

Macrocell Batch Resource Allocation for a Closed Access Femto-Macro Cellular Wireless Network

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Abstract—Femtocell is an emerging technology that promises increased network capacity and enhanced indoor coverage at a low capital and operational cost. However, macrocell network performance depreciates when macrocell users (mUEs) are located indoors with femtocell base stations (FBSs), and these users are not allowed access to the FBSs (closed access). This is a critical issue that needs to be addressed in order to successfully deploy femtocell tier over existing macrocell networks. This paper proposes a macrocell proportional fair-based batch resource allocation strategy that enables FBS to be aware of macrocell resource usage schedule. In this context, batch means multiple time-slots. The knowledge of macrocell resource usage schedule enables the FBS to effectively mitigate interference caused to mUEs in its neighborhood. We show by simulation results that our proposed cross-layer interference coordination approach significantly increases the total macrocell throughput through interference reduction.

I. INTRODUCTION

In conventional cellular networks, network operators manage base stations under the control of trained technical staff. However, the next generation of cellular networks will comprise of some base stations that will be managed by users. One type of user-managed base station is the femtocell base station (FBS). An FBS is a small size, low power home base station that operates in the licensed frequency band and backhauls data through a dedicated broadband gateway (DSL/Ethernet etc.) to the cellular operator's core network. The FBS brings various benefits to both consumers and operators, such as enlarged indoor coverage, enhanced system capacity, improved quality of service (QoS), and reduced capital and operational expenses.

Despite the numerous benefits that FBS brings, the success of its co-existence with macrocell base station (MBS) would depend on an efficient and automatic co-ordination of radio resource distribution between the two tiers. This is because FBSs are deployed without standard network planning which could cause large interference and possibly lead to the deterioration of the overall performance of the MBS network. A severe interference case involves a situation in which a macrocell user (mUE) terminal is located indoors near an FBS and the mUE is disallowed access to the FBS network resources owing to the fact that the terminal does not belong the FBS's closed subscriber group (CSG). Interested readers are referred to [1] for details on access control mechanism.

Associated technologies that will be used with FBS include WIMAX (Worldwide Interoperability for Microwave Access)

and LTE (Long Term Evolution) which are undergoing standardization by the research community. The physical layer of both technologies are based on OFDMA (orthogonal frequency division multiple access) on the downlink, which is characterized by scalable channel bandwidth, high spectral efficiency and multipath tolerance. Interestingly, sub-carrier orthogonality of OFDMA takes care of intra-cell interference. Inter-cell interference, however, remains a significant problem, and operators must devise interference mitigation techniques to keep it acceptably low.

As a step towards ensuring that the benefits of FBS are realized, various interference mitigation schemes using FBS power level setting have been investigated. The basic method of transmit power setting is the fixed power setting scheme, which is the current practice in various FBSs [2]. This method has the advantage of simplicity and ease of implementation since the transmit power is pre-configured. From a different point of view, the non-adaptive nature of this scheme is a disadvantage, since the FBS is unable to adapt to changes in the RF conditions of nearby mUEs which most times lead to large interference.

In order to mitigate interference, Li and Sousa [3] used an optimization method to periodically update the pilot power configuration of FBSs based on the RF condition of the network. In [4], Claussen et al. developed an algorithm for the self-configuration of transmit power level of FBSs based on the measured received signal level from the MBS. Li et al. in [5] used downlink power control to address the co-channel interference in a network composed of overlaid macrocell and underlaid femtocell. In [6], Ashraf et al. discussed how to update the FBS's pilot transmit power which serves to balance the user load amongst co-located FBSs as well as minimize the coverage hole and pilot transmit power. Han-Shin Jo et al. [7] proposed both open-loop and closed-loop power control strategies that adjust the maximum transmit power of femtocell users (fUE) in order to suppress the cross-tier interference at an MBS. All these techniques, however, have not adequately catered for the interference caused to nearby mUEs. This is mainly because the FBS does not usually have information about the future network resource utilization plan of the MBS, which makes it difficult to achieve effective interference coordination at the FBS. It is worth mentioning that, the gravity of the necessity to mitigate inter-cell interference has been demonstrated by the 3GPP (3rd Generation Partnership

Project) through extensive discussions in [8]–[15].

