Resource Block Assignment for Interference Avoidance in Femtocell Networks

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Abstract—**In this paper, we investigate resource block assignment in femtocell networks. A resource block assignment algorithm is considered to avoid co-channel intercell interference and ensure service quality for femtocell networks with dense and random femto deployments. We first formulate the optimization problem as the integer linear programming (ILP) on resource block assignment. The goal of the optimization problem is to maximize the overall utilization of resource blocks with quality of service (QoS) constraints. We propose an efficient and simple algorithm termed interference-aware resource block assignment (IARBA). By considering conditions of resource blocks, the proposed approach achieves better resource block efficiency and assignment within QoS requirements. Our analytical and simulation results show that IARBA not only provides interference-free resource block assignment but also outperforms existing schemes in terms of average throughput with comparable complexities.**

Keywords- femtocell; interference avoidance; resource reuse; intercell interference; co-channel interference.

I. INTRODUCTION

In recent years, the demand for higher data rates and ubiquitous wireless coverage grows rapidly with the proliferation of advanced mobile terminals and high bandwidth applications. Studies show that over 2/3 of calls and 90% of data services occur indoors [1], whereas 41% of household mobile consumers experience service interruptions on the daily basis [2]. In order to deliver high data rates to mobile devices, femtocell networks emerge as a promising solution for homes, offices, metro hotspots. A recent study estimates that the annual growth rate of worldwide femtocell market will reach 71% between 2011 and 2015 [3]. The deployment of femtocells is expected to rise rapidly in the near future.

Femtocells are deployed by users rather than network operators. Without any concerted planning, certain areas may encounter high-density deployment of femtocells. The main challenge for network operators is to ensure that femtocells can avoid interferences in using their radio resources co-existing with other neighboring cells under dense and random deployments. Since femtocell networks are co-channel deployed to reuse the same radio resources, the unavoidable co-channel interferences occur with the neighboring

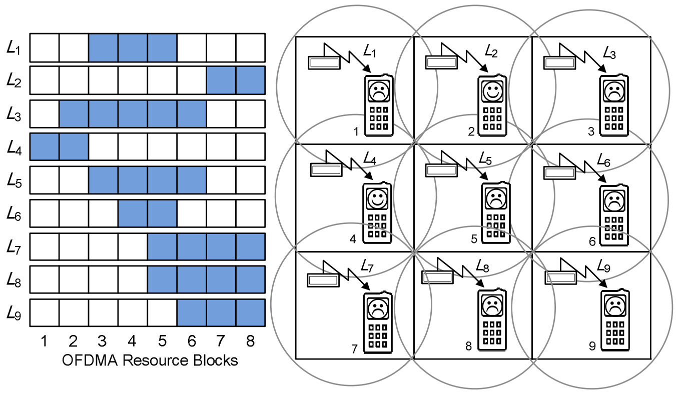

Fig. 1. Interference in femtocell networks.

femtocells using the same radio resource with the desired signals [4]. The sources of co-channel interferences include femtocells and femtocell user equipment (FUEs). Co-channel intercell interference incurred by neighboring femtocells/FUEs sharing the same radio resources decreases the quality of communications [4]. We show in Figure 1 a typical scenario of femtocell networks in an office environment, where each room is deployed with its femtocell independently without any prior agreement on resource block arrangements and femtocell placements. Based on orthogonal frequency division multiple access (OFDMA), the smallest radio resource unit that can be assigned to a FUE is a resource block. The number of resource blocks is restricted to transmission schemes for OFDMA. Moreover, the amount of resource blocks allocated to each user is based on its quality of service (QoS) requirement. With the limited radio resources, resource assignment becomes an important performance factor in femtocell networks.

In this paper, a concentrated resource block assignment algorithm is proposed to avoid co-channel intercell interference and reuse resource blocks. Since femtocells will connect to the internet through a femtocell management system (FMS) based on the 3GPP specifications [5], the FMS is designed to support the resource block assignments. Our approach, termed interference-aware resource block assignment (IARBA), considers all requests of femtocells simultaneously. We formulate the assignment problem to maximize the overall resource block efficiency with quality of service (QoS)

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constraints. A heuristic algorithm, termed interference-aware resource block assignment (IARBA) is proposed to approach the assignment problem.

