Frequency Collision Elimination Method Based on Negotiation and Non-Cooperative Game in Femtocell Networks

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Abstract —In the user deployed femtocell networks, the frequency collision dramatically decreases the throughput of femtocell networks. In this paper, we propose a frequency collision elimination method based on negotiation and non-cooperative game to avoid frequency collisions between neighboring femtocells. The frequency collisions inside a cluster are figured out by using the negotiation mechanism. The game theoretical mechanism deals with the inter-cluster frequency collisions. The femtocell network gets an equilibrium point rapidly by using the proposed methods in the context of stable femtocell network topology. Furthermore, the method is achievable in realistic communication system. Simulation results show that the proposed scheme significantly reduces the interference and considerably increases the average capacity of femtocells.

Index Terms—Femtocell network, fractional frequency reuse, frequency collision, game theory

I. Introduction

Femtocell is introduced in wireless networks as a new type of access technology. Femtocell base stations (FBSs) are usually placed by users randomly. Spectrum sharing in two-tier heterogeneous networks may lead to co-channel interference between femtocell and macrocell and even among femtocells. The interferences brought by femtocells are discussed in [1], according to which, the interference between femtocells is the most complex one. Furthermore, as the number of femtocells increases, the amount of inter-femtocell interference will increase significantly [2], [3]

To deal with the co-channel interferences, researchers have proposed several spectrum allocation methods. In [4], the fractional frequency reuse (FFR) method is directly implemented in LTE femtocell systems. In [5], the FFR is improved and adaptively configured to avoid interference caused by femtocells, according to density and locations of femtocells. Recently, game theory has been used for spectrum allocation in femtocell networks. For instance, in [6], the authors propose a distributed spectrum allocation algorithm, which is an adaptive extension of the regret matching procedure and gets a correlated equilibrium. In [7], the proposed game-theoretical radio resources management achieves better performance than that of the equal division. In [8], a cooperative solution is used to improve the achievable data rates of femtocell network.

The various resource management methods mentioned above, however, do not take into account the issue of frequency collision, which means that the neighboring femtocells are unable to reuse the sub-bands orthogonally. In fact, since FBSs are randomly deployed by users, the frequency collision is inevitable in femtocell networks, as shown in Fig. 1. Thus, it is necessary to develop a method for frequency collision avoidance between neighboring femtocells.

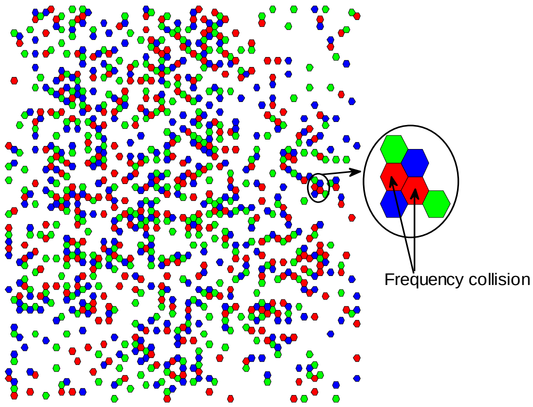

Fig. 1. An example of frequency collision in a femtocell network.

In this paper, we propose a method dealing with frequency collisions in femtocell networks based on negotiation and non-cooperative game. We have proven the convergence of the proposed method and analyzed its feasibility in the LTE system. After a femtocell network is divided into some femtocell clusters by distributed methods [9], the proposed method consists of two components: negotiation inside a cluster and inter-cluster game-theoretical mechanism. Through employing the proposed method, spectrum resources are effectively reused in the femtocell networks. Simulation results show that the average capacity is considerably increased by adopting the proposed method. The major contribution of this paper is that we propose a distributed and self-

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organizing frequency collision elimination method, which significantly enhances the performance of randomly deployed femtocell networks.

The rest of the paper is organized as follows. Section II describes the system model of femtocell networks. In Section III, details of the proposed method are given. Feasibility and convergence of the algorithm is analyzed in Section IV. Section V presents the simulation results. Finally, Section VI concludes the work.

II. System Model

We consider the scenario that femtocells and macrocell occupy non-overlapping spectrum bands, and focus on the frequency collisions among femtocells. In the femtocell networks, the available frequency resources are divided to K sub-bands. Each femtocell competes with its neighboring femtocells to get an available sub-band according to the spectral sensing results.

