Cluster-based Resource Allocation for Interference Mitigation in LTE Heterogeneous Networks

Hao Tang*, Peilin Hong*, Kaiping Xue, Jinlin Peng
The Information Network Lab of EEIS Department, USTC
Hefei, China, 230027
*thfree@mail.ustc.edu.cn, *plhong@ustc.edu.cn

***Abstract*—In order to provide high data rate for indoor services, femtocells are proposed in LTE-Advanced system. Under this architecture, the main problem is how to reduce the interference between macro and femto cells and that among femtocells. In this paper, an interference graph is constructed in which the vertexes are Macro User (MUE) and femtocell. Besides, Regional Average Channel State (RACS) metric is proposed to estimate the weight of interference. Therefore, a dynamic spectrum assignment algorithm called hybrid clustering based on interference graph (HCIG) is proposed to reduce the interference, in which the optimal clustering problem is constructed as a MAX-K cut problem and a heuristic algorithm is given. Based on the cluster results, a resource allocation scheme is given to reduce the interference and improve the spectrum efficiency. System level simulation results show that compared to other three schemes, the SINR of both MUE and femto user are improved by HCIG.**

I. Introduction

In order to provide high quality for those users at home, the Third Generation Partnership Project Long Term Evolution (3GPP LTE) has introduced low power nodes placed indoors, such as femtocell [1]. In case of the same bandwidth used by macro and femto cells, interference in the system is the key problem due to the randomness deployment of femtocells.

There are typically three types of frequency assignment schemes in the femtocell network [2]. The first approach is called shared frequency allocation (SFA): the same spectrum resource is used in macro and femto cells. It results in high spectrum efficiency, while the co-channel interference may seriously degrade the system performance. Another approach is called partitioned frequency allocation (PFA): femtocell uses partial spectrum while macrocell uses the remaining. Though this scheme avoids interference between two tiers, spectrum efficiency decreases critically. The last approach is called partial shared frequency allocation (PSFA): femtocell uses part of the bandwidth resources and macrocell uses all the available spectrum resources. It achieves a compromise between interference reduction and spectrum efficiency enhancement.

Several schemes have been proposed to reduce the interference in the LTE heterogeneous network (HetNet) mainly by means of resource allocation and power control. The cell is divided to inner and outer part in [3][4], and the femto user (FUE) in inner region uses the sub-band different from the Macro Base Station (MBS) to avoid interference. A resource management scheme based on fractional frequency reuse (FFR) is given in [5], in which orthogonal resources are used between FBS and MBS. Subject to the constraint on the minimum target SINR realized in macrocell, an iterative power selection algorithm is presented in [6] to maximize the system performance.

Recently, graph theory is widely used on the reduction of interference in LTE network. The vertex, which is generally Base Station (BS) in the traditional interference graph modeling schemes, expands to UE and femtocell BS (FBS) now. In OFDMA macrocell, Necker [7] introduces interference graph to resolve the interference coordination problem and presents graph coloring heuristic scheme to avoid interference, in which two graph nodes connected by an edge can't be assigned the same color. [8] extends the graph vertex to UEs. However, the overhead of updating the graph is very high, because the MUE node is moving every time. For macro and femto heterogeneous system, graph-based adaptive fractional frequency reuse (AFFR) scheme is presented in [9], in which the FBS is taken as the vertex of graph to avoid interference among FBSs. However, the interference between MBS and FBS is not considered.

In order to reduce the interference between macrocell and femtocell, and that among femtocells, a weighted undirected graph is proposed in this paper, in which the vertex of the graph is MUE or FBS. Based on the graph, the resource allocation problem fundamentally differs from those traditional graph-based schemes, in which graph coloring algorithms are used and the minimum colors(i.e., channels) are utilized. In our scheme, a fixed number of sub-bands are used and the hybrid clustering based on interference graph (HCIG) algorithm is proposed. After HCIG, not only one sub-band is assigned to MUE and FBS, but also other available sub-bands are assigned to FBS under the interference constraint to improve the spectrum efficiency.