Our major contributions include: 1) we formulate the assignment problem as an optimization problem; 2) we proposed a heuristic algorithm to solve this problem; 3) the co-channel and co-tiered interference can be entirely avoided, and no additional operation is needed in the design of femtocells; 4) the resource efficiency is improved and more femtocells can be accommodated within the same amount of resources; 5) the QoS requirements are guaranteed for all connections in the proposed scheme.

The remainder of the paper is organized as follows. In Section II we discuss related works on resource allocation schemes. Section III formulates the problem model as an Integer Linear Program (ILP) form. In Section IV, the proposed algorithm IARBA is presented to solve the above problem. Then, the simulation is performed to evaluate the performance of our algorithm in Section V. Finally, we conclude this paper in Section VI.

II. Related Work

Many works has been done to reduce the co-channel intercell interference and achieve good throughput performance. Several investigations were based on cognitive radio techniques to exploit their knowledge of the radio scene for interference management [6]. Huang et al. [7] proposed implementation of cognitive femtocell base stations for resource allocation by using a game-theoretic framework. With cognitive femtocell base stations, Lien et al. [8] recommended the insertion of sensing frames to scan the whole wireless resources periodically. In above approaches, cognitive radio techniques need to monitor the wireless environment and cognitive radio capabilities need to be incorporated into the femtocell base-stations. Some approaches of resource allocation were based on graph coloring algorithm. Tan et al. [9] presented GC-DSA as a graph coloring based dynamic sub-band allocation technique to avoid downlink interference. Uygungelen et al. [10] also developed GB-DFR as a resource allocation method based on graph coloring. With graph coloring algorithms, the assignment of resources to a femtocell is restricted to a determined color; therefore, the resource efficiency is limited.

In order to improve the resource efficiency in OFDMA systems, frequency reuse schemes have been introduced [11]. Rahman et al. [12] proposed a partial frequency reuse schemes for macrocells that utilizes intercell coordination. H.-C. Lee [13] proposed an adaptive fractional frequency reuse scheme where the overlapping coverage areas between femtocells are required to decide the allocated resources. To reduce the loading of femtocells, K. Sundaresan et al. [14] proposed a distributed random access (DRA) scheme which decides the allocated resources randomly. Their approaches suffer from co-channel intercell interference. In the prior work, we proposed an adaptive intercell interference avoidance scheme named RAFF to avoid co-channel intercell interference which is based on the interference experienced by femtocells [15]. IARBA differs by taking into account all connections from femtocells simultaneously. IARBA also applies to a more effective resource block assignment algorithm to improve resource efficiency.

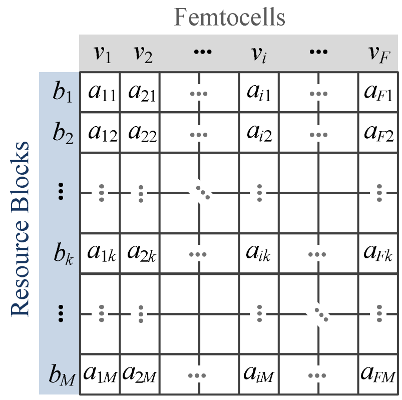

Fig. 2. The assignment indicators of resource blocks.

III. Problem Model

An optimization problem is formulated to allocate the total available resource block for all femtocells. We first model a femtocell network as a graph $G = (V, E)$, where $V = \{v_1, v_2, \ldots, v_F\}$ represents the set of femtocells and E represents the set of interfered links among neighboring femtocells. The number of femtocells is denoted as $|V| = F$. Let the interference link n_{ij} between the femtocell v_i and v_j be defined by

$$n_{ij} = \begin{cases} 1, & \text{if } (v_i, v_j) \in E \\ 0, & \text{otherwise} \end{cases}. \quad (1)$$

A set of resource blocks B maintained by a FMS is denoted as $B = \{b_1, b_2, \ldots, b_M\}$, where the number of resource blocks is $|B| = M$. To describe the assignment of resource blocks, an indicator parameter a_{ik} is defined as

$$a_{ik} = \begin{cases} 1, & \text{if } b_k \text{ is allocated to } v_i \\ 0, & \text{otherwise} \end{cases}. \quad (2)$$