According to [9], a femtocell network usually can be divided to a number of femtocell clusters by self-organizing method. The cluster consists of a cluster head member and several common members surrounding the cluster head, which means that the cluster head is the central femtocell of the cluster, as shown in Fig.2. The cluster structure facilitates the invitation for new members and information exchange inside a cluster. In the femtocell network, the achievable signal to interference plus noise ratio (SINR) on sub-band k of femtocell i in cluster n can be expressed as

$$\begin{aligned} SINR_{n,i,k} &= \frac{P_{n,i,k}G_{n,i,k}}{I + I' + N_0\Delta f} \\ I &= \sum_{j\neq i} P_{n,j,k}G_{n,j,k}, \\ I' &= \sum_{n'\neq n}\sum_{i'} P_{n',i',k}G_{n',i',k} \end{aligned} \tag{1}$$

where k is the sub-band index, n and n' are the cluster index, i , i' and j are the femtocell index, N is the total number of clusters, Δf is the bandwidth of a sub-band, and N_0 represents the power spectral density of white Gaussian noise. Let $P_{n,i,k}$ represent the useful transmit powers on sub-band k of femtocell i in cluster n . Then $P_{n,j,k}$ and $P_{n',i',k}$ are co-channel interference powers from femtocell j in cluster n and femtocell i' in cluster n' , respectively. $G_{n,i,k}$, $G_{n,j,k}$ and $G_{n',i',k}$ are the channel gain corresponding to the transmit power $P_{n,i,k}$, $P_{n,j,k}$ and $P_{n',i',k}$, respectively. Here, co-channel interferences are divided into the interference of inner-cluster and that of inter-cluster, which are denoted as I and I' respectively. Consequently, the capacity of femtocell i on sub-band k in cluster n can be given by

$$C_{n,i,k} = \Delta f log_2(1+\alpha SINR_{n,i,k}) \tag{2}$$

where α is SINR gap for target bit error rate (BER) [10]. According to the above discussion, the capacity decreases with the power increase of co-channel interferences I , I' and white Gaussian noise. In a femtocell network, frequency collisions induce co-channel interferences. In order to increase the capacity, we aim to find a method for co-channel interferences reduction by eliminating frequency collisions.

III. Proposed Method

In the aforementioned scenario, the centralized method is difficult for elaboration. We aim to find a distributed algorithm to solve this problem. According to (1), the capacity of femtocells can be increased by reducing co-channel interferences of inner-cluster and inter-cluster, respectively. Considering a femtocell cluster is much smaller than the femtocell network, we introduce a cooperative method inside the cluster, which is a negotiation mechanism to eliminate the frequency collisions. It is proven that frequency collisions inside a cluster are tackled by using the negotiation. Then, a non-cooperative game-theoretical mechanism is used to eliminate frequency collisions of inter-cluster. Finally, the femtocell network gets an equilibrium point. Details of the proposed method are described as follows.

A. Minimization of I : Inner-Cluster Negotiation Mechanism

Algorithm 1 : Negotiation between neighboring femtocells within the same cluster. To be executed by each femtocell i

Detect frequency collision.
if femto-cell i is conflicted **then**
  if femto-cell i received request **then**
    Accept or reject the request according to its radio circumstance
  else
    Send request to neighboring femtocells.
    repeat
      if a neighbor accept the request **then**
        Execute the request.
        Break
      end if
    untill waiting time is over
  end if
end if

In a femtocell cluster, the central femtocell, namely, the cluster head chooses the sub-band firstly and other femtocells reuse the remainder sub-bands. Each edge femtocell always detects whether is using the same sub-band with its neighboring femtocells that are belong to the same cluster. Once a frequency collision is detected, the involved femtocell will negotiate with its neighboring femtocells to avoid being interfered. The negotiation process is described as follows. If a femtocell detects frequency collision with its neighboring femtocell, it sends requests to all its neighboring femtocells if it receives no request from them. If the femtocell uses the same sub-band with a neighboring femtocell, the request $R=0$ is used to ask the neighboring femtocell to choose another sub-band. If a femtocell uses different sub-band with a neighboring femtocell, the request $R=1$ is used to ask the femtocell to exchange their sub-bands. The femtocell executes the request only when its request is accepted by the neighboring femtocell, otherwise it abandons the request after a certain waiting period. If a femtocell receives a request, it makes decision according to its ambient radio environment as shown in **Algorithm 1.**

In order to avoid the Ping-Pong effect, the back-off period τ is set as a random variable. Due to such a random back-off period, all the femtocells have the equal chance to eliminate frequency collision.

