q_{ns}, are busy forming coalitions.

4. Simulation Results and Analysis

For simulation, we consider an indoor region $E \times D$ with the different number of SBSs deployed, where *E*, *D* represents the width and length of the indoor, respectively. The value of *E* is fixed on 300 m, but *D* changes with the different number of SBSs in the network. One MBS is deployed outside. Specifically, from the perspective of width, the indoor region is divided into three contiguous cells side by side. Each cell indicates a 100 m × 100 m square and there exists an SBS located at the center of every square. 4 SUEs are randomly distributed in each cell. Each SBS is liable for the downlink transmission of its SUEs concurrently. We assume that each SBS randomly selects 4 corresponding sub-channels to respectively serve 4 SUEs [1] and the total number of MUEs is 6. However, the total number of SBSs and sub-channels are changeable to comprehensively evaluate the proposed CFG-PC algorithm. Each sub-channel bandwidth is 180 kHz. The wall loss attenuation between MBS and SUEs is 20 dBm. The transmit power of an SBS and the MBS is set to P_f = 20 dBm and P_M = 35 dBm respectively. It is worth mentioning that to leverage the changes of the transmission channel, we adopt the Monte Carlo method for each varying amounts of SBSs and sub-channels. All simulation results are averaged on 1000 times.

We first give a snapshot of an SCN which causes from the proposed CFG-PC algorithm deployed within a 300 m × 300 m square region with 9 SBSs. **Fig. 1** shows final Nash-stable coalition partitions result, since no player tries to leave its own coalition for another. To clarify figure, MBS is located outdoors and its MUEs are not shown. As shown in **Fig. 1**, the set of coalitional partition is $\pi = \{S_1, S_2, S_3, S_4\}$, of which every coalition member is S_1 = {SBS1, SBS2}, S_2 = {SBS3}, S_3 = {SBS4, SBS6, SBS7}, S_4 = {SBS5, SBS8, SBS9} respectively.

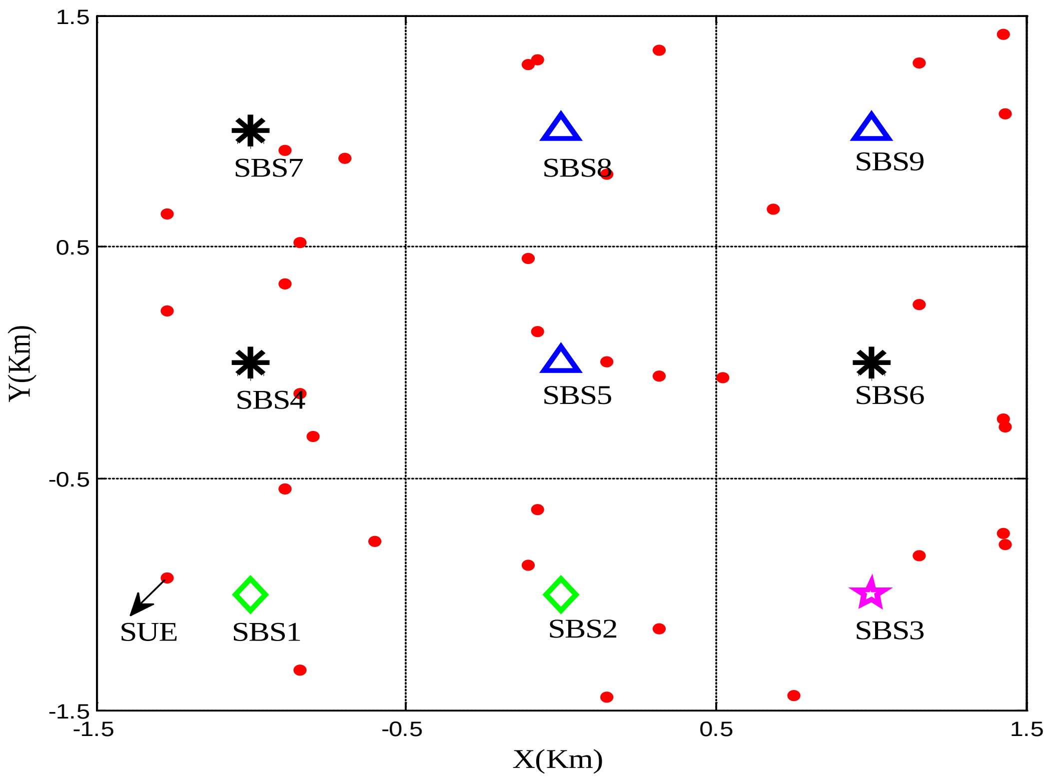

Fig. 1. A snapshot of an enterprise scenario with SCNs causing from the proposed algorithm with F =9 SBSs, N = 20 sub-channels, 4 SUEs in per SBS.

