Dynamic Clustering based Sub-band Allocation in Dense Femtocell Environments

Wei Li[2], Wei Zheng[2], Wen Xiangming [1], Tao Su[2]
Beijing university of posts and telecommunications
Beijing, P.R. China, 100876
Email: [1]{wangjian2010}@bupt.edu.cn, [2]{liweikk, zhengweius, sutao1987}@gmail.com

***Abstract*—In order to mitigate inter-femtocell interference (IFI) and utilize spectrum resource efficiently, this paper proposes a dynamic clustering-based sub-band allocation scheme (DCCSA). Firstly, DCCSA constructs a weighted interference graph base on the user measurement report mechanism. Secondly, according to the interference graph, the disjoint IFI-minimizing clusters are formed by a Max k-Cut clustering algorithm. Thirdly, a SINR-maximizing heuristic algorithm assigns sub-bands to each cluster. Finally, due to the time variation characteristic of the femtocell networks, a cognitive sub-band self-management mechanism is provided, especially to allocate the sub-band for the newly added femtocell, a reuse entropy based hybrid centralized/distributed interference-aware sub-band allocation algorithm is presented. Simulation results show that the DCCSA scheme can improve the throughput of femtocells and suppress the IFI significantly while guarantee the required QoS.**

Keywords-femtocells; inter-femtocell interference; resource allocation; clustering

I. INTRODUCTION

Recent research [1] shows that most of voice services and data services take place in indoor environments. Therefore, in order to provide high data rate and satisfied user experience, how to enhance indoor coverage becomes more and more urgent and important. However, due to the high penetration loss, macrocell coverage will cost tremendous expenses to serve massive indoor users with large demands. To resolve this problem, the application of so called femtocell base station (FBS) has been considered [1, 2]. FBS is a short-range, low-power, low-cost, as well as customer-owned cellular base station deployed by the terminal consumer, which is connected to the existing broadband access network via fixed backhaul such as coaxial cable. It is not only a very promising solution to enhance indoor coverage without much additional cost, but also brings other significant benefits such as increased spectral efficiency, offloaded macrocell burden, improved network capacity and prolonged life for phone battery.

In spite of so many advantages above, there are still some technical challenges to be further addressed before widespread deployment, e.g., interference mitigation, access control, time synchronization, handover management and so on [3]. FBSs typically operate in a small area such as residential apartments or office blocks where the majority of femtocells are very likely to be overlapped. As a result, the femtocell will suffer the serious IFI, which may significantly degrade the overall performance of femtocell networks. Hence, special attention should be paid to the IFI mitigation in orthogonal frequency division multiple Access (OFDMA) based femtocell networks [3,4]. Furthermore, FBS is a plug-and-play device deployed randomly by terminal users, but not professional technology personnel. Thus, both the number and the location of FBS are unknown to operators so that the traditional cellular network planning and interference mitigation techniques can't further handle the IFI caused by FBSs [3]. So an efficiently method for the IFI mitigation is urgently needed in femtocell networks.

One of the most important and practical solutions for IFI in OFDMA femtocell networks is radio resource management, which is an ongoing research area. In the following, some of the main related schemes proposed in the prior papers are described. Ju Yeop Kim [4] proposes an efficient joint power and sub-channel allocation scheme based on binary power allocation to solve the IFI. Mustika [5] presents a potential game method for the self-organized resource allocation. Each femtocell user attempts to select the most appropriate subset of resource blocks to mitigate the IFI. Pantisano [6] proposes a coalition formation game approach for the IFI mitigation where FBSs cooperate with each other to improve their performance by sharing spectrum resource.