The rest of this paper is organized as follows. Section II details the graph weight matrix construction rule. Based on the graph, the proposed HCIG algorithm is given in Section III. In Section IV, the cluster-based resource allocation scheme is proposed. In Section V, a system-level simulation is given to evaluate the improvement of performance. Finally, we conclude this paper in Section VI.

II. Construction of the Interference Graph

Seen from Fig.1, downlink interference in HetNet consists of three parts:

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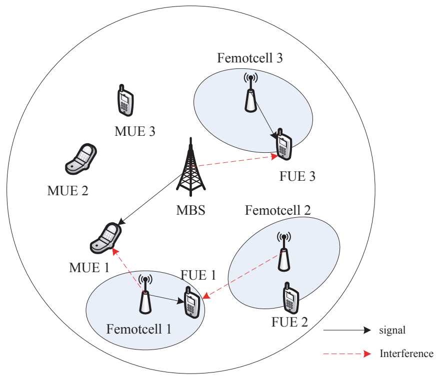

Fig. 1. Downlink interference scenarios in LTE HetNet

1) $I_{MBS,FUE}$ is the Co-Channel Interference (CCI) caused by MBS to FUE, e.g. the interference from MBS to FUE$_3$.

2) $I_{FBS,FUE}$ is the CCI among femtocells, e.g. the interference from femtocell$_2$ to FUE$_1$.

3) $I_{FBS,MUE}$ is the CCI caused by FBS to MUE, e.g. the interference from femtocell$_1$ to MUE$_1$.

In order to cancel all the three types of interference shown in Fig.1, a dynamic interference graph construction scheme is proposed in which the vertex of graph is a FBS and the MUE which is suffering interference from FBS. As the location of FBS is fixed and only partial MUEs are considered in the graph, the overhead of updating the graph is low.

Our current problem is how to determine whether two nodes can be connected by an edge in the graph and how to estimate the interference weight. Note that the effect of interference depends on the ratio of interference power to signal power, so the Regional Average Channel State (RACS) metric is proposed to evaluate the influence of interference. The RACS of region m which is served by BS$_i$ and interfered by BS$_j$ represents the average SINR, and can be calculated as:

$$RACS(i,j,A_m) = \iint_{A_m} SINR_{i,j}(x,y)dxdy/S(A_m) \tag{1}$$

where $SINR_{i,j}(x,y) = P_{r,i}(x,y)/(P_{r,j}(x,y) + N_0)$; $P_{r,i}(P_{r,j})$ is the received power from $BS_i(BS_j)$; N_0 is the noise power; $S(A_m)$ is the area of region m.

Let A$_i$ be the coverage region of BS$_i$, and when $RACS(i,j,A_i) < SINR_{th}$, orthogonal sub-bands should be assigned to BS$_i$ and BS$_j$ to avoid interference. For the three scenarios shown in Fig.1, the interference threshold based on RACS is given in the following discussion. Then the algorithm of weight matrix construction rule is given.

A. Interference between FBSs

We consider the scenario in which FBS$_k$ and FBS$_j$ are located at $(0,0)$ and (d,0), with circular coverage radius R_k and R_j. When a FUE is located at (x,y), the received power from FBS$_k$ and FBS$_j$ are as follows.

$$P_{r,k} = P_k d_k^{-\alpha} = P_k(x^2+y^2)^{-\alpha/2} \tag{2}$$

$$P_{r,j} = P_j d_j^{-\alpha} = P_j((x-d)^2+y^2)^{-\alpha/2} \tag{3}$$

where α is the path loss exponent, $P_k(P_j)$ is the transmit power of FBS$_k$(FBS$_j$); $d_k(d_j)$ is the distance from the FUE to FBS$_k$(FBS$_j$). Let $\alpha = 2$ and ignore the noise power, the SINR of the FUE which is served by FBS$_k$ is:

$$SINR_{k,j}(x,y) = \frac{P_{r,k}}{P_{r,j}+N_0} \approx \frac{P_k}{P_j} \cdot \frac{(x-d)^2+y^2}{x^2+y^2} \tag{4}$$

