Downlink Resource Management Based on Cross-Cognition and Graph Coloring in Cognitive Radio Femtocell Networks

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Abstract—**Femtocell technology features prominently in future communication system owing to its characteristic advantages. However, the coexistence of femtocells and traditional cellular system causes severe contradictions between spectrum utilization and interference. This paper studies the cross tier resource management and intra tier resource management in hybrid macro/femto network, and a novel Cross-Cognition scheme for cross tier resource management is proposed in order to achieve better spectrum utilization and lower interference. Moreover, a resource allocation scheme based on graph Coloring is also proposed for intra tier resource management to decrease the intra tier interference. Simulations show that the proposed schemes significantly increase the throughput of femtocell system, and outperform traditional cognitive resource allocation schemes.**

Keywords-Cognitive Radio; femtocell; resource allocation; cross tier interference; intra tier interference

I. INTRODUCTION

Studies on the distribution of wireless services in future mobile communication systems show that over 50% voice services and 70% data services will occur in indoor environment [1]. Therefore, academia and industry pay growing attention on improving the network performance of indoor scenario. Femtocell technology features prominently in future communication system, because it provides better indoor coverage and offloads traffic from outdoor macrocells. These various benefits for both consumers and operators have brought femtocell technology considerable attention from both industry and standardization organizations, and femtocell technology has been included in standards such as the Third Generation Partnership Project Long Term Evolution (3GPP LTE) and LTE-Advanced[2].

Alongside with the benefits of femtocells, there are also challenges resulted from the coexistence of femtocells and traditional cellular system. Because most femtocells are deployed by ordinary customers and may be turned on and off frequently, the number of femtocells and their location are unknown by operators, which increases the complexity of interference management.

Resource allocation schemes in femtocell systems have been widely investigated. Three typical resource allocation schemes are mentioned in [3]. The first type is all shared scheme (i.e. co-channel), in which the entire frequency band is shared by macrocells and femtocells. Though all shared scheme results in high system capacity, it also leads to serious co-channel interference between the macrocell and femtocells. The second type is non-shared (i.e. orthogonal) scheme, in which femtocells and the macrocell use separate frequency band. Non-shared scheme can avoid co-channel cross tier interference, indicating the interference between macrocells and femtocells, but its performance is compromised by the low frequency utilization especially when the traffic load varies greatly between macrocell and femtocells. The last type is partial shared scheme, and in this scheme only part of the frequency band is shared by macrocell and femtocells, which combines the characteristics of both schemes aforementioned.

Recently, a novel concept called cognitive radio femtocell network (CRFN) which combines cognitive radio (CR) technology with femtocell network, is presented for the resource management between macrocell and femtocells [5]~[8]. CR, originally introduced by Joseph Mitola III in 1999 [4], offers opportunistic access to the underutilized licensed spectrum and alleviates the spectrum scarcity caused by conventional static spectrum allocation policy and the thriving wireless communication market. Introducing CR technology into macro/femto hybrid LTE-A network can mitigate cross tier interference and also improve spectrum utilization of the system.

However, most of the researches about CRFN set the femtocell network to be the secondary system and macrocell network the primary system [5]~[8]. This will decrease the priority and consequently the capacity of femtocells especially when femtocells are distributed densely. Moreover, in future communication system such as LTE-A, the status of femtocells should be equal to the macrocell because large amount of voice calls and data traffic will occur indoors [1]. Therefore, the traditional cognitive schemes for femtocells are not suitable to LTE-A system yet.

Apart from the cross tier interference, the interference among femtocells, named as intra tier interference, should also be taken into consideration in the design of the resource management scheme in hybrid macro/femto LTE-A network. However, in dense femtocell network, intra tier interference is

This work is supported by National Natural Science Foundation of China (61072056) and National S&T Major Project (2012ZX03003006) and Beijing Municipal Commission of Education (Demonstration application Platform of Sensing Campus Service)

difficult to be eliminated. [8] presents Game theory strategy to mitigate intra tier interference in CRFN, but no specific solution is proposed.

In this paper, we propose a novel Cross-Cognition scheme for CRFN to allocate spectrum resource in hybrid macro/femto system. This scheme resolves the contradictions between spectrum utilization and cross tier interference by enhancing the status of femtocell network and allocating licensed spectrum resource to femtocell network. Within the Cross-Cognition macro/femto system structure, Graph Coloring theory is applied to avoid interference among nodes and therefore reduce the intra tier interference. Simulations show that compared with the traditional cognitive schemes, the Cross-Cognition scheme improves the capacity of femtocell user equipments (FUE) considerably in dense femtocell scenario, and the interference coordination scheme based on Graph Coloring increase the Signal to Interference plus Noise Ratio (SINR) and improve the capacity of FUEs in CRFN.