A very interesting scheme is proposed by Lien et al. in [16], where femtocell autonomously mitigate interference after sensing macrocell resource usage pattern. The set back of this scheme is that, in the formulation, the future resource usage plan of the macrocell is not modeled. Femtocell therefore relies largely on probability theory in its attempt to avoid resource allocation collision with the macrocell. If a multi-user case of macrocell is considered, the set of users scheduled by the macrocell scheduler may change frequently due to an attempt to ensure fairness among mUEs, thereby causing the resource usage of macrocell to vary from LTE frame to LTE frame (assuming an LTE-based network). Consequently, the correlation of resource block usage by the macrocell decreases, causing the performance of the proposed scheme in [16] to degrade to the conventional randomized scheme.

In this paper, we assume an LTE network, the downlink of which is based on OFDMA. We provide a new formulation for the resource allocation problem in OFDMA-based networks in order to enable a better cognition among different layers of a multilayer OFDMA network. In our formulation, we model a time and frequency domain scheduler which proportionally allocates network resources to mUEs in batch in such a way that, contrary to the probability approach employed in [16], the FBS is fully aware of future resource usage plan of the MBS. Even though the underlying concept of our proposed scheme is similar to [16], the aim of [16] however, is to improve the quality of service of femtocell users (fUEs). But from the viewpoint of closed access mode, mUEs are more vulnerable to severe interference when co-located indoors with FBSs to which access is denied. Hence, contrary to [16] that provides interference protection priority to fUEs, the formulation in this paper protects mUEs from femtocell-induced interference.

The rest of this paper is organized as follows: In Section II, we discuss our proposed batch resource allocation scheme while in Section III, system level simulations are used to evaluate the performance of our proposed scheme. Finally, conclusions are summarized in Section IV.

II. PROPOSAL OF BATCH RESOURCE ALLOCATION

A. MACROCELL

Fig. 1(a) and Fig. 1(b) are two ways in which an mUE may be scheduled in the time and frequency domain. The shaded

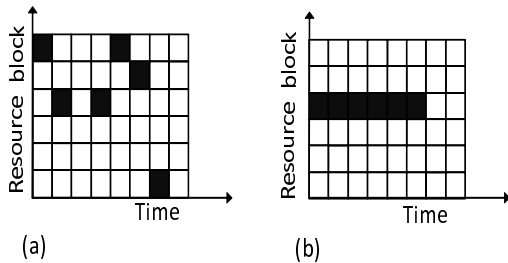


Fig. 1: Macrocell resource allocation

blocks in both figures represent an mUE's resource schedule. Considering Fig. 1(a), a nearby FBS observes the resource allocation of the mUE to be random both in the frequency and time domains. In this random scheduling scheme, it is difficult to achieve effective interference coordination at the FBS. On the contrary, Fig. 1(b) comprises of consecutive shaded blocks along the time axis which shows that the user's schedule follows an organized fashion in the time direction. In this case, an FBS can predict accurately, the resource blocks that will be used by a nearby mUE at a given time and hence mitigate interference on such resource blocks. This paper follows the resource allocation pattern of Fig. 1(b). The set of mUEs at the MBS is denoted as $\mathcal{M}$ and user throughput target is denoted as $\bar{R}_{\text{target}}$. We want to allocate some resource block index n in set $\mathcal{N}$ to members of $\mathcal{M}$ in a proportionally fair manner. We use a combination of round-robin and proportional fair approach for the allocation of $n \in \mathcal{N}$ resource index according to the following steps:

- 1) initialize parameters:

$$\mathcal{U} = \emptyset, \quad (1)$$

$$\mathcal{V} = \emptyset, \quad (2)$$

$$\mathcal{B}_m = \emptyset, \quad \forall m \in \mathcal{U}, \quad (3)$$

$$K_{m,n} = 0, \quad \forall m \in \mathcal{U}, \forall n \in \mathcal{N}, \quad (4)$$

where $\mathcal{U}$ is a set of mUEs selected from set $\mathcal{M}$, who have lower proportional throughputs than others. Set $\mathcal{V}$ is the set of users, who have been allocated a resource block index in the current allocation period. $\mathcal{B}_m$ is the set of resource block indices allocated to user m and, $K_{m,n}$ is the achievable data rate on one resource block index n of the allocation of user m .