This paper proposes a dynamic clustering-based cognitive sub-band allocation scheme (DCCSA) to reduce the IFI and utilize spectrum resource efficiently for femtocell networks. DCCSA utilizes user measurement report (UMR) base on the reciprocal of signal to interference ratio (SIR) to construct the weighted interference graph, and then assigns all FBSs into the different clusters by use of a Max k-Cut cluster algorithm. After that, the femto gateway assigns sub-bands to each cluster base on a SINR-maximizing heuristic algorithm, and FBSs in every cluster reuse the sub-band. Finally, since the topology of the femtocell network changes over time, a cognitive sub-band self-management mechanism is provided, especially a reuse entropy based hybrid centralized/distributed interference-aware sub-band allocation algorithm (RE-HISA) is presented to allocate the sub-band to the newly deployed FBS.

II. SYSTEM MODEL

Fig. 1 shows the topology of the multi-floor based 3D hierarchical cellular networks, in which a large number of

978-1-4673-0990-5/12/$31.00 ©2012 IEEE

FBSs with a height H_f covering a small range are randomly distributed on every floor of office blocks or residential buildings. The buildings are in the coverage of the single overlay macrocell base station (MBS) with the height of H_m. We assume that the interference from MBSs can be regarded as additive white Gaussian noise (AWGN) [4], thus, there is no need to consider MBSs. All the FBSs in the building are under the control of the femto gateway, which manages operation and maintenance (OAM) information such as the femtocell location and the identification through a backhaul link. Meanwhile, the femto gateway can also manage the femtocell network spectrum base on the OAM information [7].

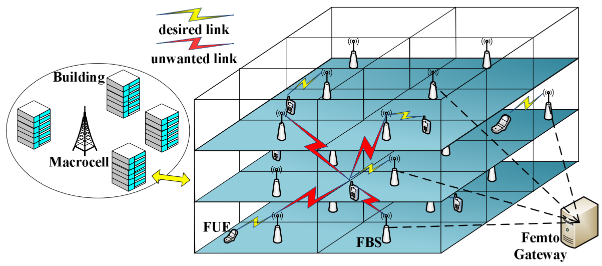

Figure 1. the 3D Hierarchical Cellular Network

All femtocells adopt the popular closed subscriber group (CSG) configuration in which only the authorized users can access a given femtocell. The femtocell in each room can be turned on or off at any time by users, which changes the operating femtocell density λ and the femtocell network topology. When λ increases, using more bandwidth in each femtocell will result in much stronger IFI, while the required QoS cannot guarantee. On the contrary, When λ decrease, the IFI becomes weaker, the femtocell throughput can be improved under the QoS constraint by use of more bandwidth. Therefore, it is desirable to employ a practical and optimal spectrum management mechanism for femtocells to transmit user data, while minimizing the IFI and ensuring the required QoS.

III. APPROACH: DCCSA ALGORITHM

In this paper, we present a practical method for sub-band allocation in OFDMA femtocell networks. The IFI problem can be solved via clustering-based sub-band allocation scheme, and spectrum efficiency can be optimized by use of cognitive sub-band self-management mechanism. Our approach consists of four main stages: (i) construction of weighted interference graph, (ii) clustering based on the interference graph, (iii) SINR-maximizing sub-band allocation, (iv) cognitive sub-band self-management. In the following, we detail these four stages.

A. Construction of Weighted Interference Graph

In this section, our objective is to construct a weighted interference graph, which involves two steps: (1) weighted interference graph representation, (2) edge weight calculation.

1) Weighted Interference Graph Representation

Based on the topology of the given femtocell network, the weighted interference graph $G=(V,E,W)$ is constructed. the vertex set is represented by $V=\{v_1,v_2...,v_N\}$ where each vertex denotes a femtocell node. E is the bi-directional edge set. Due to the use of omni-directional antennas pattern, the interference relationships between the nodes and the users can be simplified to interference relationships between the nodes. Hence, the node $v_i \in V$ and $v_j \in V$ ($i \neq j$, and $i,j \in \{1,2,...,N\}$) are connected by a directed edge $e_{ij} \in E$ if and only if the node v_i is interfered by the node v_j seriously, and vice versa. W is the weight set, and each edge e_{ij} has a weight w_{ij}, which indicates the interference degree between the nodes.