The rest of this paper is organized as follows. System model and assumptions are presented in Section Ⅱ. Section Ⅲ proposes the Cross-Cognition scheme and the interference coordination scheme based on Graph Coloring in CRFN. Simulations are analyzed in section Ⅳ. Section Ⅴ concludes the paper.

II. SYSTEM MODEL AND ASSUMPTIONS

This paper considers downlink (DL) resource allocation for hybrid macro/femto LTE-A OFDMA system. The basic resource unit of the system is physical resource block (PRB) as in OFDMA system. The closed subscriber group (CSG) femtocell is used, which means that users can only access a femtocell with a unique identifier (CSG Identity).

Cognitive radio femtocell network (CRFN) is deployed in the system, indicating that both macro base stations (MBSs) / macrocell user equipments (MUEs) and femto base station (FBSs) / femtocell user equipments (FUEs) have the cognitive function of spectrum sensing. Spectrum sensing is the premise of the avoidance against the cross tier interference in CRFN and thus need to be implemented. In this paper, energy detection is selected as the spectrum sensing technology for FBSs and MBSs due to its low complexity and low time delay.

Additive white gaussion noise (AWGN) channel is applied for FBS-FUEs/MUEs link and MBS-MUEs/FUEs link. Hence, the DL capacity of FUE and MUE can be estimated by Shannon formula:

$$C = B\log_2(1+SINR) \tag{1}$$

Where $SINR$ is DL SINR of the PRB assigned to a FUE/MUE. B is the bandwidth of a PRB, which is 180KHz in LTE-A OFDMA system.

The DL interference scenario hybrid macro/femto LTE-A OFDMA system is described in Fig. 1 and 4 types of interferences are listed in TABLE Ⅰ [9]

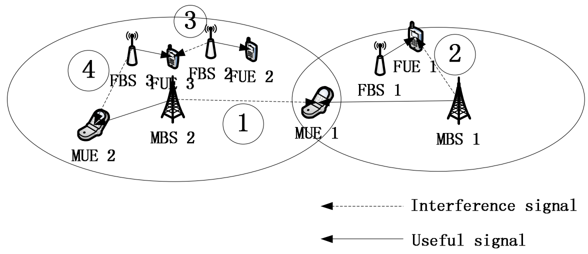

Figure 1. DL interference scenario in the system

TABLE I. INTERFERENCE SCENARIO

Number	Interference type
1	MBS-MUE
2	MBS-FUE
3	FBS-FUE
4	FBS-MUE

III. PROPOSED SCHEME

In this section, Cross-Cognition scheme is first introduced for the resource allocation in hybrid macro/femto system, and then interference coordination based on graph Coloring is proposed for intra tier resource management.

A. Resource Allocation Scheme Based on Cross-Cognition Between Macrocell and Femtocell

In order to increase the throughput of femtocells and the QoS (quality of service) of the indoor users in CRFN, a resource allocation scheme based on Cross-Cognition between macrocell and femtocell scheme is proposed.

The Cross-Cognition scheme is different from traditional resource allocation scheme in CRFN, because for both MBSs and FBSs, spectrum resource is divided into two parts, which are licensed spectrum and non-licensed spectrum as shown in Fig. 2. It means that FBSs will also be assigned exclusive licensed spectrum like MBSs rather than surrendered as a secondary system. In the Cross-Cognition scheme, MBSs/FBSs have higher priority to utilizing its licensed spectrum and lower priority to utilizing the non-licensed spectrum. When the licensed spectrum of MBSs/FBSs is exhausted, MUEs/FUEs are able to opportunistically use the unoccupied non-licensed spectrum sensed by energy detection.