- 2) resource block index allocation of all users in set $\mathcal{U}$ is:

$$\mathcal{B} = \bigcup_{m \in \mathcal{U}} \mathcal{B}_m. \quad (5)$$

- 3) calculate the proportional throughput of user m as,

$$\bar{R}_{\text{prop}}^{(m)} = \frac{\bar{R}^{(m)}}{\bar{R}_{\text{target}}}, \quad \forall m \in \mathcal{M}, \quad (6)$$

where $\bar{R}^{(m)}$ is the long term data rate of user m averaged over a time widow T .

- 4) from set $\mathcal{M}$, select a set $\mathcal{U}$ comprising of users having lower values of proportional throughput such that

$$\mathcal{U} \subseteq \mathcal{M}, \quad (7)$$

where

$$|\mathcal{U}| = \min(L, |\mathcal{M}|), \quad (8)$$

and L is a constant.

- 5) from set $\mathcal{U}$, pick a user m^* , that has the least proportional throughput,

$$m^* = \arg \min_{m \in \mathcal{U}} \{\bar{R}_{\text{prop}}^{(m)}\}. \quad (9)$$

- 6) for each of the selected users in set $\mathcal{U}$, arrange the resource block index, n , in descending order based on the magnitude of the SINR of each resource block. For the selected user m^* pick the resource block n^* which has the highest SINR and allocate it to user m^* ,

$$n^* = \arg \max_{n \in \mathcal{N}} \{\gamma_{m^*, n}\}, \quad (10)$$

where $\gamma_{m, n}$ is the SINR of the resource block index n of the allocation of user m and n is not currently in use.

- 7) add n^* to the set of resource blocks of user m^* ,

$$\mathcal{B}_{m^*} \leftarrow \mathcal{B}_{m^*} \cup \{n^*\}. \quad (11)$$

- 8) calculate $X_{\text{schedule}}^{(m^*)}$, which is the number of time-slots the selected user will be scheduled on the selected resource block,

$$X_{\text{schedule}}^{(m^*)} = \max(X_{\min}, \min(0, \lceil \alpha(X_{\min} - X_{\max}) \rceil + X_{\max})), \quad (12)$$

where

$$\alpha = \frac{\bar{R}_{\text{prop}}^{(m^*)} - \bar{R}_{\text{prop}}^{(\min)}}{\bar{R}_{\text{prop}}^{(\text{avg})} - \bar{R}_{\text{prop}}^{(\min)}}, \quad (13)$$

$$\bar{R}_{\text{prop}}^{(\text{avg})} = \frac{\sum_{m=1}^{|\mathcal{M}|} \bar{R}_{\text{prop}}^{(m)}}{|\mathcal{M}|}, \quad (14)$$

where $X_{\text{schedule}}^{(m^*)}$ is the time-slot batch-size allocated to the selected user m^* on the selected resource block index n^* , while $X_{\min}$ and $X_{\max}$ respectively denotes the minimum and maximum time-slot batch-size possible. $\bar{R}_{\text{prop}}^{(\text{avg})}$ is the average proportional throughput of all users, while $\bar{R}_{\text{prop}}^{(\min)}$ represents the expected minimum value of proportional throughput reasonably selected to be lower than the average proportional throughput. It is easily observed that the corresponding batch allocation graph in Fig. 2. has a negative slope, which implies that users with high proportional throughput $\bar{R}_{\text{prop}}^{(m^*)}$ relative to the network average proportional throughput $\bar{R}_{\text{prop}}^{(\text{avg})}$ are allocated few time-slots and vice versa. Equation (12) ensures that a user m^* with $\bar{R}_{\text{prop}}^{(m^*)}$ less than $\bar{R}_{\text{prop}}^{(\min)}$ is automatically allocated the largest time-slot batch-size, $X_{\max}$. Conversely, the user is allocated the lowest

