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Self-Organized Resource Allocation Based on CSI Overhearing in Heterogeneous Networks employing Cell Range Expansion

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***Abstract*—In this paper, we propose a self-organized resource allocation method in a macrocell/picocell heterogeneous network employing Cell Range Expansion (CRE). To protect expanded Pico User Equipments (ePUEs) from severe Macro Base Station (MBS) interference in downlink, in the conventional method, MBS makes use of reduced power Almost Blank Subframes (ABSs) where ePUEs can be scheduled. However, this severely limits the amount of usable resources/power for the MBS. In the proposed scheme, MBS predicts the ePUE's Resource Block (RB) allocation based on their overheard Channel State Information (CSI) feedback intended to Pico Base Station (PBS), and reduces its transmit power in RBs where ePUE's allocation probability is estimated to be high for mitigating downlink interference. The simulation results show that the proposed scheme outperforms the conventional reduced power ABS scheme in terms of total sum throughput as well as fairness among all heterogeneous users.** [1]

I. Introduction

Recently, the mobile data traffic has been increasing exponentially with the spread of smart phones and tablets, leading to high demands of coverage and capacity. To cope with those issues, Heterogeneous Networks (HetNets) concept where small cells created by low-power Base Stations (BSs) such as Pico BS (PBS) are overlaid within a large macrocell coordinated by a Macro BS (MBS) is introduced in Long Term Evolution (LTE)-Advanced. In HetNets, the inter-cell interference becomes a major issue since these small cells typically share the same frequency band as the macrocell [1][2].

In order to improve the data offloading from macrocell to picocells, Cell Range Expansion (CRE) has been introduced in LTE-Advanced for expanding the picocell radius [3]. Although User Equipments (UEs) are usually served by the BS with the highest Reference Signal Received Power (RSRP), CRE allows a Macro UE (MUE) to be offloaded from the MBS to a PBS with a weaker RSRP, by adding a positive offset value to the RSRP from PBS. However, these offloaded MUEs now in the range-expanded region of a PBS, hence termed extended Pico UEs (ePUEs), might experience severe downlink interference from the MBS due to its much higher transmit power as compared to that of the PBS [1].

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To protect ePUEs from severe MBS interference, the Inter-Cell Interference Coordination (ICIC) using Almost Blank Subframes (ABSs) has been proposed in LTE-Advanced [2][3][4]. In this method, MBS reduces its transmit power in certain subframes termed ABSs, and PBSs schedule ePUEs within these protected subframes. To support this time-domain partitioning, PBSs need to obtain the information about the ABS patterns configured by the MBS. This information is exchanged between different BSs using the X2 interface [1]. However, such a subframe-based blanking method limits the allocation possibilities as compared to Resource Block (RB)-based dynamic allocation. Therefore, there is currently a great interest in the design of dynamic frequency-domain allocation methods[1][5][6][7].

In this paper, we propose a self-organized resource allocation method that enables to mitigate the interference experienced by ePUEs for the downlink of an Orthogonal Frequency Division Multiple Access (OFDMA)-based macrocell/picocell overlaid HetNet. The proposed method is based on the fact that the Channel State Information (CSI) feedback of the ePUEs to their serving PBS can be assumed to be overheard by their initial MBS, by letting them keep, as long as they are within the range-expanded area, the portion of Uplink (UL) control channel assigned by the MBS, which is also received at the PBS, and letting them transmit this CSI with enough power. This is a natural assumption since ePUEs are originally served by the MBS and were assigned a portion of UL control channel by the MBS to feedback their CSI. Thus, based on their overheard CSI feedback, the MBS predicts the ePUE's RB allocation and reduces its transmit power in RBs where ePUE's allocation probability is estimated to be high for mitigating downlink interference. The effectiveness of the proposed scheme against conventional ones is confirmed through computer simulations.

