Maximizing Dual Cell Connectivity Opportunities in LTE Small Cells Deployment

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***Abstract*—Most of the LTE (Long Term Evolution) network operators are deploying low power small cells in hotspots like airports, shopping malls and corporate offices to meet increasing data demands. Since users are not deemed to fixed locations in such places, the network experiences uneven distribution of traffic load across the cells which degrades the average user throughput. This problem is even more severe if the deployment of small cells is unplanned. In order to address this, in this work, we propose two variant of small cell placement models: an optimal Femto placement with full power (OPT-FP) model and an opportunistic Femto placement with power control (OPPR-PC) model. These models incorporate a constraint which helps small cells providing dual cell connectivity (DCC) for as many number of users as possible and then schedule them jointly for improving their throughputs.**

I. Introduction

In public places like airports, shopping malls and indoor stadiums, there has been a significant rise in the traffic demand by the mobile users with smart phones or tablets. In an attempt to meet the data rates for such indoor users, 4G LTE (Long Term Evolution) network operators are deploying more small cells like Femtos and picos. Small cells not only give the indoor users high data rates, but also help operators reap economic benefits by reducing CAPEX and OPEX. Small cell networks are difficult to manage because of their overlapping operating environments. Frequent handovers, load imbalance and high interference are some of the problems faced in unplanned dense deployment of small cells. Cell edge users are the one who experience low throughput because of weak signal strength and high interference. The overlapping regions of these small cells can be exploited by the network operators by allowing Dual Cell Connectivity (DCC) for cell edge users in the overlapped regions. Unlike in [1] , where DCC is employed for letting users to connect with a Macro cell and a small cell, in this work we employ DCC for connecting users in hotspot areas (refer Fig. 1) to two different small cells: primary (PR) and secondary (SC) cells. But, in order to improve SINR from both PR and SC cells, joint scheduling of radio resources to cell edge users in the overlapping regions has to be done.

In our work, we maximize DCC opportunities to indoor users by deploying small cells using optimal placement with full power (OPT-FP) or opportunistic placement with power control (OPPR-PC) models. To ensure fair allocation of resources to all the users in the network, proportional fair (PF) scheduling algorithm is incorporated. OPT-FP placement model is an economically feasible solution, with minimum number of small cells covering the whole region (e.g., shopping mall) without any coverage holes yet it ensures a minimum SINR to the users in the overlapped regions. This placement model does not guarantee better services, for example cell edge users might not be able to play higher resolution videos. But OPPR-PC ensures better services and has been modeled by fixing various power levels for different small cells. Even though the OPPR-PC placement of Femto BSs (i.e., Small cells) improves indoor data rates, the network performance degrades when there is a sudden shift of traffic load across Femto BSs due to user mobility. This has been addressed by the proposed PF joint scheduling (PFJS) algorithm in which users are scheduled jointly by PR and SC cells. The shopping mall is consider for study in Section IV.

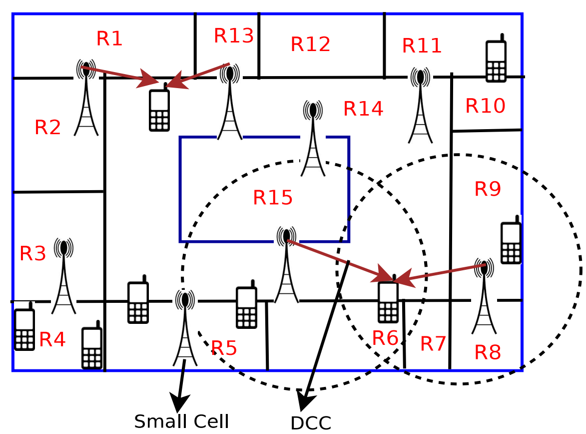

Fig. 1: An example of shopping mall with small cells and DCC users

II. Related Work

Due to the smaller coverage region of small cells, load balancing and user-level fairness across small cells is a serious problem. Existing works explored sub-optimal ways of load balancing by tuning the hysteresis threshold margins and by varying the transmit power of cells. Before applying the above methods, the first step is to place the small cells efficiently in the environment. In [2], [3], small cells are deployed optimally based on the interference measurements between Macro and small cells. This reduces the interference among small cells by guaranteeing certain SINR threshold from each small cell