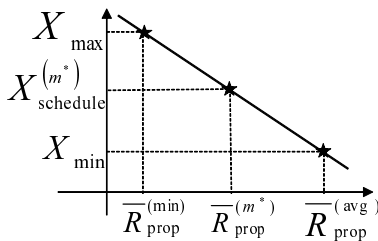


Fig. 2: Batch resource allocation graph

time-slot batch-size, $X_{\min}$, if $\bar{R}_{\text{prop}}^{(m^*)}$ is greater than $\bar{R}_{\text{prop}}^{(\text{avg})}$.

- 9) remove user m^* from set $\mathcal{U}$ and add the user to another set $\mathcal{V}$,

$$\mathcal{U} \leftarrow \mathcal{U} \setminus \{m^*\}, \quad (15)$$

$$\mathcal{V} \leftarrow \mathcal{V} \cup \{m^*\}. \quad (16)$$

- 10) update the capacity of user m^* ,

$$\bar{R}^{(m^*)} \leftarrow \beta^{X_{\text{schedule}}^{(m^*)}} \bar{R}^{(m^*)} + \left(1 - \beta^{X_{\text{schedule}}^{(m^*)}}\right) K_{m^*, n^*}, \quad (17)$$

where

$$\beta = 1 - \frac{1}{T}, \quad (18)$$

and

$$K_{m^*, n^*} = W \log_2(1 + \gamma_{m^*, n^*}), \quad (19)$$

where W is the bandwidth of a resource block. Interested readers may refer to the appendix for more explanation on Equation (17).

- 11) if $\mathcal{U} = \emptyset$, then,

$$\mathcal{U} = \mathcal{V}, \quad (20)$$

$$\mathcal{V} = \emptyset. \quad (21)$$

- 12) if there are unused resource blocks and the maximum base station power has not been exceeded, go back to step 2, otherwise, end.

According to the described MBS algorithm, the scheduler is divided into the time domain part followed by the frequency domain part. User set $\mathcal{U}$, which is a subset of set $\mathcal{M}$ is passed to the frequency domain scheduler by the time domain scheduler using a proportional fair metric for user selection. The reduction in the number of users to be considered for scheduling helps to reduce the scheduler complexity, while at the same time, the selection of low throughput users helps to achieve inter-user fairness. The frequency domain scheduler combines round-robin and proportional fair scheduling policies for resource allocation, and at the same time, effort is made to maximize spectrum efficiency by allocating the highest SINR resource block to any selected user.

B. FEMTOCELL

Usually, the interference received by an mUE from an FBS is small if the mUE is faraway from the FBS, since FBSs' transmit power is usually lower compared to MBSs'. If however, the mUE is located in the same house as the FBS, the interference received by the mUE becomes severe. It is therefore necessary for the FBS to tune its transmit power on resource blocks used by the interfered mUE.

FEMTOCELL POWER TUNING: At the FBS, resource blocks are classified into three categories:

- 1) Resource blocks that should be used at maximum power

- 2) Resource blocks that should be used at a controlled power, and
- 3) Resource blocks that are not to be used at all.

The maximum power that can be loaded on any resource block is given as

$$p_{\max} = \frac{P_T}{|\mathcal{N}_f|}, \quad (22)$$

where P_T is the total power available at the FBS, and $\mathcal{N}_f$ is the set of all resource blocks available at the FBS. The mUE m measures its channel gain towards the FBS f , such that the gain is given as

$$G_{f,m} = 10 \log(p_f^{(n)}) - I_{f,m}^{(n)} \quad (23)$$

where $I_{f,m}^{(n)}$ is the interference received by mUE m from FBS f on resource block n , while $p_f^{(n)}$ denotes the power transmitted by FBS f on resource block n . FBS f controls $p_f^{(n)}$ in a way that limits the amount of interference received by the nearest mUE m that is currently being scheduled by the MBS on resource block n . In order to achieve this, we introduce two interference thresholds $I_{th,u}$ and $I_{th,l}$, namely, upper interference threshold and lower interference threshold respectively which are used to control the maximum interference an FBS is allowed to cause to an mUE according to the algorithm shown in Fig. 3.