B. Minimization of I': Inter-Cluster Non-Cooperative Game-Theoretical Mechanism

After the inner-cluster negotiating, we need to eliminate the inter-cluster frequency collisions. We propose a non-cooperative game-theoretical method to further decrease frequency collisions. Let $\{0,1,...,N\text{-}1\}$ denote the set of clusters in a femtocell network, and $n \in \{0,1,...,N-1\}$ denote the cluster index. N is the total number of the clusters. Let Ω_n denote the strategy space of cluster n and $s_n \in \Omega_n$ denote the selected strategy by cluster n. Therefore, the strategy set of all clusters can be denoted as $S=(s_0,s_1,...,s_{N-1})$. For each strategy set S, let $u_n(S)$ denote the utility function of cluster n. Here, the utility function is defined as following.

$$u_n(S)=\sum_{i=0}^{L_n-1} C_{n,i} \tag{3}$$

where $C_{n,i}$ is the capacity of femtocell i on the selected sub-band in cluster n, and L_n is the total number of members in cluster n. Generally, $-n$ is used to denote all the clusters except cluster n. Then the strategy set $S=(s_0,s_1,...,s_{N-1})$ can be expressed as $S=(s_n,s_{-n})$. For cluster n, it always chooses the optimal strategy s_n^* to get the largest utility, that is

$$\forall s_n \in \Omega_n; u_n(s_n^*,s_{-n}^*) \geq u_n(s_n,s_{-n}^*) \tag{4}$$

The non-cooperative method is used to select the optimal strategy for each femtocell cluster, depending on their interferences. The algorithm is executed in parallel by each cluster. The process of the algorithm is illustrated by **Algorithm 2**.

During a measuring slot, every femtocell in the cluster n measures $SINR_{n,i,k}$ and calculates $C_{n,i,k}$. Then the edge femtocells send their current sub-bands and results of calculated capacity on all sub-bands to the central femtocell. The cluster head femtocell finds out the optimal strategy by (4). Finally, the optimal strategy is carried into execution if necessary. The optimal strategy means that the whole cluster suffers the least inter-cluster interference I'.

Algorithm 2: Inter-cluster non-cooperative game-theoretical mechanism. To be executed by each cluster n

1: Measure $SINR_{n,i,k}$ by each femtocell i on all sub-bands, $i=1,2,...,L_n; k=1,2,...K$.
2: Calculate $C_{n,i,k}$ by equation (2).
3: Send $C_{n,i,k}$ and current strategy to central femtocell.
4: Select the optimal strategy by equation (4).
5: **if** current strategy is not the optimal strategy **then**
6: Execute the optimal strategy.
7: **end if**

IV. Algorithm Analysis

Both **Algorithm 1** and **Algorithm 2** are executed in parallel inside each cluster. **Algorithm 1** figures out frequency collisions inside a cluster. **Algorithm 2** offers each cluster the optimal frequency reuse strategy under its current ambient radio environment. The feasibility of the method, convergence of **Algorithm 1** and equilibrium of **Algorithm 2** are analyzed in this section.

A. Feasibility of the Proposed Method

Feasibility of the proposed method is determined by two factors, namely information exchange and parameters measurement. Both **Algorithm 1** and **Algorithm 2** need information exchange between neighboring femtocells. Fortunately, it is possible in the LTE system to build an interface based on IP address between neighboring femtocells, which supports the distributed transmission of information between neighboring femtocells [11]. The parameters needed by inter-cluster game-theoretical mechanism can be indirectly obtained by measuring Reference Signal Received Power and Received Signal Strength Indicator in the LTE system [11]. In summary, the proposed method can be implemented in the LTE system.