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so that each cell can handle more users. However, there is a chance of imbalance in traffic load in these small cells owing to mobility of the users. While deploying small cells, operators should maximize the coverage area of all small cells and there by increase the possibility of joint scheduling for cell edge users. Compared to our previous work [3], in this work, we placed small cells optimally (OPT-FP model) and opportunistically with power control (OPPR-PC model) for guaranteeing certain SINR threshold from more than one small cell for cell edge users for DCC.

Several solutions have been proposed for addressing joint scheduling issues in LTE networks. In [4], the authors discussed about dual connectivity with uncoordinated power control in uplink between Macro and small cells, but, this may reduce the battery life of the user equipments (UEs) and increase the burden on the backhaul. In [5], the uplink and downlink connections are decoupled in heterogeneous network due to disparity in the transmit powers. Hence, authors proposed the uplink connection to a small cell with shortest path loss to save power and downlink connection to a Macro. But demand in the downlink is more than uplink in indoors so dual connectivity from small cells in downlink connection plays a key role. In [6], authors considered joint inter cell interference coordination and forced cooperative downlink packet scheduling. Practical deployment of this solution is difficult due to spectrum sharing issues. This solution also limits secondary cell resource usage due to forced scheduling by primary cell.

To improve the average user throughput of the system, in our work, we are proposing OPT-FP and OPPR-PC placement models which target maximizing number of DCC users in the overlapping regions and there by offer more joint scheduling opportunities.

III. Proposed work

In this section, we provide the system model and path loss models used for solving the problem of OPTimal placement of small cells (aka Femto BSs) with Full Power (OPT-FP) and opportunistic placement of Femto BSs with Power Control (OPPR-PC). The notations used are listed in Table I.

TABLE I: Glossary

Notation	Definition
M	Set of Macro BSs
F	Set of Femto BSs deployed inside Hotspot region
SR	Set of sub-regions inside Hotspot region
x_j	Sub-region number where Femto BS j is located
g_{ij}	Channel gain between sub-region i and Femto BS j
g_{im}	Channel gain between sub-region i and Macro BS m
y_{ij}	1 if sub-region i is connected to Femto BS j, 0 otherwise
P_j	Transmission power of Femto BS j

A. System and Building Model

We consider LTE HetNet system consisting of a Macro BS in outdoor environment and Femto BSs present inside a shopping mall/enterprise office building, having g floors, where each floor is divided by walls into several rooms. Each room is further logically divided into smaller sub-regions [3]. We assume that all Femto BSs are configured in open access mode i.e., UEs are authorized to connect to any Femto BS. In the system model, Femto BSs and Macro BSs are configured to operate on the same frequency (to enable maximum reuse of the spectrum) and hence they may experience high cross-tier, co-channel interference. After the placement of Femto BSs, resource allocation for non-DCC users and *joint* resource allocation for DCC users is taken care by fairness ensuring PFJS algorithm, which is a modified version of PF scheduling.

B. Channel Model

The Path Loss (PL) between Macro and UE is given by

$$PL_{MacroBS} = 40\log_{10}\frac{d}{1000} + 30\log_{10} f + 49 + n\phi \quad (1)$$

where, d is the distance between UE and Macro BS in meters, n is the number of walls existing between a Macro BS and a UE, f is the center frequency of Macro BS and ϕ is the penetration loss of walls. The PL between Femto BS and UE is given by,

$$PL_{FemtoBS} = 37 + 30\log_{10} d + 18.3v^{\frac{(v+2)}{(v+1)-0.46}} + n\phi \quad (2)$$

Here v is the number of floors in between. We also assumed that the antenna gain for Macro BS and Femto BS are 20 dBi and 2 dBi, respectively. The above PL equations and antenna gain are used for computing the channel gain.