As the FUE is moving in the coverage region of FBS$_k$ which is $A_k = \{(x,y)|x^2+y^2 < R_k^2\}$, the RACS of the coverage region of FBS$_k$ is calculated as follows.

$$\begin{aligned} RACS(k,j,A_k) &= \int_{R_{\min}}^{R_k} dr \int_0^{2\pi} SINR_{k,j} r dr d\theta / S(A_k) \\ &= \frac{P_k}{P_j}\left(1 + \frac{2d^2}{R_k^2 - R_{\min}^2} \ln\frac{R_k}{R_{\min}}\right) \end{aligned} \tag{5}$$

where R_{min} is the minimum distance between FUE and FBS.

Note that when the power of FBS is fixed, the value of $RACS(k,j,A_k)$ is only related to the distance between two FBSs. Thus, the SINR condition, i.e. $RACS(k,j,A_k) < c_{th}$, can be rewritten as the distance function:

$$d < d_{\min} = \sqrt{(R_k^2 - R_{\min}^2)(\frac{c_{th}P_j}{P_k} - 1) \Big/ (2\ln\frac{R_k}{R_{\min}})} \tag{6}$$

B. Interference from MBS to FBS

Consider the same scenario detailed in subsection A, when there is a MBS$_M$ located at $(D,0)$ with transmit power P_M, the FUE served by FBS$_k$ will suffer interference from the MBS. Similar to the analysis in subsection A, the RACS of FBS$_k$ caused by the interference from the MBS is:

$$RACS(k,M,A_k) = \frac{P_k}{P_M}\left(1 + \frac{2D^2}{R_k^2 - R_{\min}^2}\ln\frac{R_k}{R_{\min}}\right) \tag{7}$$

when $RACS(k,M,A_k) < c_{th}$, we get:

$$D < D_{\min} = \sqrt{(R_k^2 - R_{\min}^2)(\frac{c_{th}P_M}{P_k} - 1) \Big/ (2\ln\frac{R_k}{R_{\min}})} \tag{8}$$

To simplify the expression, the FBS is called inner FBS when the location of FBS satisfies inequality (8).

C. Interference from FBS to MUE

In the scenario that a MBS located at $(0,0)$ with transmit power P_M and FBS$_k$ located at (x_f, y_f) with transmit power P_F. When the MUE$_i$ served by the MBS is located at (x,y), the SINR of the UE is:

$$SINR_i = \frac{P_{r,M}}{P_{r,F}+N_0} \approx \frac{P_M}{P_F} \cdot \left[\frac{(x-x_f)^2+(y-y_f)^2}{x^2+y^2}\right]^{\frac{\alpha}{2}} \tag{9}$$

where noise power is ignored; α is the path loss exponent.

In order to estimate the interference from FBS to MUE, the MUE interference region of FBS is calculated, in which the SINR of the UE is below a predefined threshold. The region can be expressed as follows.

$$\begin{aligned} P &= \{(x,y)|SINR_i < c_{th}\} \\ &= \{(x,y)|(x-x_0)^2+(y-y_0)^2 < R_0^2\} \end{aligned} \tag{10}$$

where $x_0 = \frac{P_M x_f}{P_M - c_{th} P_F}$, $y_0 = \frac{P_M y_f}{P_M - c_{th} P_F}$, $R_0 = \sqrt{\frac{P_M P_F c_{th}(x_f^2 + y_f^2)}{(P_M - c_{th} P_F)^2}}$

Based on the information report from MUE$_i$, FBS$_k$ adds the MUE to its MUE interference set when the MUE enters region P, which can be expressed as:

$$I_M(k) = \{MUE_i(x_i, y_i) | (x_i, y_i) \in P\} \tag{11}$$

D. Graph Construction

In our proposed HCIG scheme, the interference graph G(V,E) is constructed by MBS, where the vertex set V stands for all FBSs and the MUEs which are in the interference region of FBS, and W is the weight matrix to characterize the potential interference between two vertexes in which $w(i,j) = w(j,i)$. When $w(i,j) = 0$, node$_i$ and node$_j$ is not connected in the graph.