B. Convergence of Algorithm 1

As shown in Fig. 2, edge femtocells surround the cluster head. We number the edge femtocells from 0 to L_n-2, and femtocell i is adjacent to femtocell $i+1(\bmod\ L_n-1)$ for analytical tractability. Let f_i denote the sub-band used by femtocell i. If femtocell i detects frequency collision, there are three possible situations respectively described by

$$f_i = f_{i-1(\bmod\ L_n-1)}, f_i \neq f_{i+1(\bmod\ L_n-1)} \tag{5}$$

$$f_i \neq f_{i-1(\bmod L_n - 1)}, f_i = f_{i+1(\bmod L_n - 1)} \quad (6)$$

$$f_i = f_{i-1(\bmod L_n - 1)}, f_i = f_{i+1(\bmod L_n - 1)} \quad (7)$$

Let f'_i represent the sub-band of femtocell i after a successful negotiation finished. Let q represent the number of frequency collisions before a negotiation, and q' represent the number of frequency collisions after a negotiation. For (5), a negotiation leads to two possible results represent by (8) and (9), respectively.

$$q' = \begin{cases} q-1 & f'_{i+1(\bmod L_n-1)} = f_{i+2(\bmod L_n-1)} \\ q & f'_{i+1(\bmod L_n-1)} \neq f_{i+2(\bmod L_n-1)} \end{cases} \quad (8)$$

$$q' = \begin{cases} q & f'_{i-1(\bmod L_n-1)} = f_{i-2(\bmod L_n-1)} \\ q-1 & f'_{i-1(\bmod L_n-1)} \neq f_{i-2(\bmod L_n-1)} \end{cases} \quad (9)$$

(8) means that request $R=1$ is executed and femtocell i and femtocell $i+1$ exchange their sub-bands. (9) means that request $R=0$ is executed, and femtocell $i-1$ chooses another sub-band. In fact, (6) represents the same situation as (5), and gets the same result as (5). For (7), femtocell i will find an available sub-band, and that is

$$q' = q - 2 \quad (10)$$

The number of frequency collisions keep constant or decrease after a negotiation finished. Let m denote number of frequency collisions in a cluster, and m can be modeled as a Markov process.

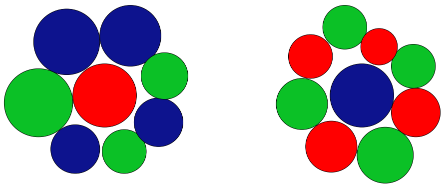

Fig. 2. Examples of spectrum allocation inside a cluster. If the number of edge femtocells is odd, then $e=1$, otherwise $e=0$.

We introduce **Theorem 1**, which proves that frequency collisions are minimized by using the negotiation mechanism (**Algorithm 1**) inside a cluster. Let e represent least number of frequency collision. In the discussed scenario $e = 0$ *or* 1, for example as shown in Fig. 2.

Theorem 1: Frequency collisions can be minimized by using the negotiation mechanism (**Algorithm 1**) inside a cluster.

Proof: See Appendix A.

Moreover, a cluster only needs a few negotiations to minimize the frequency collisions, which has been proven by simulation.

C. Correlated Equilibrium under Algorithm 2

Since the discussed scenario is a finite game, there is at least one Nash equilibrium in mixed strategy [12], which means the femtocell network gets a dynamic equilibrium point. In the discussed scenario, the Nash equilibrium can be improved to be a correlated equilibrium. Correlated equilibrium has been introduced as a concept suitable for scenarios that involve a decision process in between noncooperation and cooperation. Any Nash equilibrium can be represented as a correlated equilibrium when players can generate their optimal strategy independently [6]. In the discussed scenario, since each cluster only controls over its own strategy, the optimal strategy depends on the rational consideration of the strategies from other clusters. In (4), the optimal strategy can be generated for every cluster independently by using **Algorithm 2**. Hence, the femtocell network gets a correlated equilibrium by using **Algorithm 2**. Furthermore, the correlated equilibrium leads to an improved performance over a Nash equilibrium [13].

Moreover, a femtocell network gets a stable equilibrium point by executing **Algorithm 2**, in the context of stable femtocell network topology. Since each cluster gets exact information of its ambient radio environment and **Algorithm 2** can be independently executed in different clusters, the inter-cluster game can be regarded as a game of perfect information [14]. In a femtocell network, clusters do not stop executing **Algorithm 2** until the femtocell network reaches an equilibrium point. According to (4), each cluster improves its total capacity shown as (3) through getting a dominant pure strategy. Hence, a femtocell network gets a stable equilibrium point finally if the point is existent, which can be proven by backward induction [14]. Actually, there is at least one stable equilibrium point, which means all the FBSs orthogonally get an available sub-band. Hence, the femtocell network gets a stable equilibrium point by implementing the proposed method. Furthermore, simulation results show that femtocell networks reach a stable equilibrium point when its topology is stable.