C. OPT-FP Model

Placement of Femto BS has to be done optimally to maximize DCC, guarantee minimum SINR and avoid coverage holes in a given deployment region. In order to achieve OPT-FP placement of Femto BS and maximizing DCC, we have taken necessary constraints and formulated a mixed integer non-linear programming (MINLP) model. By solving the MINLP optimization model, the following values can be found out: **(a)** Optimal locations for Femtos deployment. **(b)** The set of sub-regions which each Femto BS has to serve.

The model is defined as follows.

$$\arg\max_{x} \sum_{i=1}^{|SR|}\sum_{j=1}^{|F|} y_{ij} \quad (3)$$

where,

$$y_{ij} = \begin{cases} 1, & \text{if } SINR_{ij} \geq \lambda \\ 0, & \text{otherwise} \end{cases}$$

$SINR_{ij}$ is the SINR at sub-region *i* from Femto BS *j* and λ is the threshold SINR value. The Femto BS *j* can serve the sub-region *i* only when $SINR_{ij}$ is greater than λ. The above mentioned objective function will try to maximize the number of Femtos that can serve a sub-region (thus increasing the possible DCC connections) and ensure no coverage hole. SINR received by a particular sub-region i from the Femto BS j, is given by the R.H.S of Eqn (4).

$$SINR_{ij} = \frac{g_{ij}P_{max}}{N + \sum_{m \in M} g_{im}P_{macro} + \sum_{j' \in S/i} g_{ij'}P_{max}} \quad (4)$$

Where P_{max} is the maximum power emitted by Femto BS, P_{macro} is the power emitted by Macro BS and N is the system noise. Eqn (5) ensures that sub-region number of the Femto BS j lies between the minimum and maximum sub-region number.

$$1 \leq x_j \leq |SR| \qquad \forall j \in F \quad (5)$$

The constraint in Eqn (6) ensures that the total SINR of all the sub-regions inside the building is above the threshold (γ). This constraint will help to boost the capacity of the system.

$$\sum_{i=1}^{|SR|} \sum_{j=1}^{|F|} SINR_{ij} \geq \gamma \quad (6)$$

Finally the OPT-FP model is formulated as follows,

$$max \sum_{i=1}^{|SR|} \sum_{j=1}^{|F|} y_{ij}, \text{ such that (5), (6)}$$

D. OPPR-PC Model

Though OPT-FP model guarantees SINR threshold with fewer number of Femtos, due to many practical constraints (e.g., lack of space and power) and hotspots inside the building, it may not be possible to deploy Femtos at the optimal locations. In order to deploy Femto BSs more realistically, we placed the Femtos based on the occupancy pattern of users. Further, Femto transmit power is tuned optimally to maximize DCC users in the network. Similar to OPT-FP model, we have formulated OPPR-PC MINLP model. By solving this model, the following values can be found out: **(a)** Optimal transmission power of Femto BSs. **(b)** The set of sub-regions which each Femto BS has to serve. The model is defined as follows.

$$\arg\max_{P} \sum_{i=1}^{|SR|} \sum_{j=1}^{|F|} y_{ij} \quad (7)$$

The SINR received by a particular sub-region i from the Femto BS j, is given by the R.H.S of Eqn (8).

$$SINR_{ij} = \frac{g_{ij}P_j}{N + \sum_{m \in M} g_{im}P_{macro} + \sum_{j' \in S/i} g_{ij'}P_{j'}} \quad (8)$$

The Constraint in Eqn (9) ensures that power transmitted by the Femto BS j is less than the maximum transmission power.

$$P_j \leq P_{max} \quad (9)$$

Finally the OPPR-PC model is formulated as follows,

$$max \sum_{i=1}^{|SR|} \sum_{j=1}^{|F|} y_{ij}, \text{ such that (6), (9)}$$

Both OPT-FP and OPPR-PC are MINLP models, which can not be easily solved using traditional MINLP algorithms.

TABLE II: Simulation Parameters

Parameter	Value
Building dimensions	48 m × 48 m × 4m
P_{max}, P_{macro} and λ	20 dBm, 46 dBm and -4 dB
Macro BS Height	30 m
Number of Floors	One
Femto Placement	Ceiling (center of sub-region)
Buffer status	Full Buffer
Femto's Bandwidth	5 MHz (25 RBs)
Simulation time	100 s

Hence, we used Genetic Algorithm (GA) to solve both the models.