The Cross-Cognition scheme can be described as follows:

$$\psi_W = \{PRB_n \mid n \in [1, N]\} \tag{3}$$

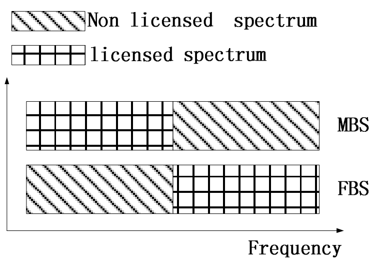

Figure 2. Cross-Cognition scheme

Where ψ_W is the set of the entire frequency resource of the system, and N is the number of PRBs of the system.

$$\psi_{FL} = \{PRB_m \mid m \in [1, M], M < N\} \qquad (4)$$

$$\psi_{FNL} = \psi_W - \psi_{FL} \qquad (5)$$

Where ψ_{FL} is the set of the licensed spectrum for FBSs, ψ_{FNL} is the set of the non-licensed spectrum for FBSs, and M is the number of the licensed spectrum resources.

$$\psi_{ML} = \{PRB_k \mid k \in [M+1, N]\} \qquad (6)$$

Where ψ_{ML} is the set of the licensed spectrum for MBSs. The number of the licensed spectrum resources is $N - M$.

$$\psi_{MNL} = \psi_W - \psi_{ML} \qquad (7)$$

Where ψ_{MNL} is the set of the non-licensed spectrum for MBSs,

$$\psi_{FE} = \{PRB_k \mid \tau_F < E_{th}, k \in [M+1, N]\} \qquad (8)$$

Where ψ_{FE} is the available non-licensed frequency resources for FBSs sensed by energy detection. τ_F is the result of energy detection of FBSs, and E_{th} is the threshold of energy detection.

$$\psi_{ME} = \{PRB_m \mid \tau_M < E_{th}, m \in [1, M], M < N\} \qquad (9)$$

Where ψ_{ME} is the available non-licensed frequency resources for MBSs sensed by energy detection. τ_M is the result of energy detection of FBSs.

$$\psi_F = \psi_{FL} \cup \psi_{FE} \qquad (10)$$

Where ψ_F is the set of the available frequency resources of FBSs in CRFN.

$$\psi_M = \psi_{ML} \cup \psi_{ME} \qquad (11)$$

Where ψ_M is the set of the available frequency resources of MBSs in CRFN.

Traditional cognitive schemes in CRFN usually set MBSs to be the primary system and have the highest priority of all the frequency resources, while FBSs can only use the resources which is unoccupied by MBSs. The proposed scheme overcomes the limitation of traditional resource management in CRFN and allocates licensed spectrum to FBSs, which means FBSs has higher priority in its own licensed spectrum while FBSs can still access the licensed spectrum of MBSs via Cross-Cognitive. Therefore the proposed scheme is more suitable for LTE-A systems and improves the QoS and the throughput of femtocell network.

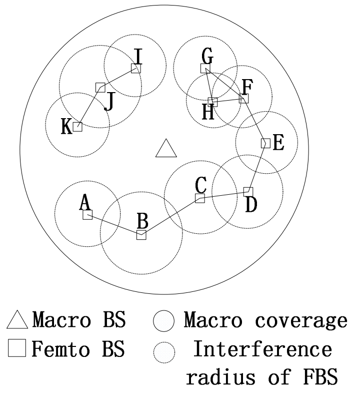

Figure 3. interference constraint graph in CRFN

B. Interference Coordination based on Graph Coloring

In CRFN, multiple FBSs may identify the same set of available PRBs and hence cause serious intra tier interference, especially when these FBSs are located close to each other. In this research, a novel interference coordination scheme based on graph Coloring theory is introduced to mitigate the intra tier interference.

As shown in Fig. 3, the intra tier interference coordination problem in femtocell network can be modeled as a Graph Coloring problem, which can be described as $G = (U, E_C, L_B)$, where U is the vertex set of G, and each vertex represents a FBS. E_C is the set of interference edge, which is determined by matrix C. L_B is the set of available colors, and each color represents a PRB for the femtocell network.

Useful matrix in graph Coloring, including the matrix of available resources, the matrix of interference constraint and the matrix of resource allocation, are described as follows:

The matrix of available resource is $L = \{l_{n,m} \mid l_{n,m} \in \{0,1\}\}_{N \times M}$, where N represents the number of FBSs in one cell. M represents the number of available resources of femtocell network. If $l_{n,m} = 1$, PRB m is available to FBS n. Otherwise, if $l_{n,m} = 0$, PRB m is unavailable to FBS n.

The matrix of interference constraint is $C = \{c_{n,\hat{n}} \mid c_{n,\hat{n}} \in \{0,1\}\}_{N \times N}$. $c_{n,\hat{n}} = 1$ represents that there will be severe interference between FBS n and FBS $\hat{n}$ if the same set of PRBs are allocated to them. In the proposed scheme, if the coverage of the interference radius of FBS n and FBS $\hat{n}$ is overlapping, $c_{n,\hat{n}}$ is set to be 1.