TABLE I: SIMULATION PARAMETERS

Cell Coverage	30 m
Target BER	10-6
SINR Gap (α)	-1.5/ln(5*BER)
Channel Bandwidth	3MHz
Transmission power	20dBm
AWGN power	-90dBm
Path Loss	$PL[dB] = L_{50}(r) + L_{FM} + L_W$; $L_{50}(r)[dB] = 20\log_{10} f_c + 10\lambda \log_{10} r + L_f(n_f) - 28$; $L_{FM} = 7.7\ dB$; $L_W = 0\ dB$; $f_c = 2\ GHz$; $\lambda = 2.8$; $n_f = 0, L_f(n_f) = 0$; $PL = \infty, if\ r > 400m.$

V. SIMULATION RESULTS

In this paper, we focus on the frequency collisions in femtocells network of rotundity-shaped cell layout. Initially, each femtocell competes for an available sub-band. If there is no available sub-band, femtocell has to share a sub-band with one of its neighboring femtocells. Users are randomly and uniformly located in femtocell network. We use the path loss model proposed by ITU-R P.1238 [15]. Since we use statistical average capacity to evaluate the proposed method, we ignore the effect of small-scale fading. Simulation parameters are listed in Table I.

We compare the proposed method with general FFR method and selfish competing method. Moreover, the average capacity of ideal situation is given as a reference, where there is no frequency collision in femtocell networks. Simulation results are shown as follows.

Firstly, we have evaluated convergence rate of the negotiation mechanism by simulating. Fig. 3 shows the statistical results of the number of negotiations a cluster needs to deal with frequency collisions. According to Fig. 3, nine negotiations can almost ensure that all clusters decrease frequency collisions as much as possible. Furthermore, more than 91% of clusters can tackle frequency collisions by less than five negotiations.

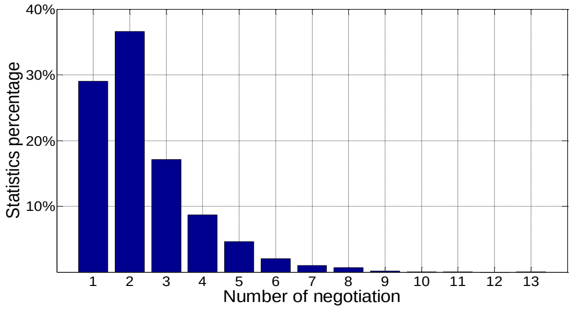

Fig. 3 Statistical results of the number of negotiations inside a cluster.

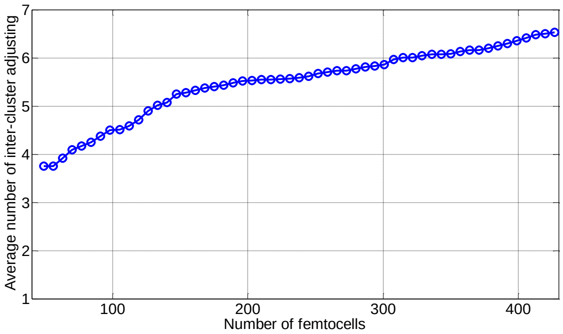

Fig. 4. Average number of inter-cluster adjusting times during implementing Algorithm 2 under different network size.

Fig. 4 illustrates the convergence rapidity of inter-cluster game-theoretical mechanism in context of stable femtocell network topology. Since the inter-cluster game-theoretical mechanism is executed in parallel inside different clusters, the average number of inter-cluster adjusting times can show the convergence rapidity of **Algorithm 2**. It is shown that femtocell network reaches an equilibrium point by less than seven parallel inter-cluster adjustments.

Fig. 5 shows the average capacity of femtocells when the spectrum resources are divided to different number of sub-bands. Generally, frequency collisions in femtocell network can be mitigated by increasing K. Hence, we show the results of ideal frequency reuse method with $K=3$, $K=4$ and $K=5$, respectively. Obviously, the bandwidth of sub-band for each femtocell is reduced once the number of sub-bands increases, which decreases the average capacity of femtocell networks as shown in Fig. 5. Furthermore, the proposed method even outperforms the ideal situation with four and five sub-bands. Hence, we compare the proposed method with existing methods setting $K=3$.