E. Proportional Fair Joint Scheduling (PFJS)

A centralized controller (CC), which runs at Femto-Gateway (F-GW) determines which UEs can get benefit from joint scheduling by which Femto BSs. The CC informs Femto BSs to enable DCC for selected UEs so that they could get scheduled jointly.

$$PFMetric_i = IAR_i / LAT_i \quad (10)$$

Each user inside the building gets scheduled according to the $PFMetric_i$ metric shown in Eqn (10). For each user the instantaneous achieved rate (IAR_i) is calculated based on data transmitted in each radio resource block according to the SINR range (e.g., MCS values: QPSK, 16-QAM or 64-QAM) in a given TTI. The Last Average Throughput (LAT_i) for user i is calculated in a given TTI by averaging throughput over all past TTIs. This metric ensures fairness to all users (DCC and non-DCC) inside each cell. QoS requirement of each user is known by the CC and it decides and reports to small cells how many resource blocks have to be allocated from each of PF scheduler (running on each Femto BS) depending on current channel conditions. If one small cell is heavily loaded, joint scheduling can be applied to cell edges UEs of the loaded cell with the help of one of less loaded neighboring cells whose SINR at the cell edge UEs is above the SINR threshold. Both primary cell and secondary cell maintain the same LAT value for a particular DCC user, which assists to attain throughput fairness between the two cells (explained further in Section IV-C).

IV. Experimental Results

MATLAB based LTE system simulator is developed with the parameters given in Table II. The shortest distance between building and Macro BS is 300 m (diagonally from the south-west side of the building). We have conducted experiments for evaluating how OPPR-PC and OPT-FP models maximize DCC opportunities to users in all possible overlapping sub-regions of small cells. Finally, we have evaluated both models with PFJS in terms of fairness for both DCC and non-DCC users.

A. OPPR-PC Model: Performance Analysis

In this model, Femtos are placed inside the building based on expected user occupancy levels. Further, they operate at the optimal power to meet the SINR threshold for maximizing