II. System Model

We consider the downlink of the macrocell/picocell HetNet depicted in Fig. 1, where I picocells are overlaid within a macrocell. The picocell is divided into the original area $\mathcal{A}_\mathcal{P}$ and the CRE area $\mathcal{A}_\mathcal{D}$. The original area $\mathcal{A}_\mathcal{P}$ is a disk of radius of R_{Pico} from each PBS and the CRE area $\mathcal{A}_\mathcal{D}$ is the blue area with width D shown in Fig. 1. The macrocell

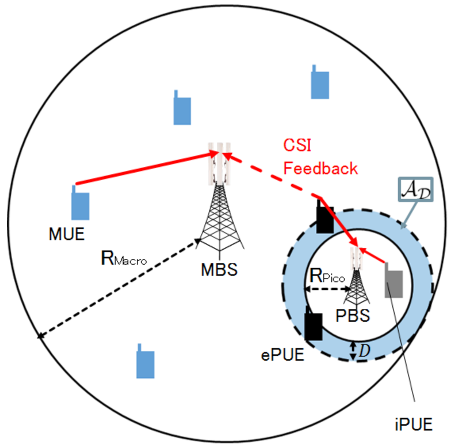

Fig. 1. System Model

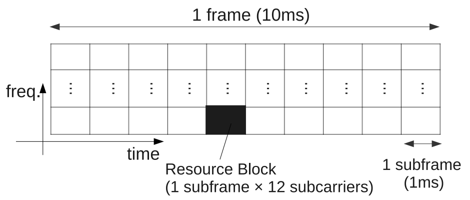

Fig. 2. Frame Structure in LTE-Advanced

area, denoted $\mathcal{A}_{\mathcal{M}}$, is a disk of radius of $R_{\rm Macro}$ from MBS without the picocell areas $\mathcal{A}_{\mathcal{P}} \cup \mathcal{A}_{\mathcal{D}}$. K MUEs are uniformly distributed within $\mathcal{A}_{\mathcal{M}}$, $L_{\rm iPUE}$ inner PUEs (iPUEs) are uniformly distributed within $\mathcal{A}_{\mathcal{P}}$, and $L_{\rm ePUE}$ ePUEs are uniformly distributed within $\mathcal{A}_{\mathcal{D}}$ for each picocell. Note that PUEs are divided into the iPUEs within $\mathcal{A}_{\mathcal{P}}$ and the ePUEs within $\mathcal{A}_{\mathcal{D}}$.

Fig. 2 shows the frame structure in LTE-Advanced [8]. In LTE-Advanced, transmissions are based on OFDMA and all MUEs and PUEs share the same frequency band composed of N RBs, where each RB consists of 12 subcarriers in the frequency domain and one subframe in the time domain.

In each macrocell/picocell, UEs feedback their CSI on a per-frame basis to their serving BS, using an UL control channel dedicated to each cell. Note that the CSI feedback of ePUEs to their serving PBS can be assumed to be overheard by their initial MBS, by letting them keep, as long as they are within $\mathcal{A}_{\mathcal{D}}$, the portion of UL control channel assigned by the MBS, which is also received at the PBS, and letting them transmit this CSI with enough power, as explained above. On the other hand, the CSI feedback of iPUEs cannot be overheard by MBS since they transmit CSI to only their serving PBSs with low power, and the UL control channels assigned to them are unknown to the MBS. The specific design of control signaling for the proposed scheme will be considered in a subsequent study.

CSI is composed of the instantaneous received Signal-to-Noise Ratio (SNR) levels from the serving BS for each RB. Note that it is possible for UEs to estimate these SNR values instead of SINR values based on orthogonal pilot sequences to each neighboring cell, such as Cell-specific Reference Signal (CRS) or CSI-RS [1][8]. In addition, this SNR estimation is further improved in Release 11 thanks to the CSI-Interference Measurement (IM) reports that provide an accurate estimation of the interference plus noise level [1]. Since the interference pattern changes every frame depending on the scheduling decisions of neighboring cells, while the SNR is rather constant over several frames in low-mobility scenarios, SNR-based scheduling offers in fact more robustness towards the future, i.e., unknown interference occurring in the next frame for the considered self-organizing distributed context. This is why we assume that UEs feedback their instantaneous received SNR values. However, their actual throughput will be evaluated based on their received SINR values.