The matrix of resource allocation $A = \{a_{n,m} \mid a_{n,m} \in \{0,1\}\}_{N \times M}$ represents the result of resource allocation, where $a_{n,m} = 1$ represents that PRB m is allocated to FBS n and otherwise 0. In the process of resource allocation, non-interference constraint should also be satisfied.

The algorithm of the proposed interference scheme can be described as follows:

Step1: update the system initialization information. Then go to step 2.

Step2: if the degrees of the vertices are the same, skip to step 4. Otherwise, skip to step 3

Step3: select the vertex whose has the maximum degree and allocate PRBs to this vertex (FBS) according to the matrix L and C. Then go to step 5.

Step4: select a vertex (FBS) randomly and allocate PRBs to the vertex (FBS) according to the matrix L and C. Then go to step 5.

Step5: if the requests of all the vertices are satisfied or all the colors are exhausted, the algorithm is finished. Otherwise, skip to step1.

By giving the vertex with greater degree higher priority, the proposed Graph Coloring algorithm can maximize the capacity of femtocell network. Because more PRBs will be allocated to FBSs with lower interference, the throughput of femtocell network is effectively improvemed.

IV. SIMULATION RESULTS

In this section, simulation results are presented to evaluate the performances of the proposed Cross-Cognition and Graph Coloring scheme.

A. *Simulation Design*

Simulation parameters are given in TABLE Ⅱ, which are in accordance with 3GPP TR 36.814 [10]. 7 cell structure is implemented in the simulation. The MBS located in the center of the macrocell with 6 macrocells around. FBSs are randomly distributed in macrocells, and each FBS is located in the center of a femtocell. $\alpha_{non-shared}$ is the ratio of frequency bandwidth for femtocell to the total bandwidth. $\alpha_{cross-cognitive}$ is defined as the ratio of licensed spectrum bandwidth for femtocell to the total bandwidth.

TABLE II. SIMULATION PARAMETERS

Parameter	Macrocell	Femtocell
System bandwidth	10MHz	
Carrier frequency	2000Mhz	
Cell layout	hexagonal 7 cells	circular cell
Cell size	500 m	10 m
Maximum TX power	49 dBm	20 dBm
BS noise Fig	5 dB	5 dB
UE noise Fig	9 dB	9 dB
White noise power density	-174 dBm/Hz	-174 dBm/Hz
Number of UEs	varies	Maximum HUE number:10
$\alpha_{non-shared}$	0.5	
$\alpha_{cross-cognitive}$	0.5	

B. *Simulation Analysis*

1) *Resource allocation based on Cross-Cognition*

Fig. 4 shows the average throughput of FBS with the number of MUEs varying from 0 to 60, in which FBSs are distributed densely in macrocell (200 FBSs per macrocell). When the number of MUEs is smaller, the average throughputs of FBS in Cross-Cognition scheme and traditional cognitive radio scheme are almost the same, because the capacity of MBS is not in saturation and FBS can use the PRBs which are not occupied by MUEs. However, the average throughput of FBS in non-shared scheme is the lowest due to its limitation of available PRBs of FUE. As the number of MUEs increases, the average throughput of FBS in Cross-Cognition scheme surpasses that in traditional cognitive scheme, because licensed spectrum bandwidth is allocated to FBSs, which ensures the QoS of FUEs.

As shown in Fig. 5, the throughput of MBS in traditional cognitive scheme is the highest compared with the other two schemes, because in traditional cognitive scheme MBSs have the absolute priority of the frequency resources.