2) Edge Weight Calculation

The edge weight is determined by use of UMR mechanism based on R-SIR. We consider a simple femtocell environment comprising two femtocells. Femtocell v_i and femtocell v_j are respectively the source node and the interfering node, and a femtocell user r is served by node v_i. Assume that the user r can calculate the received power $P_r^{v_i}$ and $P_r^{v_j}$ of the reference signal from node v_i and node v_j respectively, and send the received power ratio $P_r^{v_j}/P_r^{v_i}$ back to node v_i.

The weight w_{ij} is represented by the received power ratio which is the reciprocal of SIR. Obviously, the higher the weight is, the stronger the IFI is. In addition, if the interference between the femtocells is lower than the receiver sensitivity which is -97 dBm [8], the weight can be neglected to reduce the complexity of the algorithm discussed in the later section. The weight can be expressed as follows:

$$w_{ij} = \Delta P_r^{ij} = \begin{cases} \dfrac{P_r^{v_j}}{P_r^{v_i}} & P_r^{v_j} / P_r^{v_i} \geq \delta^{th} \\ 0 & P_r^{v_j} / P_r^{v_i} < \delta^{th} \end{cases} \tag{3}$$

B. Clustering based on the Interference Graph

The second step is to assign the nodes into disjoint clusters based on the weighted interference graph. Firstly, we should determine the number of the cluster. Our objective is to maximize the femtocell throughput under the SINR constraint, while minimizing the IFI as much as possible. The user interference level depends on the total number of femtocells N, the number of sub-bands M, the operational femtocell density λ and the operational femtocell state vector S_f including location, working frequency and on-off information. Hence, the SINR of each user is a function of N, M, λ and S_f, and the value of M is formulated as below.

$$M = \underset{M=\{1,2,3,..\}}{\arg\min} \left\{ SINR_r = \frac{P_r^{v_i}}{I\left(M,N,\lambda,S_f\right)+N_0} \geq SINR^{th}, \forall r \right\} \tag{4}$$

Once the cluster number M has been determined, all nodes are assigned into M clusters to mitigate the IFI. The IFI-minimizing cluster problem based on the sub-band allocation is highly associated with the Max k-Cut problem in graph theory. That is to say, given N nodes and M sub-bands, the former can be solved to achieve IFI reduction by the solution of the latter.

P1: Given the weighted interference graph $G=(V,E,W)$ with N nodes and the edge weight w_{ij} for each edge (v_i,v_j) as mentioned above, find a method to divide the graph into M $(M\geq 2)$ disjoint cluster sets $\mathbb{C}_l$, $l=1,2,\cdots,M$ in a way to satisfy the conditions as below.

$$\begin{aligned} &\max: \ \sum\nolimits_{v_i\in\mathbb{C}_m, v_j\in\mathbb{C}_n, m\neq n} w_{ij} \\ &st: \bigcup\nolimits_{l=1}^{M}\mathbb{C}_l = V \\ &\mathbb{C}_m\bigcap\mathbb{C}_n=\varnothing, m,n\in\{1,2,...,M\} \end{aligned} \tag{5}$$

The optimal clustering problem described above has been proved to be a NP-Hard problem [9], thus, the suboptimal heuristic algorithm is often adopted to solve this problem. Here, The modified heuristic Max k-Cut clustering algorithm is applied to solve **P1**, the key of which is to deal with the nodes being interfered severely first, and then minimize the mutual interference in the same cluster as much as possible. The detail description of the modified algorithm is given in Table I.

TABLE I. A HEURISTIC CLUSTERING ALGORITHM TO SOLVE **P1**

Definition:

$W_l=\sum\nolimits_{v_i,v_j\in\mathbb{C}_l} w_{ij}$ denotes the edge weight sum of nodes in $\mathbb{C}_l$.

$w_i=\sum_{j=1,j\neq i}^{N} w_{ij}$ denotes the sum of edge weight of the node v_i.

$W_l^u=\sum\nolimits_{v_i\in\mathbb{C}_l, u\notin\mathbb{C}_l} w_{uv_i}$ denotes the newly added weight sum of $\mathbb{C}_l$ when assigning the node u into $\mathbb{C}_l$.