In **Fig. 2**, we show that the average utility of per SBS versus the number of SBSs in the SCN is in accordance with Pareto order, by comparing with RCA [11] without considering the real-time power allocation and non-cooperative case with our proposed method. As shown in **Fig. 2**, the average data rate of per SBS achieved by our proposed algorithm outperforms other two cases. When the network size is small (N = 3), the performance of all three cases is similar owing to the limited options as for the cooperation. In addition, when only three SBSs locate in the network, the desired mitigating interference is relatively small. Nevertheless, with the increasing number of SBSs, there are more opportunities among SBSs to cooperate for reducing the interference. As shown in **Fig. 2**, the data rate of per SBS is improved as the number of SBSs increases, especially the proposed algorithm. The simulation result shows that the proposed CFG-PC algorithm has a great advantage in terms of the average data rate of per SBS versus the number of SBSs, respectively reaching up to 37.27% and 142.84%, which are relative to RCA and non-cooperative for a large size SCN of 27 SBSs.

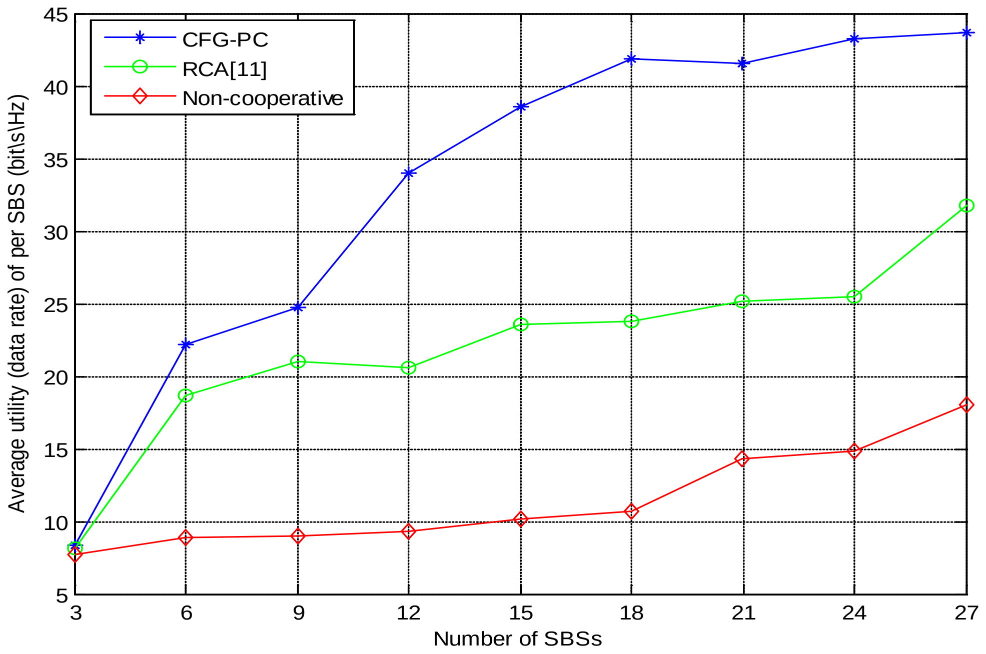

Fig. 2. Average utility of per SBS versus number of SBSs *F*.

In **Fig. 3** illustrates that system utility versus the number of SBSs in the SCN is in accordance with utilitarian order. Similarly, by comparing with two cases, the simulation result is shown. The analysis process of **Fig. 3** is similar to **Fig. 2**, which is omitted here. As shown in **Fig. 3**, using CFG-PC algorithm, system utility also outperforms RCA and non-cooperative by 42.46% and 187.66% for 27 SBSs respectively.