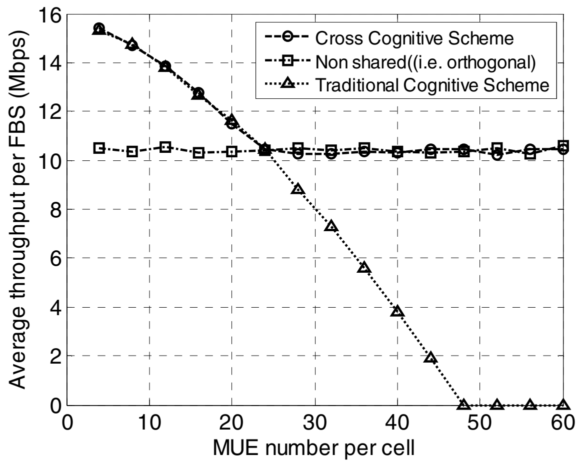

Figure 4. Average throughput of FBS vs MUE number

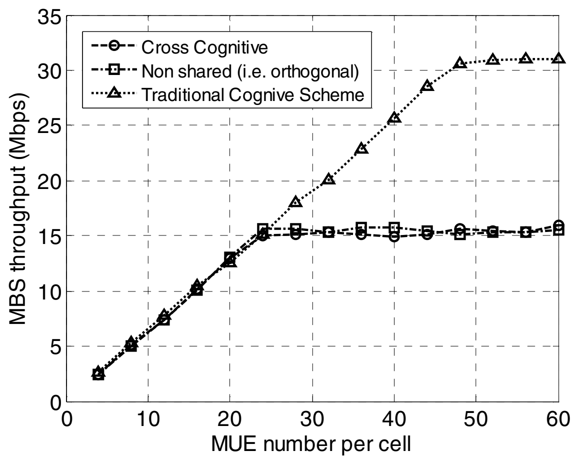

Figure 5. MBS throughput vs MUE number

2) Resource allocation based on Graph Coloring

The average SINRs of FUEs of random resource allocation and Graph Coloring with different interference radius are presented in Fig. 6. As the figure shows that the average SINR of FUEs in the proposed scheme is higher than that in the random resource allocation scheme, because in the proposed scheme FUE can avoid severe interference through reasonable resource allocation scheme based on graph Coloring. It can also be seen that the shorter the interference radius of FBS is, the smaller SINR for FUE is, because the interference radius determines the scope inside which FBSs can use the same set of PRBs to communicate with FUEs.

As shown in Fig. 7, the average throughput of FBS in the proposed scheme is higher than that in the random resource allocation scheme due to the ability of interference avoidance. However, the throughput of FBS depends on not only the SINR of FUE but also the number of available PRBs for FUEs. A longer interference radius results in a higher SINR, and conversely fewer available PRBs for FUE. Thus, the average throughput of FUE in the proposed scheme (interference radius r=100m) decreases faster with the increasing FBS number.

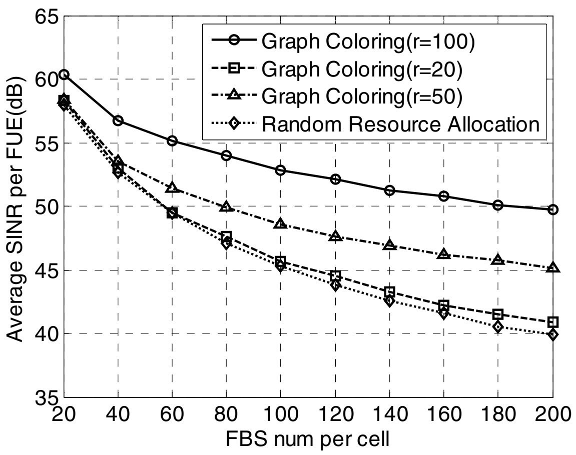

Figure 6. Average SINR of HUE vs HUE number

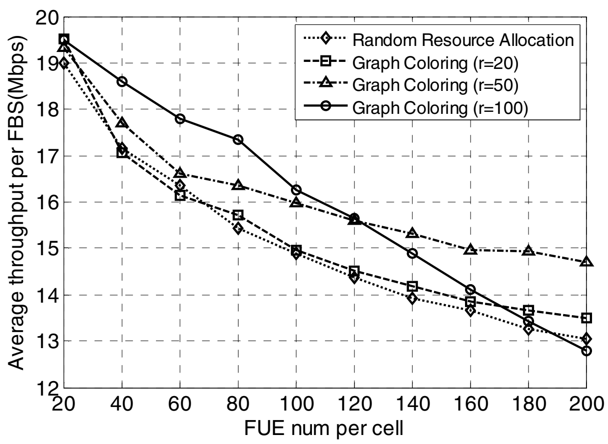

Figure 7. Average throughput of FBS vs FUE number

V. CONCLUSIONS

In this paper, we study the cross tier resource allocation scheme and intra tier resource allocation scheme in CRFN. A Cross-Cognition scheme for cross tier resource allocation is proposed to enhance the QoS of FUEs via allocating licensed frequency resources to femtocell network. Simulations show that compared to the traditional cognitive scheme in CRFN, the throughput of FUE of the proposed scheme is significantly increased when FBS are distributed densely, which makes the scheme more suitable to LTE-A system. Interference coordination scheme based on graph Coloring for intra tier resource allocation is also proposed which can mitigate interference among FBSs. Simulations show that the proposed scheme can evaluate both the SINR and the throughput of FUEs in dense femtocell network, and the performance of the proposed scheme depends on the interference radius of femtocell.

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