To judge whether two nodes are connected by an edge, the distance threshold in subsection A and B as well as the interference region in subsection C are utilized. Meanwhile, as MBS is not the graph vertex, inner FBS node and MUE node are connected in the graph to avoid the interference shown in subsection B.

As two MUEs can't be assigned the same resources in LTE network, we let the weight between them be w_0 which is a very large value. As MUE has higher priority than FUE, w_0 is assigned to denote the interference from FBS to MUE in order to guarantee the performance of MUE. For other types of interference, 1/RACS is used to express the amount of interference.The algorithm to construct the interference graph matrix is given in Algorithm 1.

Algorithm 1 Graph Weight Matrix Construction Rule

Initializing $\mathbb{F}$: FBS set; $\mathbb{M}$: MUE set which are in the interference region of FBS; $V = \mathbb{F} \cup \mathbb{M}$; $W(G) = [w_{i,j}]_{N*N}$: Graph weight matrix, $N = |V|$
for $i = 1$ **to** $N-1$ **do**
  for $j = i+1$ **to** N **do**
    if $V_i \in \mathbb{M}$ and $V_j \in \mathbb{M}$ **then**
      $w_{i,j} = w_0$;
    else if $V_i \in \mathbb{M}, V_j \in \mathbb{F}$ and $V_i \in I_M(V_j)$ **then**
      $w_{i,j} = w_0$;
    else if $V_i \in \mathbb{M}, V_j \in \mathbb{F}$ and $D_j < D_{min}$ **then**
      $w_{i,j} = 1/RACS(j, M, A_j)$;
    else if $V_i \in \mathbb{F}, V_j \in \mathbb{F}$ and $D_(i,j) < d_{min}$ **then**
      $w_{i,j} = 1/RACS(i, j, A_i)$;
    else
      $w_{i,j} = 0$;
    end if
  end for
end for

III. Proposed Clustering Method

Based on the interference graph, the channel assignment problem becomes the clustering problem, where a cluster represents a channel. In the regular clustering schemes, the goal is to minimize the number of clusters(i.e. channels). However, our proposed clustering scheme uses all the available channels and aims at minimizing the interference in the system to improve the users' throughput.

Assume that the number of sub-bands is K and the weight between node i and j is $w(i,j)$. On the conditions that the nodes in a cluster reuse the same sub-band, the optimal clustering problem becomes the MAX K-CUT problem in the graph theory. In other word, how to partition vertexes set V into K disjoint sets $D = \{D_1, D_2, ..., D_K\}$ to maximize the weight between the disjoint sets in graph G= (V, E) should be studied. It can be formulated as:

$$\max \sum_{i=1}^{K-1} \sum_{j=i+1}^{K} \sum_{v_1 \in D_i, v_2 \in D_j} w(v_1, v_2) \tag{12}$$

which is a NP hard problem. Therefore, a heuristic algorithm named HCIG algorithm is presented as follows.