Figure 2 shows the relation of a_{ik} between resource blocks and femtocells. We define the resource block efficiency α_k as the accumulative utilization of b_k, where $\alpha_k = \sum_{\forall i=1\ldots F} a_{ik}$. Our objective function is to maximize the amount of all resource block efficiencies, expressed as $\max \sum_{\forall k=1\ldots M} \alpha_k$. In order to prevent co-channel intercell interference, a resource block cannot be assigned to adjacent femtocells. Therefore, the condition $n_{ij} \cdot a_{ik} \cdot a_{jk} = 0$ should be satisfied, $\forall i = 1 \ldots F$, $\forall j = 1 \ldots F$, and $\forall k = 1 \ldots M$. Moreover, the amount of assigned resource blocks should be constrained as $\sum_{\forall k=1\ldots M} u_k \leq M$, where

$$u_k = \begin{cases} 1, & \text{if } \alpha_k \neq 0 \\ 0, & \text{otherwise} \end{cases}. \quad (3)$$

Since different connections require different amounts of resource blocks to support the QoS specifications, the QoS constraints, as measured by the required number of PRBs, are taken into consideration. We apply nine different services specified by 1~9 QoS class identifiers (QCIs) defined in 3GPP long term evolution (LTE). A connection c belongs to a type of QCIs including the constraints of GBR, the required PRBs, and the delay. Let $\mathrm{N} = \{\mathrm{n}_1, \mathrm{n}_2, \ldots, \mathrm{n}_9\}$ be the set of all connections with QCI $1 \ldots 9$, where n_q represents the set of connections with QCI q. The services of QCI 1~4 are applicable to conventional voice, conventional video, buffered streaming, or real-time gaming. The QCI 5~6 applies to IP multimedia signaling or live streaming; QCI 7~9 applies to file sharing, email, P2P, or Web. The allocated resources must be sufficient to meet the requirements for the corresponding QCIs in both uplink and downlink transmissions. Furthermore, because guarantee bit rate (GBR) is required in QCI 1~4, the allocated number of resource blocks should be equal to the requested ones. We denote $\mathrm{N}_{\mathrm{GBR}} = \{\mathrm{n}_1, \mathrm{n}_2, \mathrm{n}_3, \mathrm{n}_4\}$ as the set of connections constrained by GBR. The remaining QCI 5~9 are non-GBR which allows flexible resource block assignments. The set of connections constrained by non-GBR is defined as $\mathrm{N}_{\mathrm{nG}} = \{\mathrm{n}_5, \mathrm{n}_6, \ldots, \mathrm{n}_9\}$ with QCI $5 \ldots 9$. Notice that $\mathrm{N} = \mathrm{N}_{\mathrm{GBR}} \cup \mathrm{N}_{\mathrm{nG}}$ and $\mathrm{N}_{\mathrm{GBR}} \cap \mathrm{N}_{\mathrm{nG}} = \emptyset$. The allocated PRB z_c of a connection c needs to satisfy the requested PRB r_c if $\mathrm{c} \in \mathrm{N}_{\mathrm{GBR}}$. For the connections with QCI $5 \ldots 9$, the allocated PRB z_c is allowed to be less than the required PRBs r_c. The delay of a connection c, denoted as d_c, should be no longer than the maximum delay limitation D_q of QCI q.

The above considerations can be summarized as the following optimization problem to allocate the total resource blocks for all connections.

Maximize:

$$\textstyle\sum_{\forall k=1\ldots M} \alpha_k. \tag{4}$$

Subject to:

$$n_{ij} \cdot a_{ik} \cdot a_{jk} = 0, \forall i, \forall j, \forall k, \tag{5}$$

$$\textstyle\sum_{\forall k=1\ldots M} u_k \leq M, \tag{6}$$

$$Z_N = R_N, \exists R_N \in Q_c, c \in GBR, \tag{7}$$

$$1 \leq Z_N \leq R_N, \exists R_N \in Q_c, c \notin GBR, \tag{8}$$

$$d_N \leq D_c, R_N \in Q_c. \tag{9}$$

The expression of the objective function (4) aims at maximizing the total resource block efficiency over the network. Equations (5)-(9) are the model constraints as described above. To prevent the co-channel intercell interference, the equation (5) ensures that the same resource blocks cannot be allocated to neighboring femtocells. The inequality (6) gives the upper bound of assignments. The constraints (7)-(9) guarantee QoS requirements for connections.