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 $p_f^{(n)} = p_{\max}, \forall n \in \mathcal{N}_f$ 
for all  $n \in \mathcal{N}_f \cap \mathcal{B}_m$  do
  if  $I_{f,m}^{(n)} > I_{th,u}$  then
     $p_f^{(n)} = 0$ 
  else
    if  $I_{th,l} \leq I_{f,m}^{(n)} \leq I_{th,u}$  then
       $p_f^{(n)} = 10^{\frac{I_{th,l} + G_{f,m}}{10}}$ 
    end if
  end if
end for

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Fig. 3: Femtocell power control algorithm

The elements of $\mathcal{N}_f \cap \mathcal{B}_m$ are the resource blocks in $\mathcal{N}_f$ on which power must be controlled. Each FBS overhears the MBS resource allocation before running the FBS power control algorithm. The MBS resource allocation does not necessarily occur at every time-slot since MBS allocates a batch of resource units that spans several time-slots to each mUE selected by the MBS time domain scheduler. This implies that the FBS runs the FBS power control algorithm only when MBS allocation changes. In reality, cell edge FBSs consider more than one MBS allocation since they are likely to cause interference to mUEs served by different MBSs. Our FBS power control formulation does not reflect this case for the sake of simplicity. However, the multiple MBS case can easily be accommodated by our formulation. For example, if

a set of UEs in the vicinity of an FBS are scheduled on the same resource block by different MBSs, the FBS only need to consider the mUE to which it has the highest channel gain.

By setting $I_{th,l}$ and $I_{th,u}$ relatively low, an mUE in the vicinity of an FBS can enjoy a relatively high throughput. If an mUE is located indoors with an FBS, the signal strength from the co-located FBS will likely dominate all the other signals received by this mUE since wall loss attenuates the outdoor signals received by the indoor mUE. If closed access mode is considered, and the indoor macro UE does not belong to the CSG of the co-located FBS, a relatively high throughput can still be enjoyed by this mUE if our proposed power control algorithm is used by the FBS.

III. SIMULATION RESULTS

System level simulations are performed to demonstrate the effectiveness of our proposed MBS batch resource allocation scheme. The LTE downlink, which has a system bandwidth of 5 MHz is considered in this work. The MBS network has a layout of one ring, i.e seven cells with each cell comprising two regions namely, the cell edge and cell center regions. The MBS is of radius 500 m, and has 10 FBSs which are randomly and uniformly deployed in its coverage area. The location of any FBS represents the center of a house of dimension 20×20 m², and each FBS is forced to be separated by at least 30 m away from its closest neighbor FBS. The maximum total transmission power of the MBS is set to 43 dBm while that of the FBS is set to 23 dBm. In the coverage area of the MBS, 20 outdoor mUEs are randomly and uniformly dropped. Each mUE is then considered for indoor placement using an indoor probability ρ (which we vary from 0.0 to 1.0 during assessment) such that, an indoor mUE is relocated and placed in the same house as the FBS nearest to it.