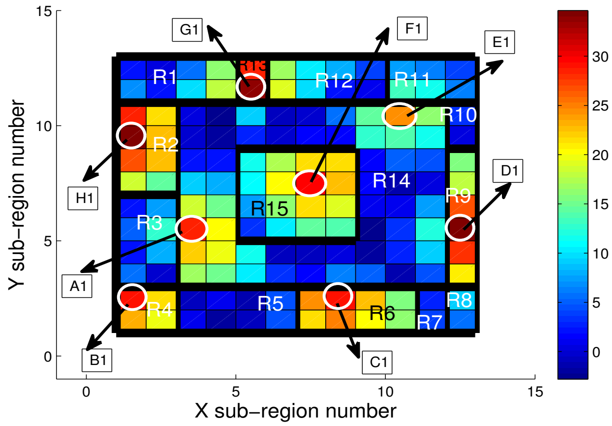

Fig. 2: Femto Location and SINR Variation in OPPR-PC

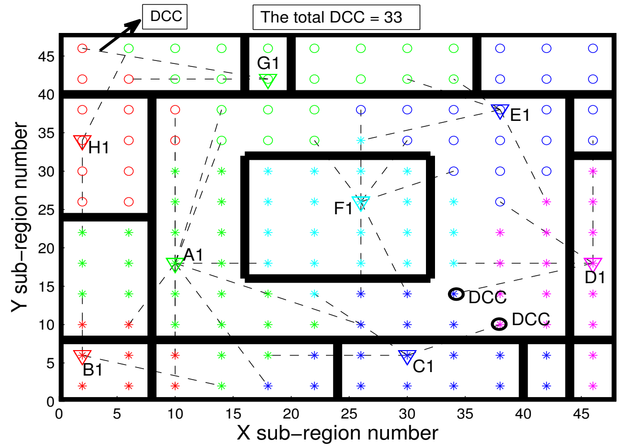

Fig. 3: DCC Connections in OPPR-PC Model

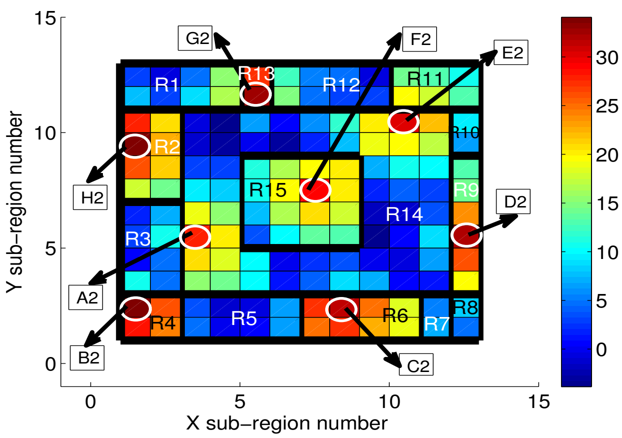

Fig. 4: Femto Location and SINR Variation in OPPR-FP

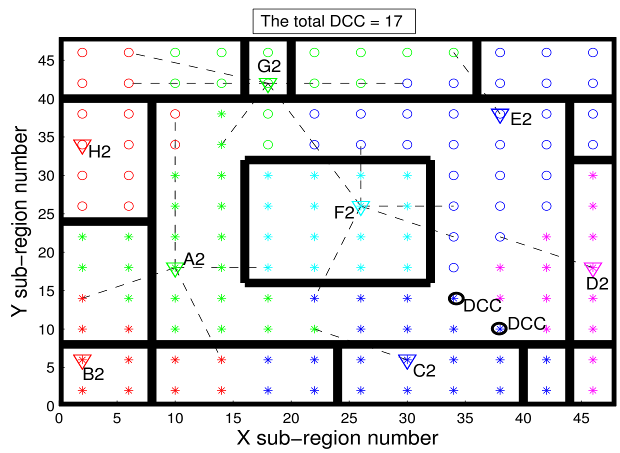

Fig. 5: DCC Connections in OPPR-FP Model

DCC for cell edge users. Thus, we need to place 8 Femtos (named as A1, B1, C1, D1, E1, F1, G1, H1 as shown in Fig. 2) inside the building. The transmission powers of these Femto BSs are set using GA solution for the OPPR-PC model. SINR of all sub-regions of the building is shown in Fig. 2. The darkest regions in the REM plot mean higher SINR values where the Femtos are actually placed. Compared to OPPR-FP (refer Fig. 4), Femtos $A1$ and $B1$ are configured with less transmit power to reduce interference to neighbor Femtos, but remaining Femtos ($H1$, $G1$ and $D1$) are configured with the peak transmit power. As shown in Fig. 3, the total number of DCC sub-regions in OPPR-PC based deployment model are more (i.e., 33) compared to OPPR-FP model (refer Fig. 5). The same color users (denoted by circles or stars) are connected to the corresponding color Femto BSs (denoted by triangles). The dotted lines represent DCC links to neighboring Femtos (secondary cell). From this figure, we can observe that the OPPR-PC model guarantees 33 sub-regions with DCC opportunities.

For example, in OPPR-PC model, even though Femtos $C1$ and $D1$ (refer Fig. 3) are very close to each other, their co-tier interference is reduced by power tuning (P_j) such that $D1$ can guarantee λ to a UE of Femto $C1$. Similarly, $C1$ guarantees λ to a UE of $D1$. Unlike in Fig 3, these Femtos $C1$ and $D1$ are unable to provide similar DCC links as they transmit at their peak power in OPPR-FP model. This experiment demonstrates the need for power control at Femtos to limit interference and thereby increase the number of DCC opportunities to cell edge users in the overlapping regions of multiple Femtos.