$\left|w_{uv_i}\right|_{\mathbb{C}_l}$ denotes the number of nodes in $\mathbb{C}_l$ which have a interference relationship with the new node u.

Initialize: $W_l=0$, $w_i=0$.

1.Calculate w_i for all nodes $v_i\in V$, and then sort nodes in an descending order of w_i, all nodes form a new set V'.

2.Assign the first M nodes of the set V' into M clusters arbitrarily, delete these M nodes from V'.

3.Choose a node from V' each time. For the node u, calculate W_l^u and then assign node u into $\mathbb{C}_{l^*}$ where $l^*=\arg\min_{l\in\{1,2,...,M\}} w_l^u$.

4.Calculate $\left|w_{uv_i}\right|_{\mathbb{C}_{l^*}}$ if there is more than one minimum, put node u into $\mathbb{C}_{l^{**}}$ where $l^{**}=\arg\max_{l^*}\left|w_{uv_i}\right|_{\mathbb{C}_{l^*}}$.

5.Update the weight to $W_{l^{**}}+W_{l^{**}}^u$ in $\mathbb{C}_{l^{**}}$, delete node u from the set V'. If there is still more than one minimum, break the tie arbitrarily.

6.Repeat steps 3-5 for all nodes until the set V' is empty.

C. SINR-Maximizing Sub-band Allocation

After the disjoint cluster been formed, The third step is to allocate sub-bands to the operating femtocells. Among M! possible sub-band assignment choices, we should select the option which maximizes the femtocell network throughput. The problem can be formulated as follows.

P2: Let the binary matrix $A=\left\{a_{kl}\,|\,a_{kl}\in\{0,1\}\right\}_{M\times M}$ represent the sub-band assignment among clusters, where $a_{kl}=1$ denotes that the sub-band k is allocated to the cluster $\mathbb{C}_l$, otherwise $a_{kl}=0$. Our objective is to find the binary matrix A^* which corresponds to the maximum femtocell throughput. Let F be a set of the binary matrix denoting the M! possible sub-band assignment choices, hence the formulation can be given by:

$$A^*=\arg\max_{A\in F}\left\{\sum_k\sum_l \log_2\left(1+\overline{SINR_{kl}}\right)a_{kl}\right\}, k,l\in\{1,2,...,M\} \tag{6}$$

The exhaustive search method which should compute M! times is infeasible. Instead, a suboptimal SINR-maximizing heuristic algorithm is proposed and iteratively assigns the sub-band to each cluster, which is showed in Table Ⅱ.

TABLE II. SUB-BAND ALLOCATION ALGORITHM FOR P2

Definition:

$\left|\mathbb{C}_l\right|$ represents the number of the nodes in $\mathbb{C}_l$. K denotes a set including M sub-bands.

1.Sort the cluster in an increasing order according to $\left|\mathbb{C}_l\right|$, and form a new set L (break the tier arbitrarily).

2.Orderly choose a cluster $\mathbb{C}_l$ from the set L at a time, and then calculate the capacity T_k^l of the cluster $\mathbb{C}_l$ for each sub-band k where $T_k^l=\sum_{v\in\mathbb{C}_l}\log_2\left(1+\overline{SINR_{vk}}\right), \forall k\in\{1,2,...,M\}$.

3.Assign the sub-band k^* to $\mathbb{C}_l$ where $k^*=\arg\max_k\left(T_k^l\right)$.

4.Update the set K, $K\rightarrow K\setminus\{k^*\}$.

5.Repeat 2-4 until the set K is empty .

D. Cognitive Sub-band Self-management Mechanism

As stated earlier, the femtocell can be turned on or off at any time, which may change the operating femtocell density and the femtocell network topology. Based on the number of the operating femtocell, the changing environments can be divided into three cases: (i) Only a few FBSs have changed their states, namely the switched FBS number is lower than $TH_{reallocation}$; (ii) A moderate number of FBSs have changed their states, but the operating femtocell density is almost unchanged, namely the changed FBS density is lower than the threshold; (iii) a large number of femtocells have changed their states, meanwhile, the operating femtocell density is also changed. Since the femto gateway can perceive the change of the network and adapt the sub-band alloation correspondingly. Hence, For case 1, the problem can be formulated as below.