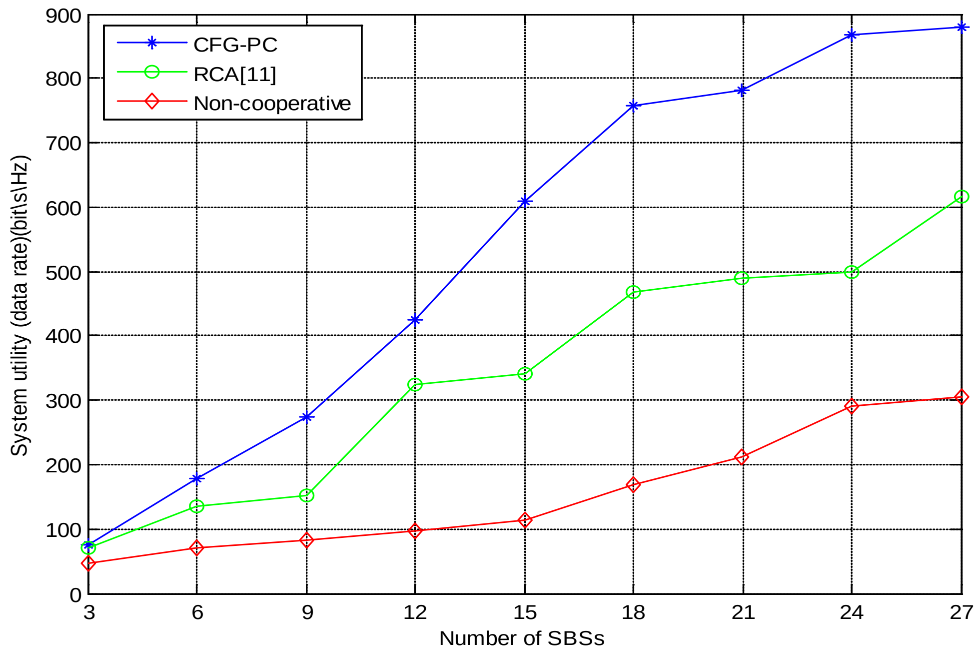

Fig. 3. System utility versus number of SBSs *F*.

Fig. 4 and **Fig. 5**, respectively, show that the cumulative density function (CDF) of the average utility of per SBS and the system utility for the fixed number of sub-channels. These CDF curves are separately caused by non-cooperative case, the RCA scheme and CFG-PC algorithm from left to right. As seen from two figures, CFG-PC algorithm executes better than two other cases, whether in terms of the average utility per SBS or in terms of system utility. The reason is that CFG-PC algorithm yields a more flexible transmit power allocation method rather than to perform the constant power model from the SBS to its SUEs. Particularly under the large scale network, this advantage is more apparent. In addition, we adopt the co-channel frequency assignment scheme rather than the orthogonal frequency assignment, which is also to improve the performance to some extent. Moreover, the two CDF results are also further confirmed our results in **Fig. 2** and **Fig. 3**.