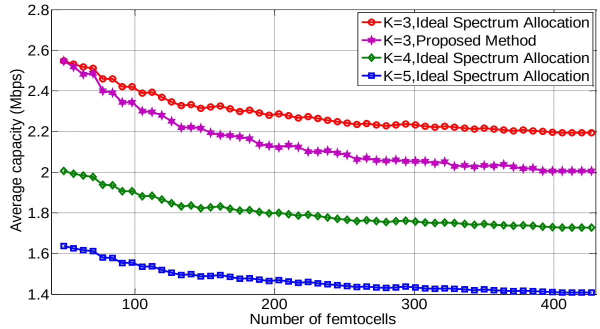

Fig. 5. Average capacity of femtocells under different network size. Spectrum resources are divided to three or seven sub-bands.

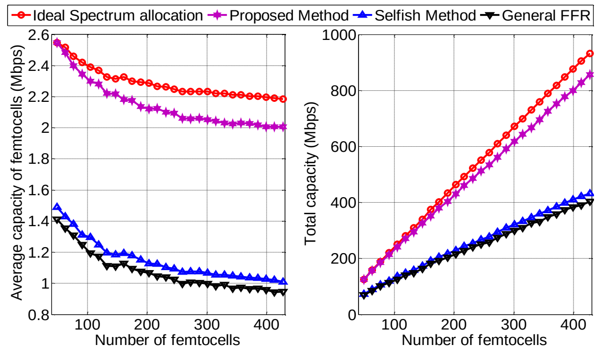

Fig. 6. Average capacity of femtocells and total capacity of femtocell networks under different network size.

Fig. 6 illustrates the average capacity of a femtocell in a femtocell network with different methods. As shown in Fig. 6, femtocell network using general FFR, which has no measure for frequency collisions, gets the worst performance. Selfish method, by which each femtocell chases individual interests alone, improves a little capacity. Obviously, the proposed method increases the average capacity dramatically. In small-scale femtocell networks, the proposed method can even perform as well as ideal situation where there is no frequency collision between neighboring femtocells. If the number of femtocells exceeds 400, the proposed method almost gets a constant average capacity. Different from average capacity, the total capacity increases with the number of femtocells. The proposed method gets a much faster growth rate than general FFR and selfish method.

In Fig. 7, we show the results of Price of Anarchy (PoA), which measures how the efficiency of a system degrades due to selfish behavior. Here, the PoA is defined as $\frac{\max_{S\in\Omega^n} u_n(S)}{\min_{S\in\Omega^n} u_n(S)}$, which is the ratio between the "worst equilibrium" and the ideal spectrum allocation. The results show that the proposed method performs as well as the ideal spectrum allocation in the small number of femtocells. In the large number of femtocells, the PoA is less than 1.2.

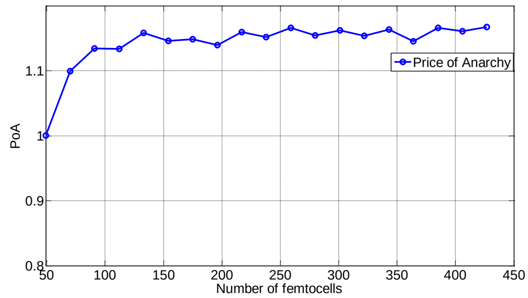

Fig. 7. Price of Anarchy versus number of femtocells.

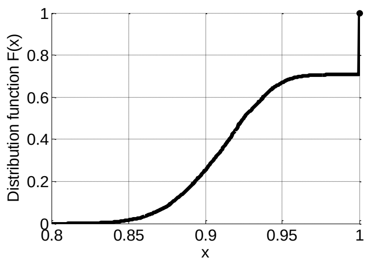

Fig. 8. Distribution function of average capacity of femtocell network.

Fig. 8 illustrates the distribution function of capacity of a femtocell network achieving the proposed method. The distribution function is $F(x) = P(c \le x)$, where c denotes the normalized capacity of a femtocell network and $P(\bullet)$ denotes statistical probability. The proposed method achieves more than 80% of the ideal capacity. The point $x=1$ means that femtocell networks get the optimal equilibrium point with 30% probability. Hence, the capacity of femtocell networks can be dramatically increased.

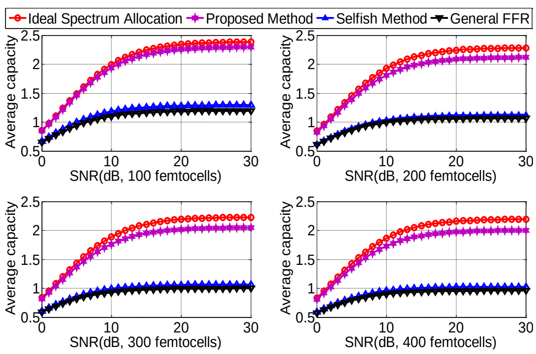

Fig. 9. Results of average capacity under varied white Gaussian noise in femtocell networks with 100, 200, 300 and 400 femtocells, respectively.