P3: The interference graph is almost unchanged, the sub-band self-management problem can be simplified as how to allocate the sub-band to the new FBS u. Our objective is to choose the most suitable sub-band to maximize the FBS throughput, while meeting the following constraints: (1) the interference of neighboring cells as small as possible, (2) the spatial distribution of the sub-band as uniform as possible, (3) the complexity of the sub-band allocation for the later deployed FBS as low as possible.

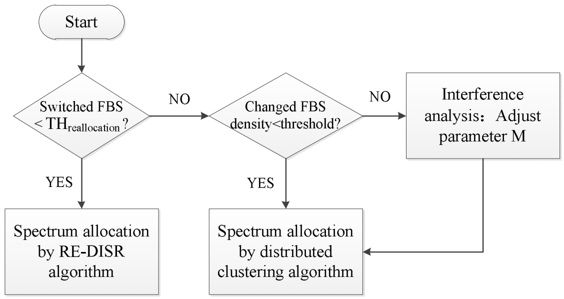

Figure 2. flowchart of cognitive spectrum allocation mechanism

A simple heuristic algorithm called a reuse entropy based hybrid centralized/distributed interference-aware sub-band allocation algorithm (RE-HISA) is adopted to solve this problem, as showed in Table Ⅲ. For case 2, the femto gateway re-executes the clustering algorithm. For case 3, the femto gateway adjusts the parameter M . The flowchart of the proposed mechanism is represented in Fig. 2.

Definition: the sub-band reuse entropy H in the RE-HISA algorithm guarantees that both the reuse times and the spatial distribution of the whole sub-bands tend to balance as much as possible. Let p_m denote the ratio of the using times for the given sub-band m to the total using times for all sub-bands, and the sub-band reuse entropy of can be calculated as:

$$H = -\sum_{m} p_m \log p_m \tag{7}$$

TABLE III. A RE-HISA ALGORITHM FOR CASE 1

1.Calculate the $SINR_u^{\mathbb{C}_l}$ of the new node u for the cluster $\mathbb{C}_l$.

2.Choose the cluster $\mathbb{C}_{l^*}$ which meets $SINR_u^{\mathbb{C}_l} \geq SINR^{th}$ as a new cluster set X as below.

$$X = \left\{ \mathbb{C}_{l^*} \middle| \mathbb{C}_{l^*} = \arg_{\mathbb{C}_l}\left(SINR_u^{\mathbb{C}_l} \geq SINR^{th} \right), l \in [1, 2, \ldots M] \right\}$$

3.Calculate the $SINR_v^{\mathbb{C}_{l^*}}$ of all nodes $v \in \mathbb{C}_{l^*}$.

4.Choose cluster $\mathbb{C}_{l^{**}}$ which meets $SINR_v^{\mathbb{C}_{l^*}} \geq SINR^{th}$, $\forall v \in \mathbb{C}_{l^*}$ as a new cluster set Y .

$$Y = \left\{ \mathbb{C}_{l^{**}} \middle| \mathbb{C}_{l^{**}} = \arg_{\mathbb{C}_{l^*}}\left(SINR_v^{\mathbb{C}_{l^*}} \geq SINR^{th} \right), \mathbb{C}_{l^*} \in X, \forall v \in \mathbb{C}_{l^*} \right\}$$

5.Calculate the reuse entropy $H_{l^{**}}$ of each cluster in the set Y , And then assign the new node u to the cluster $\mathbb{C}^u$ which meets $\mathbb{C}^u = \arg\max_{\mathbb{C}_{l^{**}} \in Y}(H_{l^{**}})$. Break the tie randomly, if there is more than one minimum.