Algorithm 2 HCIG algorithm

1: **Initializing** Ω_k: the degree of vertex k;N_{MUE}: the number of MUE in the graph;N_{inner}: the number of inner FBS.
2: **Initializing** Let $W_i = \sum_{u \in \mathbb{R}_i, v \in \mathbb{R}_i} w_{u,v}$ be the intra cluster weight of cluster $\mathbb{R}_i$. Initially, as the cluster is empty, $W_i = 0, \forall i = 1, ..., L$ where L is the number of sub-bands.
3: Assign MUE nodes to N_{MUE} clusters, one in each cluster.
4: **if** $N_{MUE} + N_{inner} < L$ **then**
5:   Assign inner FBSs to the unallocated N_{inner} clusters
6: **else**
7:   Assign arbitrary $L - N_{MUE}$ inner FBS nodes to the remaining unallocated clusters.
8: **end if**
9: Sort the remaining FBS nodes in terms of Ω_k in descending order. Let V' be the sorted version of remaining FBS nodes, and select node m from the front of V'
10: **if** $\exists \mathbb{R}_j = \emptyset$ **then**
11:   Assign node m to cluster $\mathbb{R}_j$.
12: **else**
13:   **for** $i = 1$ **to** L **do**
14:     Calculated the increased intra-cluster weight if node m is assigned to $\mathbb{R}_i$, $\Delta W_i = \sum_{u \in \mathbb{R}_i} w_{m,u}$
15:   **end for**
16:   Assign node m to the cluster $\mathbb{R}_j$ where $j = \arg\min_i \Delta W_i$
17:   Update intra-cluster weight, $W_j = W_j + \Delta W_j$
18: **end if**
19: $\mathbb{R}_j \leftarrow \mathbb{R}_j \cup \{V_m\}$,$V' = V' - \{V_m\}$
20: Go to step 10 until $V' = \emptyset$

IV. Cluster Based Resource Allocation

After the cluster assignment procedure, the nodes in the graph are grouped into L clusters and the nodes in a cluster are allocated the same sub-band. However, as only partial MUEs are taken as the graph nodes, we should decide which sub-bands will be allocated to the remaining MUEs to achieve the highest throughput in the system. The problem is formulated as follows.

$$\arg\max \sum\nolimits_{m=1}^{M} \sum\nolimits_{n=1}^{L} B_w \log_2(1 + SINR_m \delta_{m,n}) \quad (13)$$

which is a NP hard problem, and M is the sum number of MUE and FBS; L is the number of sub-bands; $\delta_{m,n} = 1$ when sub-band n is allocated to node M, otherwise equals 0.

Meanwhile, after the channel allocation procedure based on the cluster results, only one sub-band is allocated to FBS. Therefore, a resource allocation scheme based on HCIG is proposed to reduce the system interference and improve the spectral efficiency, which is shown as follows.

Step 1: Based on the clustering results, one sub-band is randomly allocated to a cluster and the nodes in the cluster reuse the same resource.

Step 2: In HCIG, orthogonal resources are allocated to MUE and inner FBS in order to cancel the high interference from MBS. However, when there are not enough orthogonal resources after the resource allocation of MUE in the graph and inner FBS, the remaining MUE should reuse the sub-bands which are used by inner FBS. To minimize the system interference, the sub-band used by the inner FBS which is farthest from the MBS is reused by the remaining MUE.

Step 3: After the above two steps, each FBS is assigned a sub-band. In order to improve the spectrum efficiency of FBS, this step will search more sub-bands which can be assigned to FBS on the condition that the sub-bands are not used by the interfering nodes. Through the graph connection information, a FBS could know the resource set used by connected FBSs in the graph. Therefore, the sub-bands which are unused by neighbor FBSs are assigned to the FBS to improve the spectrum efficiency.

V. Performance Evaluation

The system simulation parameters are configured according to 3GPP LTE specifications [10], as presented in Table I where Inter-Station Distance (ISD) indicates the distance between two neighbor MeNBs. In our simulation, 19 macrocells are considered, in each of which the same number of femtocells are placed. Due to the interference from neighbor cells can't be ignored, only the results of central 7 cells are collected. The MUEs are uniformly distributed over the macrocell area and the FUEs are distributed in the coverage area of femtocells. The SINR threshold for construction the interference graph detailed in Section II is set to 10 dB.