The above optimization problem is formulated by using ILP which incurs huge computational complexities because an ILP problem is a NP-complete problem. In the assignment problem, the system parameters include the huge number of connection requests, available resource blocks, and femtocells, which incur high complexities. Therefore, the optimality is to be approximated through our proposed heuristic approach in the next section.

IV. PROPOSED ALGORITHM

As shown in Section III, the femtocell resource block assignment problem is NP-complete; the optimal algorithm achieving the optimum resource block assignment often incurs high complexities. Thus, we resort to the heuristic algorithm that can efficiently provide moderate solution. Here, the computational efficiency is a major concern because the femtocell resource block assignment occurs frequently. The feasible solution is to provide a non-optimal but useable assignment in an efficient way, instead of the high-complexity optimal algorithm.

The design of our proposed IARBA is due to the observation that the combination of different maximal weight independent set (MWIS) usually gives a good fit of resource block assignment. With such observation in mind, the realization of such idea could be straightforward. For a femtocell network with F femtocells, each has its own demanded resource blocks. Let A be an arbitrary approximation algorithm for MWIS. After receiving the demands from all of the femtocells, the initial condition $\mathrm{G}^{(0)}$ is set as the minimum requirement of resource blocks for each QCI, where $\mathrm{G}^{(0)} = \mathrm{G}^{\min}$. Then, a FMS iteratively applies A on the graph $\mathrm{G}^{(\mathrm{i})}$ in the i-th iteration, $\mathrm{i} \geq 0$, with $\mathrm{G}^{(0)}$. We should note that $\mathrm{G}^{(\mathrm{i}+1)}$ is constructed in a way such that $\mathrm{G}^{(\mathrm{i}+1)}$ is a sub graph in which the vertices belonging to the MWIS of $\mathrm{G}^{(\mathrm{i})}$ have been removed. The above procedure is iteratively applied until all resource blocks are assigned. Finally, the unsatisfied femtocells are particularly assigned with non-interfering resource blocks.

From the graph theory point of view, different MWISs are selected in each iteration. From femtocell resource block assignment point of view, a set of femtocells offering maximal resource satisfaction in the corresponding iteration is selected. Note that the set of femtocells that offer the globally maximal resource satisfaction will be selected with the highest priority, i.e., it will be selected in the first iteration. Particularly, considering a MWIS selected in a specific iteration, we can observe that, for the current iteration, the allocation of the resource blocks for those nodes achieves the maximal satisfaction in a greedy way. More importantly, the selection of MWIS is able to guarantee that assigning the resources to those nodes do not lead to interference among those nodes.

Assume that for a specific MWIS, the node v has the maximal weight; i.e., v has the most demands m in the corresponding iteration. In our IARBA, the first m resource blocks are all allocated to the nodes in the MWIS in the current iteration. This is to avoid the interference between the nodes from different MWISs. Thus, our algorithm works as follows. Each time the FMS finds a MWIS with m being the maximal demand for resource blocks. The first m resource blocks are then reserved for the nodes in MWIS in the current iteration. At the end of the current iteration, the nodes in the MWIS will be removed from the graph and the remaining nodes constitute the graph for the next iteration. Note that the next iteration will be executed in a similar way with the exception that the resource blocks will not be distributed from 1. For example, in the second iteration, resource blocks will be from $\mathrm{m} + 1$. Figure 3 gives an example to describe the procedure of our algorithm, where ten femtocells with their corresponding demands and interfered edges are given to request eight resource blocks. For