B. OPT-FP Model: Performance Analysis

The objective of OPT-FP model is to maximize DCC links with minimum count of Femto BSs. In order to guarantee the SINR threshold to the whole building, OPT-FP model gives six (found iteratively by GA) Femtos (named as A, B, C, D, E, F in Fig. 6). SINR of all sub-regions of the building is shown in Fig. 6. Compared to Femto BSs A, C, D and E, the Femto BSs B and F have lower SINR values, due to interference from the neighboring Femto BSs. DCC users in OPT-FP model are shown in Fig. 7. From this figure, we can observe that OPT-FP model guarantees 29 sub-regions with DCC opportunities. This helps us to do efficient load balancing and joint scheduling during unpredictable load situations. Suppose the Femto A is heavily loaded than neighbouring BS by

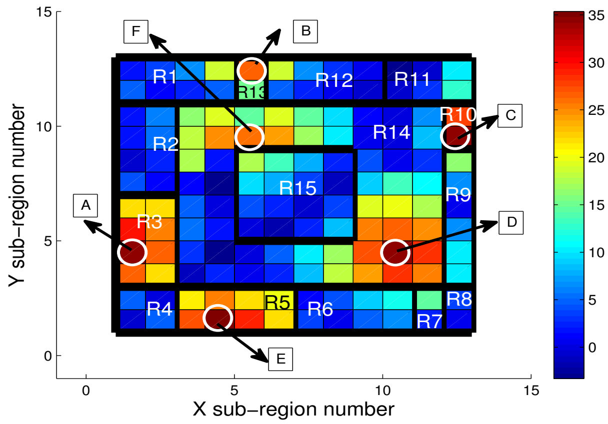

Fig. 6: Femto Location and SINR Variation in OPT-FP

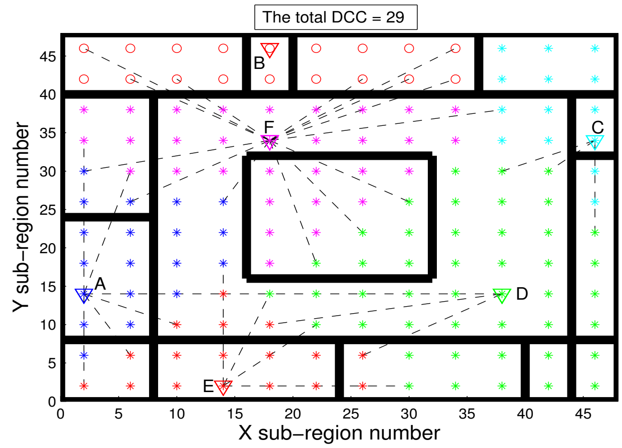

Fig. 7: DCC Connections in OPT-FP Model

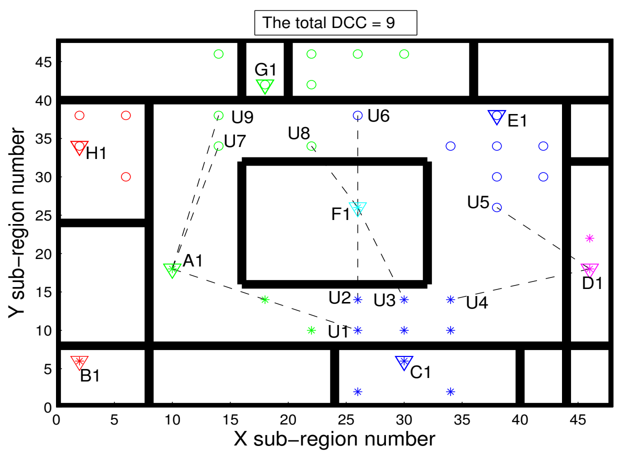

Fig. 8: OPPR-PC: Locations & Connectivity of DCC Users

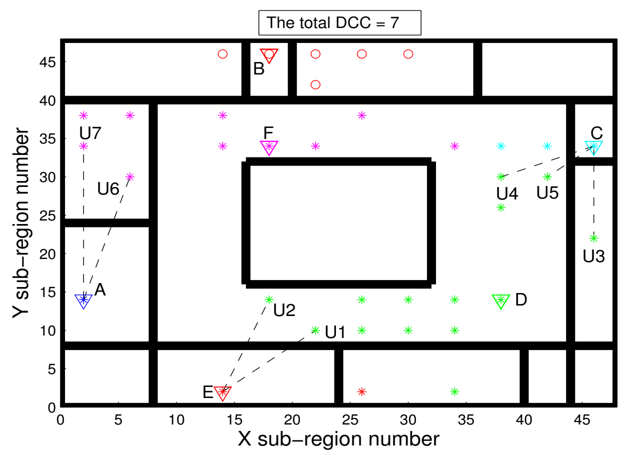

Fig. 9: OPT-FP: Locations & Connectivity of DCC Users

using DCC links we can share the load to Femto E, F and D.

C. PFJS Performance Analysis

The objective of this use case is to show how PFJS algorithm can improve the fairness in OPPR-PC and OPT-FP models for DCC users. OPPR-PC and OPT-FP placement models are evaluated by assuming the same user occupancy pattern as shown in Fig. 8 and Fig. 9. We have compared the performance of PFJS algorithm for DCC links with two different methods: (a) NO PFJS-Attached to Primary Cell (NO PFJS-APC): In this method, users receive data only from the primary cell (b) NO PFJS-Attached to Secondary Cell (NO PFJS-ASC): In this method, users receive