As partitioned frequency allocation (PFA) algorithm sacrifices spectrum efficiency seriously, the following three schemes are taken as comparisons with HCIG:

(1) SFA: MBS and FBS use all the sub-bands.

(2) PSFA: MBS uses all the sub-bands, while FBS uses 20 percent($\alpha = 0.2$) or 30 percent($\alpha = 0.3$) of the sub-bands.

(3) AFFR: Sub-bands are assigned to FBS using the graph algorithm [9].

TABLE I
SIMULATION PARAMETERS

Parameters	Macrocell	Femtocell
System Bandwidth	20MHz	20MHz
Cell Layout	Hexagonal Grid,19 BSs	Circular Cell
Cell Size	ISD = 500m	Radius = 20m
Transmit Power	43 dbm	20 dbm
Antenna Gain	14dBi	0dBi
Pathloss	$128 + 37.6 * \log_{10}(d)$	$127 + 30 * \log_{10}(d)$
Fast Fading	SCME	SCME
Shadowing Deviation	4 dB	4 dB
Penetration Loss	10dB	10dB
Noise Level	-174dBm/Hz	-174dBm/Hz
UE Distribution	80 per cell	2 per cell

A. MUE/FUE SINR of Different Alogrithms

Fig.2 shows the probability of interference between MUE and FBS with different SINR threshold in (10). The results show when femtocells are densely deployed, MUEs will likely suffer high interference from FBS which is not considered in the previous graph-based schemes, e.g. the probability reaches 50% when 80 FBSs are distributed in each macrocell and SINR_{th}=10db.

Fig.3 shows the Cumulative Distribution Function (CDF) of MUEs' SINR. Since the interference from FBS to MUE is dynamically canceled by HCIG, the proposed scheme remarkably improves the SINR performance of MUE, especially reduces the number of MUEs with low SINR. As partial resources are used in femtocell by PSFA, the MUEs' SINR in PSFA is higher than that in SFA and AFFR. In addition, as only the interference among FBSs is considered in AFFR, the MUEs' SINR in AFFR is similar to that in SFA.

Fig.4 shows the CDF of inner and outer FUEs' SINR. Note that the interference to FUE can be divided into two types: from neighbor FBSs; from the MBS. In addition, the interference from MBS to FUE is getting more seriously when FUE is closer to the MBS. In AFFR, only the interference from neighbor FBSs is canceled and that from MBS is not considered; while in HCIG, the interference from MBS is also canceled by assigning orthogonal resources to MUEs and inner FBSs. So for inner FUEs, the SINR performance is significantly improved by HCIG compared to SFA and AFFR; for outer FUEs, the SINR of FUEs is improved similarly by AFFR and HCIG compared to SFA.

Fig.5 shows the CDF of all FUEs' SINR. Since partial resources are used in femtocell by PSFA, the interference among femtocells is very serious, leading to the lowest SINR performance. Besides, when fewer resources are used in femtocell ($\alpha = 0.2$), the FUEs' SINR is getting lower. It's also shown that as the interference from MBS to inner FUEs is canceled by HCIG, the FUEs' SINR is remarkably improved by HCIG compared to AFFR.

B. MUE/FUE SINR with Different Femtocell Densiy

In this part, the influence of femtocell density is discussed. Fig.6 and Fig.7 show the average SINR of MUE and FUE with different femtocell density. With the increasing number of femtocells, the interference in the system is getting more