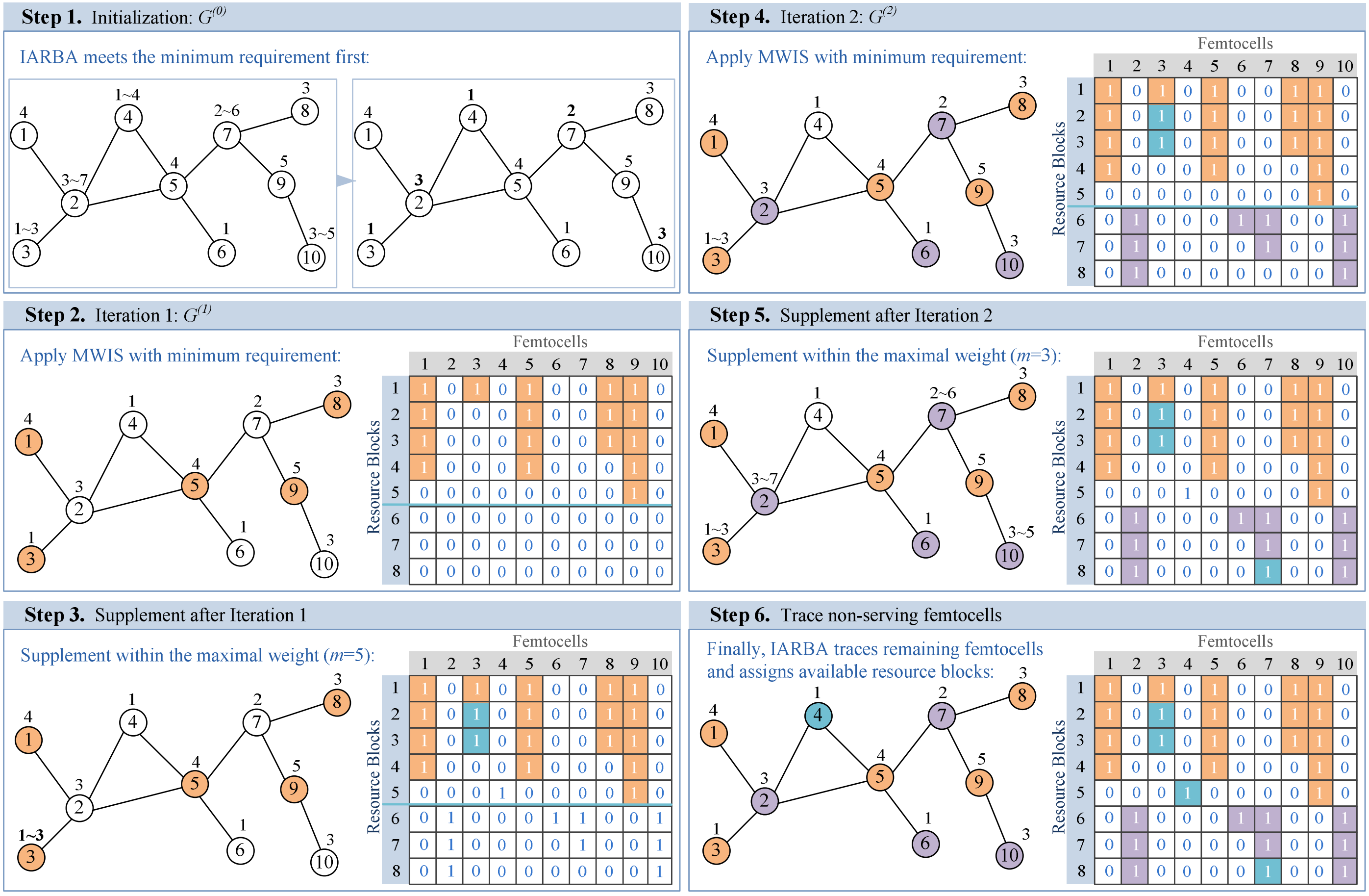

Fig. 3. An example of the proposed IARBA.

instance, femtocell 2 requires 3-7 resource blocks and its interfering node is femtocell 1, 3, 4 and 5. In IARBA, the initial graph $G^{(0)}$ is set as the minimum requirement of resource blocks. Then, MWIS is continuously applied to assign most resource blocks for non-interfering femtocells until all resource blocks are assigned in iterations. Remaining resource blocks can be allocated to the requested femtocells within the maximal weight m.