data only from a secondary cell. In our setup, we considered a shopping mall with following rooms, R5, R6: Entertainment Zone, R15: Food court, R3: Electronic shop, R14: Waiting hall, R2, R12: Gifts shop, R4, R7, R8, R10, R13: ATMs, R1, R11: Garments, and R9: Restaurant and Bar. Fig. 10 (a) shows throughput of DCC users. For example: DCC user U2's primary cell is C1 and secondary cell is F1 i.e., U2: C1↔F1. From Fig. 8, we observe that Femtos C1, E1 and G1 are deployed in the waiting hall and entertainment zone as they are heavily loaded (as more number of users are connected to them). With help of DCC users in these zones, the load can be shared with secondary cells F1, A1 and D1, which are deployed in food court, restaurant and bar. Users U2, U3, U6 and U8 avail DCC opportunities with food court secondary cells as shown in Fig. 8 and Fig. 10 (a). Our OPPR-PC model guarantees DCC to total 9 users. Fig. 10 (a) shows the DCC users are getting better throughput from PFJS compared to NO PFJS-APC method and NO PFJS-ASC method. Initially, users U2 and U3 are connected to the primary cell C1. Similarly, the primary cell for user U6 is E1 and U8 is G1. These primary cells are heavily loaded due to more number of users, but U2, U3, U6 and U8 can have DCC with secondary cell F1. But, only users U4 and U5 with NO PFJS-ASC method got better throughput from secondary cell because Femto BS (D1) has to serve only these two users. Similarly, users U5 and U6 with NO PFJS-APC method got better throughput from primary cell (E1), because these users are deployed closer to E1 in the waiting hall and the wall is not playing any major role in path loss to degrade the throughput.

As we have used PFJS algorithm, the DCC users are getting proportionally equal throughput from each cell. This approach