Associated with each FBS are three fUEs. The placement of indoor UEs (user equipment) follows a random and uniform manner, and the UEs are forced to be at least 0.2 m away from the FBS located in the same house [18]. Typical placement of UEs and BSs (base station) is illustrated in Fig. 4. All

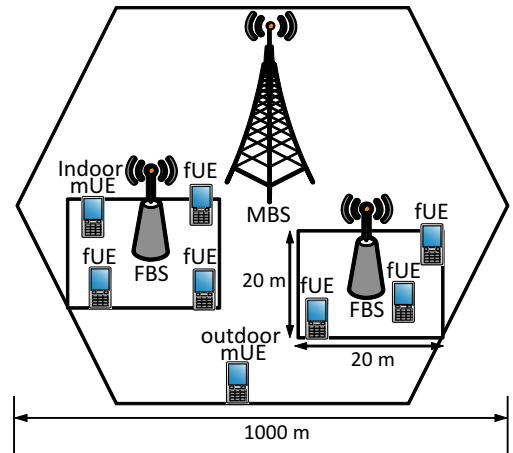


Fig. 4: Network model.

mUEs connect to the MBS throughout, including when they are indoors. During the scheduling process, the MBS uses the time domain scheduler to select 10 users for resource unit allocation according to our proposed MBS algorithm. Each FBS is assumed to be aware of mUEs allocation and therefore coordinate interference using our proposed FBS power control algorithm. For reference purposes, we denote our proposed scheme as *batch-based* scheme. Another similar setup is implemented as a comparative scheme, but in this case, MBS allocates resources during every time-slot. In this case, FBSs introduce interference to nearby mUEs since they are unaware of MBS resource allocation beforehand. We call this setup *slot-based* scheme. Link adaptation is modeled by mapping SINR to capacity, using the *attenuated and truncated Shannon bound method* [17]. Pathloss is computed using the pathloss models recommended for suburban deployment in [18]. Outdoor wall penetration wall loss is set to 20 dB, while the loss due to internal walls is modeled as a log-linear value, equal to 0.7dB/m [18]. The results of our investigations are illustrated in Figs. 5 through 7.

As can be seen in Fig. 5, the total throughput of mUEs is almost insensitive to the changes in the indoor/outdoor condition of mUEs in the case of our proposed scheme, *batch-based* scheme. In the case of the *slot-based* scheme however, the total MBS throughput decreases very rapidly as more users are placed indoors. This is due to the proportional fair nature of the MBS scheduler. For example, at $\rho = 0.2$, approximately 4 out of 20 users are indoors and are experiencing high interference. Since the time domain scheduler of the MBS picks 10 lowest throughput users for resource allocation, it implies that almost half (4/10) of the scheduled users are experiencing very high interference which leads to a low overall cell throughput. If these users are allocated more than one resource block each, the total network throughput drops even further.

Fig. 6 compares the throughput of worst 10% mUE through-

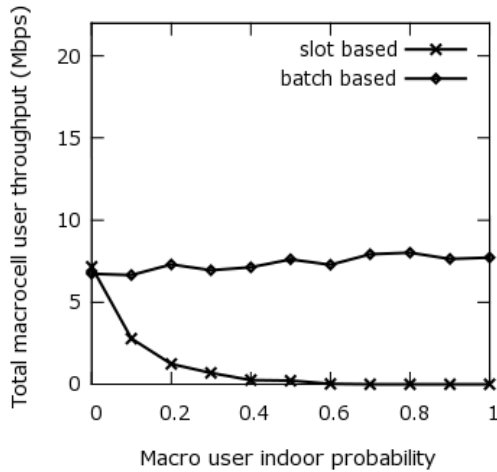


Fig. 5: Total throughput of macrocell users as a function of user indoor probability.

put of our *batch-based* scheme with the *slot-based* scheme as mUEs are placed indoors. It is easily seen that the throughput of our *batch-based* scheme is almost insensitive to changes in the indoor probability of the mUEs. Finally, Fig. 7 illustrates the average FBS throughput plotted against the indoor probability of mUEs. The power control that our proposed *batch-based* scheme implements caused our scheme to have a slightly lower average FBS throughput compared to the *slot-based* scheme. This is due to the fact that the FBS is sometimes prohibited from using some resource blocks whenever an mUE is co-located indoors. The drop in throughput, however, is not large because mUEs are spread all over the MBS coverage area. Hence, at any given period of time, each FBS causes interference to only a few mUEs in its neighborhood which implies that restrictions are placed on only a few resource blocks during those periods.