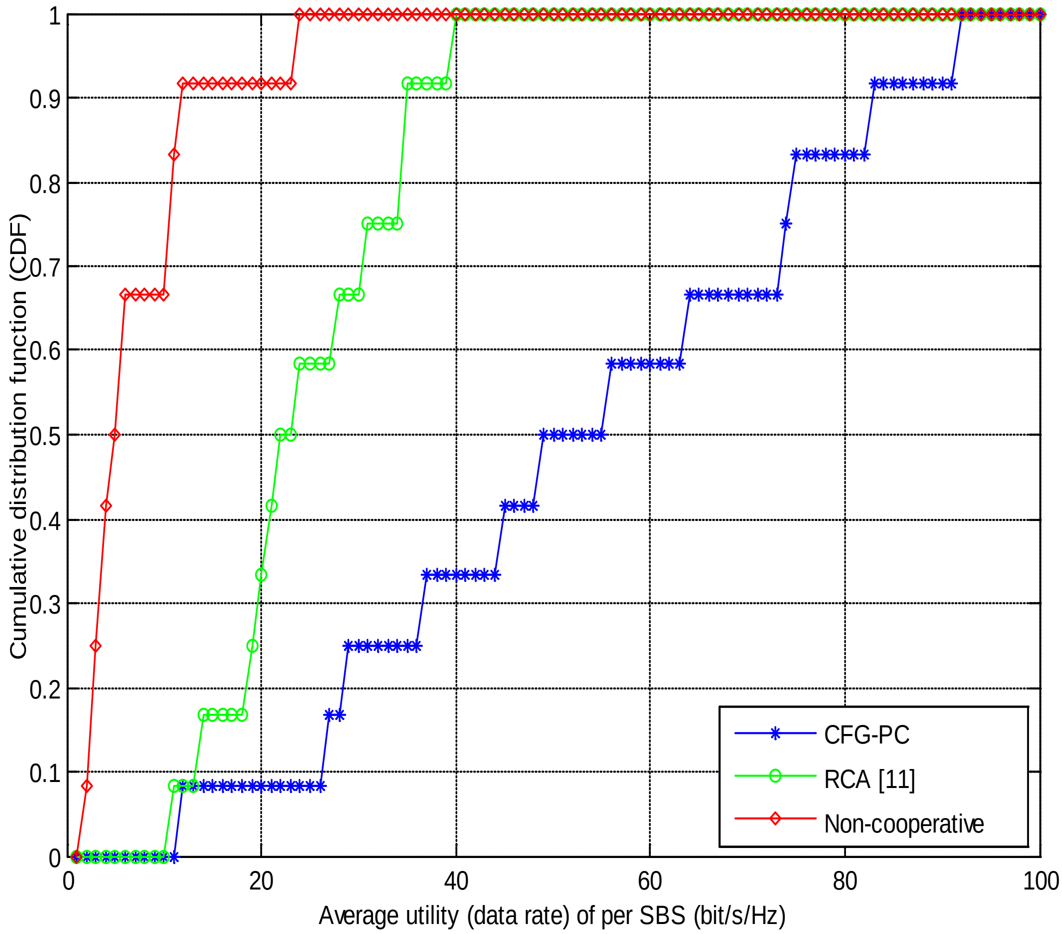

Fig. 4. Cumulative distribution function of the average utility of per SBS.

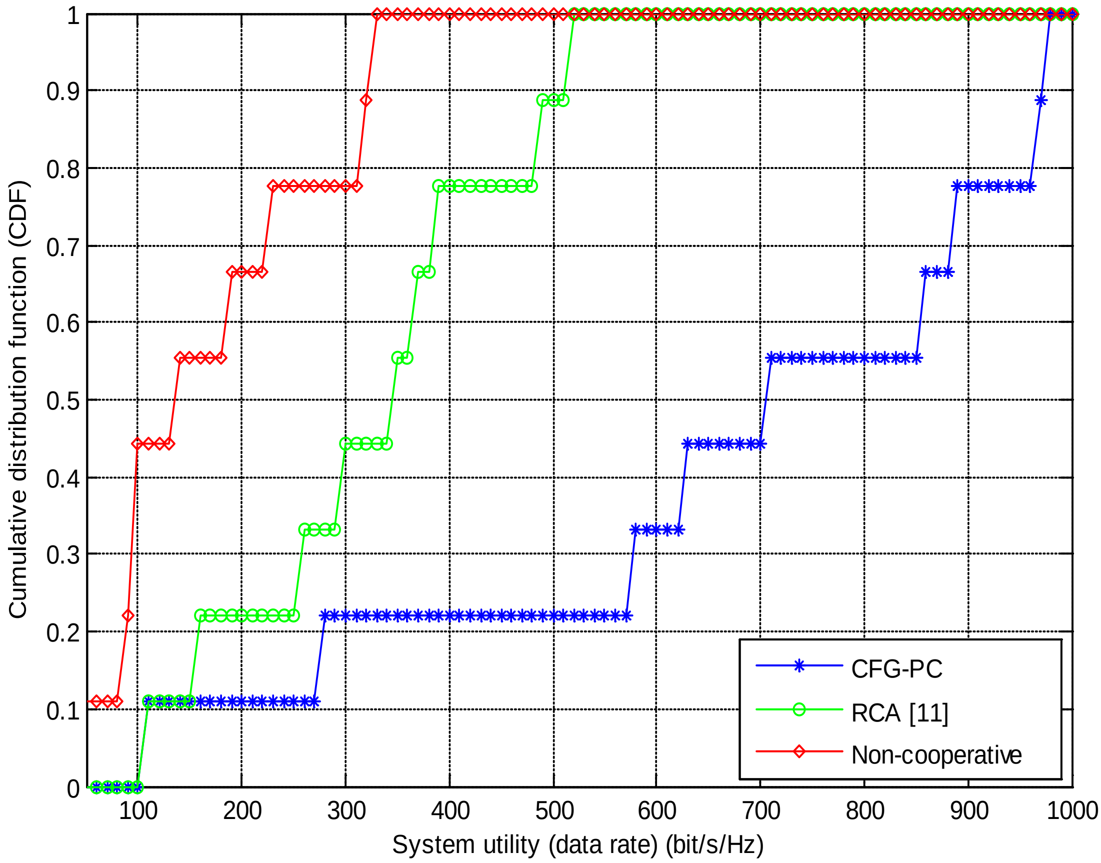

Fig. 5. Cumulative distribution function of the system utility.