IV. PERFORMANCE EVALUATION

To evaluate the performance of the proposed scheme, Monte Carlo simulation analysis is used. A dual-strip model in [10] is chosen to simulate the multi-floor based 3D hierarchical cellular networks. In this model, each strip has 2 by 10 apartments and 6 floors. Each apartment is of size $10m \times 10m$,there is a street between two strips with the width of 10m. Moreover, channel model in [10] is adopted for the urban deployment, and the simulation parameters are mostly referenced from [10] as summarized in Table Ⅳ. According to the above parameters, the operating femtocell density and the number of sub-bands are associated by the simulation as follows in Table Ⅴ.

Performance analysis is divided into two parts. Firstly, the RE-HISA algorithm is evaluated in terms of the average SINR and throughput, compared with random sub-band allocation algorithm (RSA) [11], which the newly added FBS access a random sub-band within the available femtocell spectrum. Secondly, The average SINR and throughput of the dynamic clustering-based cognitive sub-band allocation scheme is also evaluated, compared with the traditional Fixed sub-band allocation (FSA) scheme which divides the available spectrum band into three parts.

TABLE IV. SIMULATION PARAMETERS

Parameter		Value
System Parameters	Carrier frequency/ bandwidth	2GHz/10 MHz
	Log-normal shadowing standard deviation	8dB
Macrocell parameters	Antenna pattern	Omni-directional
	MBS height	32m
	Maximum MBS TX power	46dBm
Femtocell parameters	Maximum FBS TX power	20dBm
	User per femtocell	1
$10\lg\delta^{th}$		-70dB
$SINR^{th}$		8dB
$th_{reallocation}$		10%

TABLE V. THE NUMBER OF SUB-BAND FOR GIVEN DENSITY

λ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
M	1	1	1	1	1	2	5	8	10	14

A. *Performance analysis of the RE-HISA algorithm*

Fig. 3 depicts the average throughput according to the femtocell density. It can be seen from Fig. 3 that as the density increases, the average throughput decreases. That is mainly due to the fact that the greater the femtocell density, the more serious IFI. In addition, it also showed that the average throughput of RE-HISA is better than that of RSA.

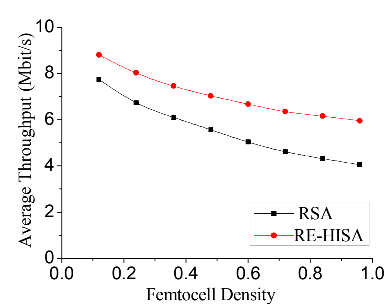

Figure 3. Average throughput vs. the femtocell density

Fig. 4 shows the average SINR of the added femtocells vs. the cluster number. From Fig. 4, RE-HISA outperforms RSA for all cluster numbers. That is mainly because that the proposed algorithm can effectively suppress the IFI, while RSA is vulnerable to the IFI. However, the complexity of RE-HISA is higher than that of RSA.

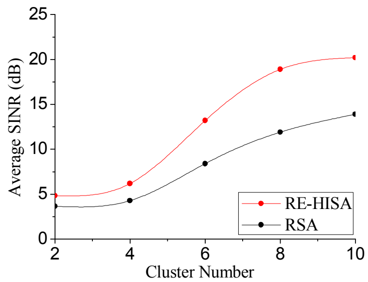

Figure 4. Average SINR vs. the cluster number

B. *Performance analysis of the DCCSA scheme*

Fig. 5 depicts the SINR of the femtocell user according to the femtocell density. It can be seen that as the femtocell density increases, the SINR of the femtocell user decreases. In addition, when the femtocell density is higher than 0.7, the average SINR of the femtocell user is lower than the threshold in FSA, while it is better than the threshold in DCCSA.