V. SIMULATION RESULT

We compare the performance of IARBA with two other resource block assignment algorithms, DRA and RAFF. We evaluate IARBA using the system parameters of 3GPP LTE, which are listed as in Table I. The scenario is consisting of an area of 100 square meters uniformly random distributed with femtocells with a circular coverage radius of 10 meters. The coverage areas of femtocells may overlap with one another in the deployment. We arrange a certain number of femtocells which were 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 for each simulation, where the average numbers of neighbors are 1.40, 4.10, 4.80, 6.30, 7.08, 7.69, 8.49, 9.63, 10.44, and 11.88, respectively. All femtocells are controlled by a FMS in charge of allocating resources. The required data rate and the number of required resource blocks are set to meet the requirement in 64 QAM wireless channel quality in 3GPP specification [5].

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Map Range	100 m × 100 m
Number of Femtocell	100
Radius	10 m
Deployment	Uniformly distributed
Number of Neighboring Femto	1 ~ 22
Antenna Pattern	Omni Directional
Frame Structure	FDD
Bandwidth	5 *MHz*
Subframe Duration	0.5 *ms*
Number of Available PRBs	25 *(in ferauency domain)*
Modulation	64 *QAM*
PRB Spectral Efficiency	3.7 *b/s/Hz*

Since different QCIs apply to different types of applications, we generate traffics corresponding to the various applications in mobile phone networks.

We compare the average throughput of IARBA, DRA and RAFF in Figure 4. When the number of femtocells is 10, approximately 50% resource blocks are assigned. Since there are still a lot of available resources to be allocated, the average throughputs of the proposed IARBA, RAFF and DRA are similar. When the number of femtocells increases to be more than 20, the network is congested and the resources are limited by the amount of resource blocks. The average throughputs become relatively stable. Figure 4 shows that, compared with DRA and RAFF, IARBA achieves 23% and 11% improvement in the average throughput respectively. It shows that connections gathered by the FMS are important to conduct good assignments to improve resource efficiency. Figure 5 shows the average interference ratio of connections for IARBA, DRA and RAFF. According to the random scheme utilized by DRA, one resource block could be allocated to different femtocells. Although the assigned resource blocks are not limited by the interference in DRA, their connections suffer from the interference. Notably, the proposed IARBA and RAFF assign resource blocks without interference, so that there will be no interference for each connection. The proposed IARBA can completely avoid the interfering resources in contrast to the average interfered connection ratio of 40%~50% in DRA.

VI. CONCLUSION

In recent years, femtocell networks have attracted industrial and research attentions due to the demand of indoor services. The femtocells are assumed to be independently set up by inexperienced users. Therefore, developing an efficient resource assignment algorithm is very important in femtocell networks. In this paper, we formulate the resource block assignment problem as an optimization problem. Because this problem is NP-complete, we propose a heuristic algorithm IARBA to provide interference-free assignment. IARBA overcomes the weaknesses of DRA, RAFF and other approaches. In IARBA, a set of femtocells that can offer maximal resource satisfaction in the corresponding iteration will be selected. We propose the IARBA algorithm and conduct simulations to verify the effectiveness of the proposed approach. Simulation results show that our mechanism provides effective resource assignments without interference. Compared with DRA and RAFF, the proposed algorithm improves by 23% and 11% in the average throughput respectively.

REFERENCES

[1] J. Zhang and G. D. L. Roche, *Femtocells: technologies and deployment*. United Kingdom: John Wiley & Sons Ltd, 2010.

[2] Park Associates, “Global consumer survey of in-home mobile services and femtocells,” Femto Forum, May 2011.

[3] Informa Telecoms & Media, “Femtocell market status,” Femto Forum, Oct. 2011.

[4] D. López-Pérez, A. Valcarce, G. de la Roche, and J. Zhang, "OFDMA femtocells: a roadmap on interference avoidance," *IEEE Commun. Mag.*, vol. 47, pp. 41-48, Sep. 2009.

[5] Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2 (Release 10), 3GPP Technical Specification TS 36.300 V10.5.0, Oct. 2011. [Online]. Available: http://www.3gpp.org.

[6] A. Attar, V. Krishnamurthy, and O. N. Gharehshiran, "Interference management using cognitive base-stations for UMTS LTE," *IEEE Commun. Mag.*, vol. 49, pp. 152-159, Aug. 2011.