In **Fig. 6**, through the comparison of CFG-PC algorithm and RCA scheme as well as non-cooperative case, we show the system data rate versus the total number of sub-channels in an SCN with the fixed number of 9 SBSs. From **Fig. 6**, the system data rate is successively improved with the increasing total number of available sub-channels. The reason is that for the ever-increasing N, the possibility of each sub-channel occupied is gradually decreased under any cases. Therefore, whether the co-tier interference or the cross-tier interference (note: the more the number of available sub-channels in the two-tier SCN, the effect of the cross-tier interference is more negligible), is reduced and the system performance is improved.

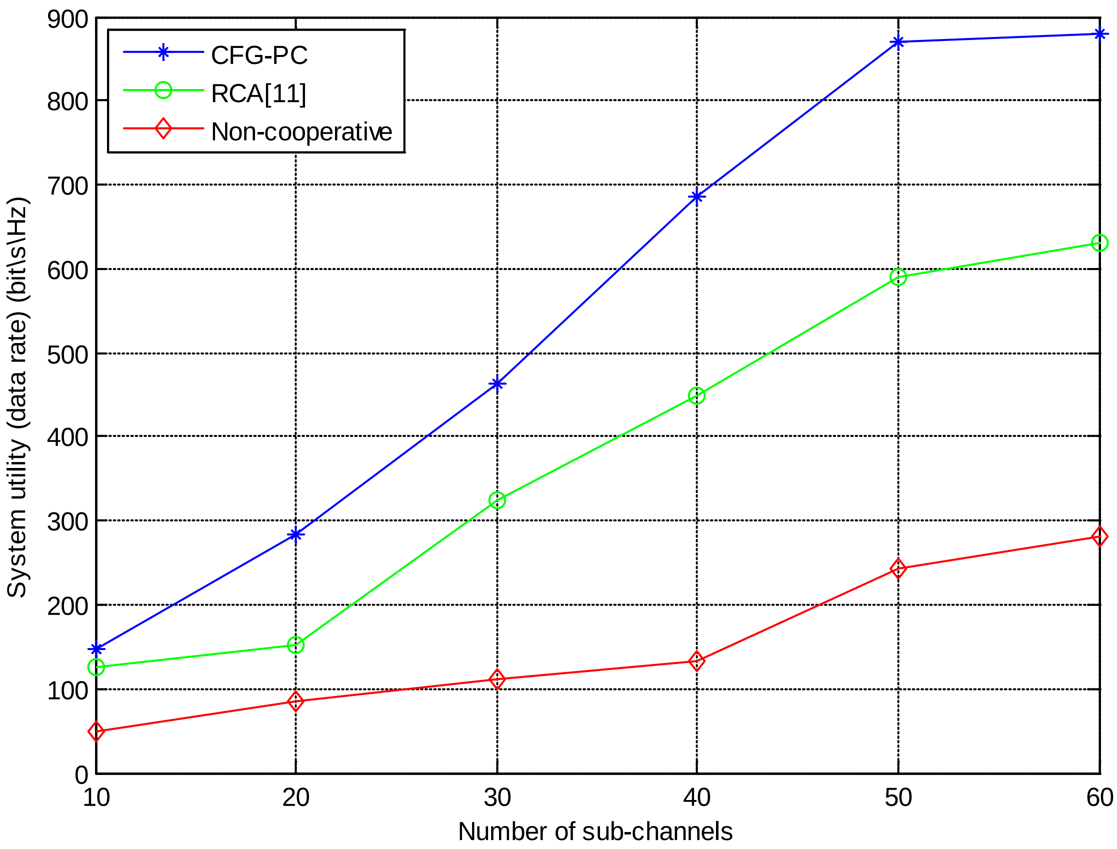

Fig. 6. System utility versus number of sub-channels *N*.