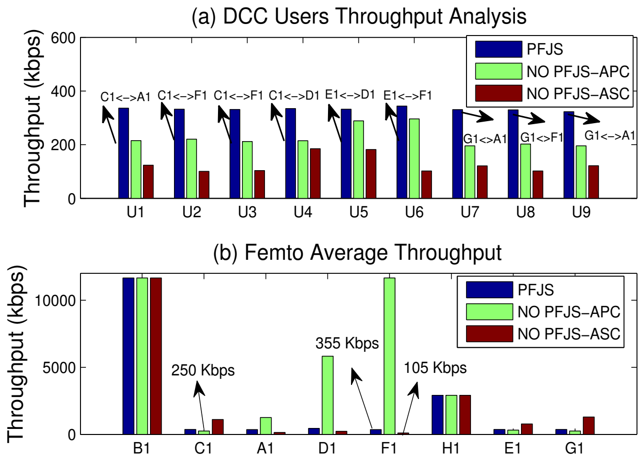

Fig. 10: OPPR-PC: User Throughput and Femto Average Throughput

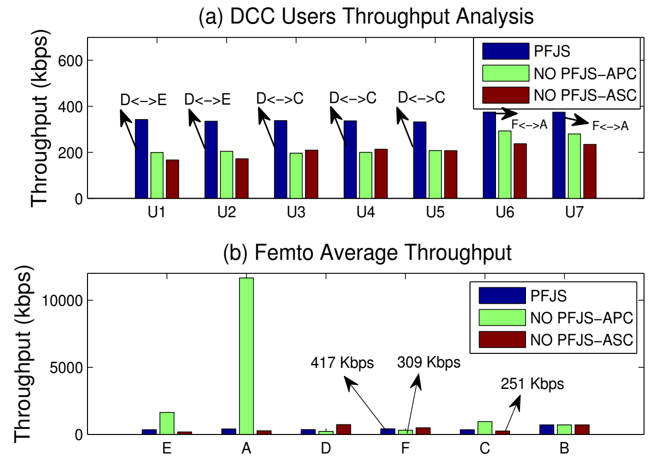

Fig. 11: OPT-FP: User Throughput and Femto Average Throughput

also maintains equilibrium state (i.e., all users are getting approximately equal throughput) for all the DCC users in the overlapping regions of all the Femto BSs. Hence, this joint scheduling leads to uniform load distribution across Femto BSs.

OPT-FP model with 7 DCC users gives similar performance as shown in Fig. 11 (a). One notable observation here is the throughput of DCC users U6 and U7 which is quite different (i.e., non equilibrium state) from that of DCC users U1 to U5. This happens because, U6 (F↔A) and U7 (F↔A) share the bandwidth from both the primary (F) and secondary cells (A), but these cells do not have common overlapping area with other Femto BSs (refer Fig. 9). Remaining DCC users (U1 to U5) obtain proportionally equal throughput due to common overlapping region.

D. Femto Average Throughput:

Fig. 10 (b) and Fig. 11 (b) show the Femto BS average throughput with respect to to all three methods (i.e., NO PFJS-APC, NO PFJS-ASC, PFJS). In OPPR-PC and OPT-FP placement models, PFJS ensures fairness to all DCC users. Also the non-DCC users in the overlapping region of Femto BSs (A1, C1, D1, E1, F1, G1, A, C, D, E and F) are ensured fairness by PFJS as shown in Fig. 10 (b) and Fig. 11 (b). If we observe the Femto BS (B1) in Fig. 10 (b) of OPPR-PC model, its average throughput is approximately 12 Mbps because only one user got connected. Similarly, the Femto BS H1 also has approximately 2.5 Mbps for its three users (i.e., whole bandwidth is used only for this three users). It does not have any users in overlap region. The user U2 and U3 initially connected to the primary cell C1 along with six more users (refer Fig. 8). Hence, it achieves less average throughput but fairness is maintained to all six users with the average throughput of 250 Kbps. Similarly, U6 and few more users attached with E1 and U8 with more users attached with G1. Initially, the Femto BS F1 has all bandwidth (i.e., less loaded in terms of primary cell throughput) but all the neighboring users (U2, U3, U6 and U8) got attached to secondary cell F1. Thus, it reduced the average Femto throughput (i.e., 105 Kbps). At the same time it achieves reasonable average throughput (i.e., 355 Kbps) for DCC users of F1. The same pattern can be observed in Fig. 11 (b) for OPT-FP model. The Jain's fairness index for OPPR-PC model in PFJS, NO PFJS-APC and NO PFJS-ASC is 0.994, 0.371 and 0.619, respectively. It shows that PFJS offers fairness among cells. Similarly, the Jain's fairness index for OPT-FP model in PFJS is 0.998.

V. Conclusion and Future work

In this work, we proposed an optimal Femto placement model OPT-FP and OPPR-PC for a fixed user occupancy pattern to maximize the DCC opportunities. In future work, to support dynamic user occupancy pattern, these models can be extended with power constraints.

ACKNOWLEDGMENT

This work was supported by the Deity, Govt of India (Grant No. 13(6)/2010CC&BT).

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