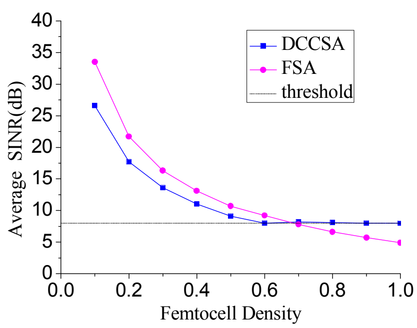

Figure 5. Average SINR vs. the femtocell density

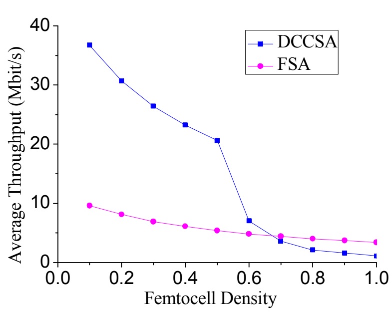

Figure 6. Average throughput vs. the femtocell density

Fig. 6 depicts the average throughput vs. the femtocell density. When the density is lower than 0.7, the throughput of DCCSA greatly outperforms that of FSA. However, when the density is greater than 0.7, the situation is just the reverse. Although DCCSA does not perform as well as FSA in the highly dense deployment, it meets the SINR constraint. FSA cannot do this, which results in an unacceptable received signal quality.

V. CONCLUSION AND FUTURE WORKS

In this paper, we have considered the design of a practical and efficient sub-band allocation mechanism in OFDMA femtocell networks and proposed a novel resource allocation scheme called DCCSA, which divides the resource allocation problem into sub-problems by means of clustering. Meanwhile, the proposed scheme can be easily applied to multi-femtocell environments such as enterprise blocks. Simulation results show that the average SINR and throughput of the proposed scheme have improved relative to other scheme. In the future, we will further study the clustering-based femtocell resource allocation scheme combined with the interference coordination scheme such as fractional frequency reuse (FFR) in the multi-macrocell scenarios.

ACKNOWLEDGMENT

This work is supported by the National S&T Major Project of China (No.2011ZX03003-002-01).

REFERENCES

[1] V. Chandrasekhar, J. Andrews, and A. Gatherer, "Femtocell networks: a survey," *Communications Magazine, IEEE,* vol. 46, pp. 59-67, 2008.

[2] H. Claussen, L. T. W. Ho, and L. G. Samuel, "An overview of the femtocell concept," *Bell Labs Technical Journal,* vol. 13, pp. 221-245, Spr 2008.

[3] D. Lopez-Perez, A. Valcarce, G. de la Roche, and Z. Jie, "OFDMA femtocells: A roadmap on interference avoidance," *Communications Magazine, IEEE,* vol. 47, pp. 41-48, 2009.

[4] K. Juyeop and C. Dong-Ho, "A Joint Power and Subchannel Allocation Scheme Maximizing System Capacity in Indoor Dense Mobile Communication Systems," *Vehicular Technology, IEEE Transactions on,* vol. 59, pp. 4340-4353,2010.

[5] I. W. Mustika, K. Yamamoto, H. Murata, and S. Yoshida, "Potential Game Approach for Self-Organized Interference Management in Closed Access Femtocell Networks," in Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd, pp. 1-5.

[6] F. Pantisano, M. Bennis, W. Saad, R. Verdone, and M. Latva-aho, "Coalition formation games for femtocell interference management: A recursive core approach," in Wireless Communications and Networking Conference (WCNC), 2011 IEEE, pp. 1161-1166.

[7] 3GPP, TS 25.467, V10.2.0, "UTRAN architecture for 3G Home Node B(HNB)," Jun 2011.

[8] 3GPP, TS 36.521-1, V9.5.0, "User Equipment (UE) conformance specification Radio transmission and reception," Jun 2011.

[9] S. Sahni and T. Gonzalez, "P-Complete Approximation Problems", *Journal of the ACM,* Vol. 23, Issue 3, pp. 555-565, 1976.

[10] 3GPP, TR 36.814, V9.0.0, "Further advancements for E-UTRAN physical layer aspects," Mar,2010.

[11] V. Chandrasekhar and J. Andrews, "Spectrum allocation in tiered cellular networks," Communications, IEEE Transactions on, vol. 57, pp. 3059-3068, 2009.