In previous simulations, we assume that the wall loss attenuation between MBS and SUEs is set to 20 dBm and there is no wall between SBSs and SUEs. However, in order to describe the effect of channel characteristics on the results, we modify the above simulation parameter, i.e., the wall loss between SBSs and SUEs is also set to 20 dBm. In this case, the cross-tier interference has more influence on the network system than ever, i.e., there is no wall between SBSs and SUEs such as in **Fig. 3**. As shown in **Fig. 7**, CFG-PC algorithm also has an advantage comparing with RCA and non-cooperative. Without doubt, due to the more influence of cross-tier interference, the advantage of CFG-PC algorithm in **Fig. 7** is less effective than in **Fig. 3**.

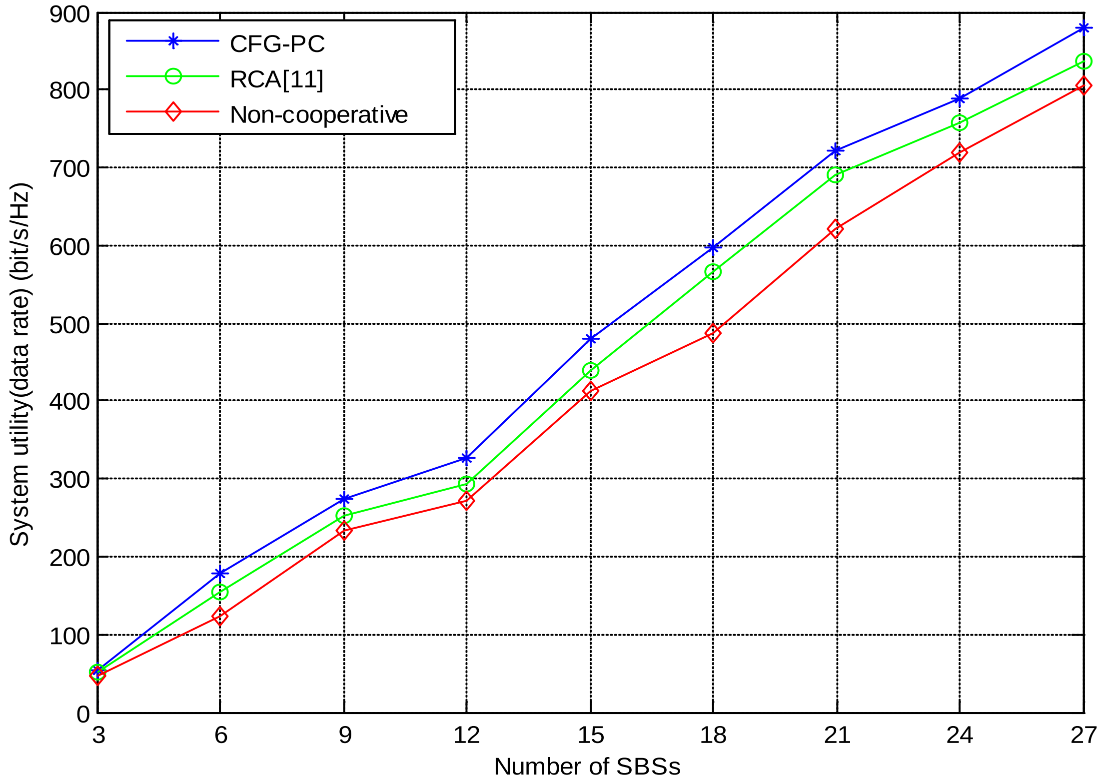

Fig. 7. System utility with wall loss in the SBS tier versus number of SBSs *F*.

5. Conclusion

In this paper, we presented an expanded approach based on coalition formation games to address the resource allocation problem in an SCN. First, the co-channel frequency assignment was adopted to improve spectrum efficiency. Second, we formulated the sub-channel allocation problem as a coalition formation game between the SBSs. Pareto order and utilitarian order were used to evaluate the data rate in two aspects：individual and system. Third, on the basis of formed coalitions, we expanded the power control by means of PSO so that the power of each SUE achieved was more available. Simulation results showed that our CFG-PC yielded a notable performance advantage relative to both RCA scheme and non-cooperative case. For the future work, we plan to study the generalized scenario with more than one MBS or both MBS and SBSs outside. In these scenarios, how to solve the cross-tier interference will be focused on.

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