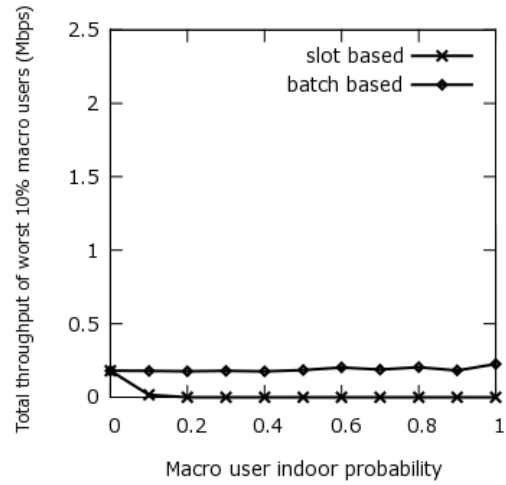


Fig. 6: Total throughput of worst 10% macrocell users as a function of user indoor probability.

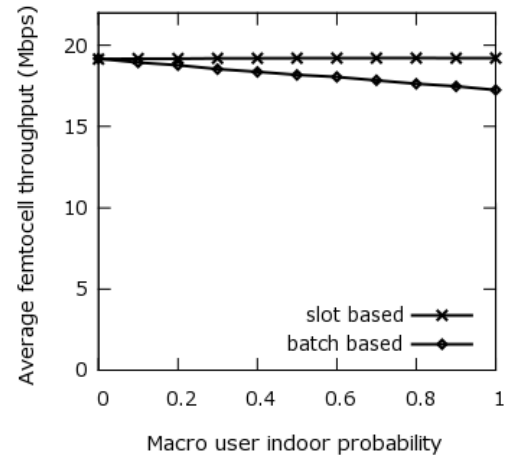


Fig. 7: Average FBS throughput as a function of macrocell user indoor probability.

IV. CONCLUSIONS

In this paper, we discussed a batch resource allocation strategy for a closed access femto-macro cellular wireless network in which macrocell base stations allocate resources to macrocell users in batch in the time domain. In this context, “batch” denotes multiple time-slots which means that macrocell scheduler allocates network resources in such a way that future resources to be used are known. Based on the knowledge of resources that will be used by the macrocell, femtocell base stations located near macrocell users coordinate interference using a power control algorithm in order to limit the amount of interference received by these users. Simulation results show that our proposed scheme, compared to the conventional *slot-based* scheme, yields a significant improvement in the macrocell total cell throughput, and also the worst 10% macrocell user throughput at the cost of a slight reduction in the average femtocell throughput.