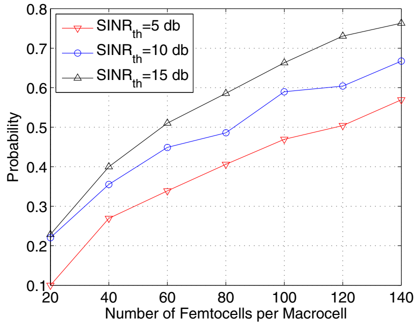

Fig. 2. Probability of interference between MUE and FBS

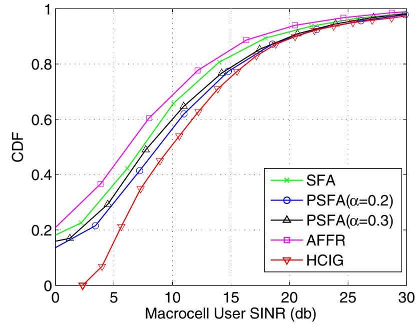

Fig. 3. MUEs' SINR CDF

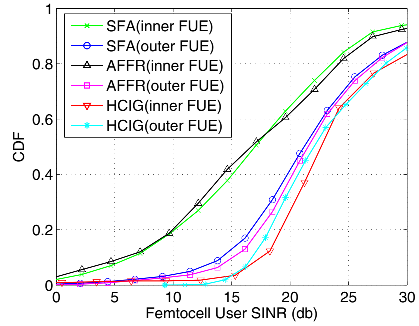

Fig. 4. inner and outer FUEs' SINR CDF

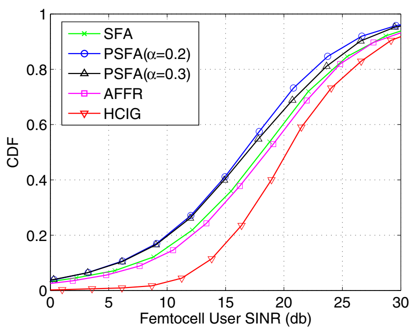

Fig. 5. FUEs' SINR CDF

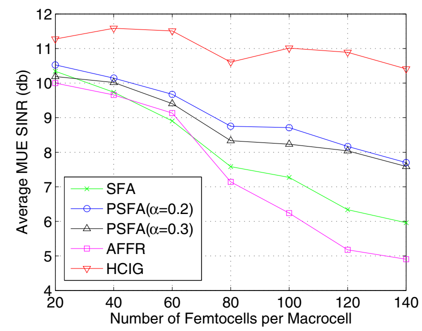

Fig. 6. Average MUEs' SINR

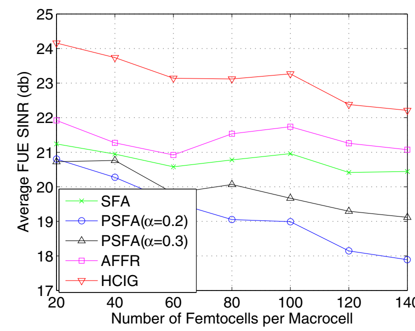

Fig. 7. Average FUEs' SINR

seriously, leading to the lower SINR for all the four schemes. But for HCIG scheme, the SINR of MUE and FUE decreases the slowest, as major of interference from FBS to MUE and that from FBS to FUE can be canceled through clustering method in HCIG.

VI. Conclusion

In this paper, three types of downlink interference in LTE heterogeneous network are investigated. Observed that only the interference among femtocells is canceled in the traditional graph-based schemes, a hybrid graph construction scheme is proposed, in which the vertexes are FBS and interfered MUE. In order to determine whether two graph nodes can be connected by an edge, the distance threshold for connection two nodes are given. Based on the proposed interference graph, the cluster-based resource allocation scheme named HCIG is proposed, in which all three types of interference is reduced. In addition, the optimal clustering algorithm is formulated and a heuristic algorithm is given. After HCIG, not only the minimum sub-bands are allocated to FBS, but also other sub-bands which are not interring with neighbor FBSs are assigned to FBS to enhance the spectral efficiency. Furthermore, as the location of FBS is fixed and only interfered MUEs are taken as graph node, the overhead of updating the interference graph in HCIG is very low. The system level simulation shows that both the SINR of MUE and FUE are significantly improved by HCIG compared to SFA, PSFA and AFFR.

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