Fig. 9 simulates the proposed algorithm with respect to different noise level and different network scale. The white noise power varies from -65dBm to -95dBm, namely average signal to noise ratio (SNR) in a femtocell varies from 0dB to 30dB, where $SNR = (P_{n,i,k} G_{n,i,k})/(N_0 \Delta f)$. The proposed method is shown to be stably superior to general FFR and the selfish method. The results illustrate that co-channel interference is the main factor of decrease of average capacity when SNR is larger than 10dB.

In summary, frequency collisions decrease femtocell capacity significantly. The proposed method dramatically increases the average capacity of femtocell networks. The inner-cluster negotiation converges rapidly and femtocell network gets an equilibrium point quickly. The proposed method outperforms the existing methods for frequency spectrum allocation.

VI. Conclusions

In this paper, a negotiatory and game-theoretical method has been proposed to reduce the frequency collisions in the femtocell network. The negotiation mechanism has been proven capable of minimizing the frequency collisions in a cluster. Femtocell networks can reach an equilibrium point rapidly by using the proposed method. Information exchange between neighboring femtocells and parameters measuring required by the proposed algorithm are supported by LTE standard. The proposed method can be a prospective choice for industry to enhance capacity of their products. Simulation results show that the proposed method enhances the capacity of femtocell and decreases interferences caused by frequency collision.

Appendix A Proof of Theorome 1

Let $\beta_{m,m'}$ denote the one-step transition probability with which the number of frequency collision decreases from m to m' in a cluster after the inner-cluster negotiation algorithm is executed once. According to the (8), (9) and (10), the one-step transition probability of the number of frequency collision is subjected to

$$\begin{cases} \beta_{m,m}' = 1 & (m = m' = e) \\ \beta_{m,m'} = 0 & (m > m'+2 \ or \ m < m') \\ \beta_{m,m'} \in (0,1) & (m' \le m \le m'+2). \end{cases} \tag{11}$$

Let M represent the largest number of frequency collisions. Thus, the one-step transition probability matrix can be expressed as follows.

$$B = \begin{bmatrix} \beta_{e,e} & \beta_{e,e+1} & \cdots & \beta_{e,M-1,} & \beta_{e,M} \\ \beta_{e+1,e} & \beta_{e+1,e+1} & \cdots & \beta_{e+1,M-1} & \beta_{e+1,M} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \beta_{M-1,e} & \beta_{M-1,e+1} & \cdots & \beta_{M-1,M-1} & \beta_{M-1,M} \\ \beta_{M,e} & \beta_{M,e+1} & \cdots & \beta_{M,M-1} & \beta_{M,M} \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & \cdots & 0 & 0 \\ \beta_{e+1,e} & \beta_{e+1,e+1} & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & \beta_{M-1,M-1} & 0 \\ 0 & 0 & \cdots & \beta_{M,M-1} & \beta_{M,M} \end{bmatrix}. \tag{12}$$

Let $\Pi = [\pi_e, \pi_{e+1}, ..., \pi_{M-1}, \pi_M]$ represent stationary distribution when the negotiation finished. Then there is $\Pi = \Pi B$, namely

$$\begin{cases} \pi_M = \beta_{M,M}\pi_M \\ \vdots \\ \pi_m = \pi_{m+2}\beta_{m+2,m} + \pi_{m+1}\beta_{m+1,m} + \pi_m\beta_{m,m} \\ \vdots \\ \pi_e = \pi_e + \pi_{e+1}\beta_{e+1,e} + \pi_{e+2}\beta_{e+2,e}. \end{cases} \tag{13}$$

Combining (11) and (13), there are $\pi_M = \pi_{M-1} = \cdots = \pi_{e+1} = 0$ and $\pi_e = 1$, which means that frequency collisions are decreased as much as possible by using the negotiation mechanism.

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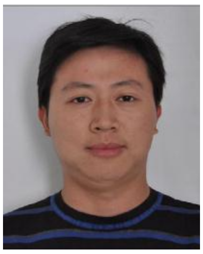

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