[7] LTE/3GPP femtocells: a correlated equilibrium game-theoretic approach," *IEEE Trans. Commun.*, pp. 1-9, Oct. 2011.

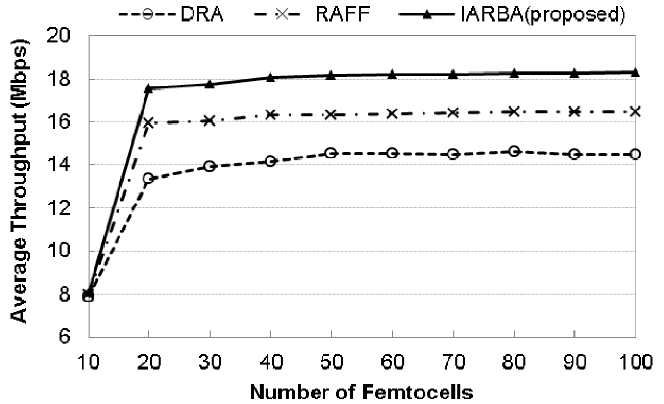

Fig. 4. Average throughput for different schemes.

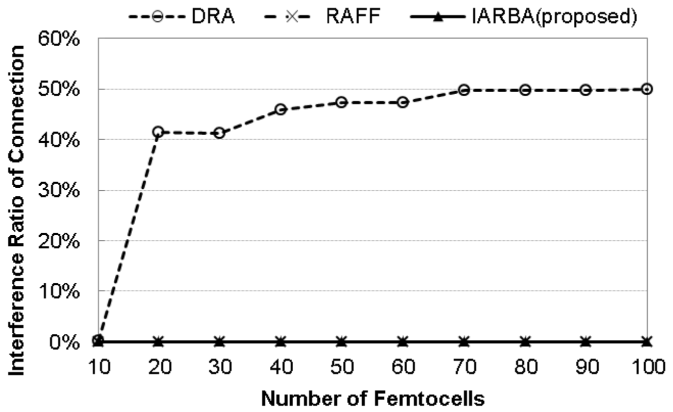

Fig. 5. Interference ratio of connections.

[8] S.-Y. Lien, C.-C. Tseng, K.-C. Chen, and C.-W. Su, "Cognitive radio resource management for QoS guarantees in autonomous femtocell networks," in *IEEE Int. Conf. on Commun.*, May 2010, pp. 1-6.

[9] L. Tan, Z. Feng, W. Li, Z. Jing, and T. A. Gulliver, "Graph coloring based spectrum allocation for femtocell downlink interference mitigation," in *IEEE Wireless Commun. Networking Conf.*, Mar. 2011, pp. 1248-1252.

[10] S. Uygungelen, G. Auer, and Z. Bharucha, "Graph-based dynamic frequency reuse in femtocell networks," in *IEEE Veh. Technol. Conf.*, May 2011, pp. 1-6.

[11] D. López-Pérez, A. Valcarce, G. de la Roche, and J. Zhang, "OFDMA femtocells: a roadmap on interference avoidance," *IEEE Commun. Mag.*, vol. 47, pp. 41-48, Sep. 2009.

[12] M. Rahman and H. Yanikomeroglu, "Enhancing cell-edge performance: a downlink dynamic interference avoidance scheme with inter-cell coordination," *IEEE Trans. Wireless Commun.*, vol. 9, pp. 1414-1425, Apr. 2010.

[13] H.-C. Lee, D.-C. Oh, and Y.-H. Lee, "Mitigation of inter-femtocell interference with adaptive fractional frequency reuse," in *IEEE Int. Conf. on Commun.*, May 2010, pp. 1-5.

[14] K. Sundaresan and S. Rangarajan, "Efficient resource management in OFDMA femto cells," in *ACM Int. Symp. on Mobile Ad Hoc Networking and Computing*, May 2009, pp. 33-42.

[15] Y. S. Liang, W. H. Chung, H. K. Zhang and S. Y. Kuo, "Interference mitigation through self-organization in OFDMA femtocells," in IEEE Int. Symp. on Personal, Indoor and Mobile Radio Commun., Sep. 2011.