REFERENCES

- [1] Guillaume de la Roche, Alvaro Valcarce, and David Lopez-Perez, “Access control mechanisms for femtocells,” IEEE Communications Magazine, pp. 33–39, Jan. 2010.
- [2] M. Morita, Y. Matsunaga, and K. Hamabe, “Adaptive power level setting of femto cell base stations for mitigating interference with macro cells,” IEEE Proc. VTC-Fall, pp. 1–5, Sept. 2010.
- [3] Yang-Yang Li and E. S. Sousa, “Base station pilot management for user-deployed cellular networks,” IEEE Proc. ICC, pp. 1–5, June 2009.
- [4] H. Claussen, L. T. W. Ho, and L. G. Samuel, “Self-optimization of coverage for femto cell deployments,” Wireless Telecommunications Symposium, pp. 278–285, April 2008.
- [5] X. Li, L. Qian, and D. Kataria, “Downlink power control in co-channel macrocell femto cell overlay,” Conference on Information Science and Systems, pp. 383–388, March 2009.
- [6] I. Ashraf, H. Claussen, and L. T. W. Ho, “Distributed radio coverage optimization in enterprise femtocell networks,” IEEE Proc. ICC, pp. 1–6, May 2010.
- [7] Han-Shin Jo, Jong-Gwan Yook, C. Mun, J. Moon, “A self-organized uplink power control for cross-tier interference management in femtocell networks,” IEEE Proc. MILCOM 2008, pp. 1–6, Nov. 2008.
- [8] Qualcomm Europe, “Hybrid HeNB interference scenarios and techniques,” 3GPP Standard Contribution (R4-092498), June – July 2009.
- [9] Motorola, “Femtocell and macrocell coordination based on SFR,” 3GPP Standard Contribution (R4-093092), May 2009.
- [10] CMCC, “Downlink interference coordination between HeNBs,” 3GPP Standard Contribution (R4-092872), Aug. 2009.
- [11] NTT DOCOMO, “Downlink interference coordination between eNodeB and home eNodeB,” 3GPP Standard Contribution (R4-093203), Aug. 2009.
- [12] NEC, “HeNB downlink interference avoidance with adaptive frequency selection,” 3GPP Standard Contribution (R4-093556), Oct. 2009.
- [13] Kyocera, “Network Assisted Interference Coordination between Macro eNodeB and Home eNodeB in Downlink,” 3GPP Standard Contribution (R4-093620), Oct. 2009.
- [14] picoChip Designs, “Victim UE aware downlink interference management,” 3GPP Standard Contribution (R4-100051), Jan. 2010.
- [15] Nokia Siemens Networks, Nokia, “Macro+HeNB performance with escape carrier,” 3GPP Standard Contribution (R1-101453), Feb. 2010.
- [16] S.-Y. Lien, C.-C. Tseng, K.-C. Chen, and C.-W. Su, “Cognitive radio resource management for QoS guarantees in autonomous femtocell networks,” IEEE Proc. ICC, pp. 1–6, May 2010.
- [17] 3GPP, “Evolved universal terrestrial radio access (E-UTRA); radio frequency (RF) system scenarios,” 3GPP Technical Report 36.942 (3GPP TR 36.942 v8.2.0), May 2009.
- [18] Alcatel-Lucent, picoChip Designs, Vodafone, “Simulation assumptions and parameters for FDD HeNB RF requirements,” 3GPP Standard Contribution (R4-092042), May 2009.

APPENDIX

Fig. 8 is an illustration of an LTE resource frame in which resource units a, b, c, d, e and f are allocated in batch to a user. Assuming T denotes time window, $\bar{R}$ denotes long term throughput while K denotes the instantaneous data rate on one resource unit, then, the moving average throughput for multiple resource units can be determined as follows:

$$\beta = 1 - \frac{1}{T} \quad (24)$$

- 1) update of $\bar{R}$ for 1 resource unit (a) is

$$\beta \bar{R} + (1 - \beta)K \quad (25)$$

- 2) update of $\bar{R}$ for 2 resource units (a, b) is,

$$\begin{aligned} & \beta(\beta \bar{R} + (1 - \beta)K) + (1 - \beta)K \\ &= \beta^2 \bar{R} + (1 - \beta)(1 + \beta)K \end{aligned} \quad (26)$$

- 3) update of $\bar{R}$ for 3 resource units (a, b, c) is

$$\begin{aligned} & \beta(\beta^2 \bar{R} + (1 - \beta)(1 + \beta)K) + (1 - \beta)K \\ &= \beta^3 \bar{R} + (1 - \beta)(1 + \beta + \beta^2)K \end{aligned} \quad (27)$$

- 4) update of $\bar{R}$ for n resource units is

$$\begin{aligned} & \beta^n \bar{R} + (1 - \beta)K \frac{1 - \beta^n}{1 - \beta} \\ &= \beta^n \bar{R} + (1 - \beta^n)K \end{aligned} \quad (28)$$

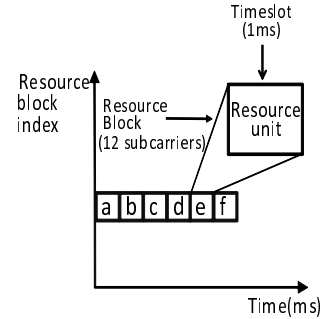


Fig. 8: LTE resource unit.