The instantaneous received SNR of MUE k and PUE l in picocell i at RB n, denoted $\gamma_{k,n}$ and $\gamma_{l_i,n}$ respectively, are defined as

$$\gamma_{k,n} = \frac{P_n^{\rm M} L_k^{\rm MM} |h_{k,n}^{\rm MM}|^2}{N_0}, \quad \gamma_{l_i,n} = \frac{P_n^{{\rm P}_i} L_{l_i}^{{\rm P}_i{\rm P}_i} |h_{l_i,n}^{{\rm P}_i{\rm P}_i}|^2}{N_0},$$

where $h_{k,n}^{\rm MM}, h_{l_i,n}^{{\rm P}_i{\rm P}_i}$ denote the fading coefficients in RB n of the MBS-MUE k and PBS i-PUE l channels, respectively. We assume Rayleigh fading channels, so $h_{k,n}^{\rm MM}, h_{l_i,n}^{{\rm P}_i{\rm P}_i} \sim \mathcal{CN}(0,1)$. N_0 is the power of Additive White Gaussian Noise (AWGN). $P_n^{\rm M}, P_n^{{\rm P}_i}$ denote the transmit powers allocated on RB n by the MBS and PBS i, respectively. Moreover, $L_k^{\rm MM}, L_{l_i}^{{\rm P}_i{\rm P}_i}$ are the path loss from MBS to MUE and from PBS i to PUE l, respectively, and defined as

$$L_k^{\rm MM} = \left(\frac{c}{4\pi f}\right)^2 \left(\frac{1}{r_k^{\rm MM}}\right)^{\alpha_{\rm M}}, L_{l_i}^{{\rm P}_i{\rm P}_i} = \left(\frac{c}{4\pi f}\right)^2 \left(\frac{1}{r_{l_i}^{{\rm P}_i{\rm P}_i}}\right)^{\alpha_{\rm P}},$$

where f is the carrier frequency of the signal, c is the speed of light, $r_k^{\rm MM}, r_{l_i}^{{\rm P}_i{\rm P}_i}$ are the distance from MBS to MUE k, from PBS i to PUE l, respectively, and $\alpha_{\rm M}, \alpha_{\rm P}$ are the path loss exponents of the macrocell and picocell, respectively [12].

Similarly, the instantaneous received SINR of MUE k and PUE l in picocell i at RB n, denoted $\tilde{\gamma}_{k,n}$ and $\tilde{\gamma}_{l_i,n}$ respectively, are defined as

$$\tilde{\gamma}_{k,n} = \frac{P_n^{\rm M} L_k^{\rm MM} |h_{k,n}^{\rm MM}|^2}{\sum_{i=1}^{I} P_n^{{\rm P}_i} L_k^{{\rm P}_i{\rm M}} |h_{k,n}^{{\rm P}_i{\rm M}}|^2 + N_0},$$

$$\tilde{\gamma}_{l_i,n} = \frac{P_n^{{\rm P}_i} L_{l_i}^{{\rm P}_i{\rm P}_i} |h_{l_i,n}^{{\rm P}_i{\rm P}_i}|^2}{P_n^{\rm M} L_{l_i}^{{\rm MP}_i} |h_{l_i,n}^{{\rm MP}_i}|^2 + \sum_{j\neq i} P_n^{{\rm P}_j} L_{l_i}^{{\rm P}_j{\rm P}_i} |h_{l_i,n}^{{\rm P}_j{\rm P}_i}|^2 + N_0}.$$

Here, $L_k^{{\rm P}_i{\rm M}}$, $L_{l_i}^{{\rm MP}_i}$, $L_{l_i}^{{\rm P}_j{\rm P}_i}$ denote the path loss from PBS i to MUE k, from MBS to PUE l, from PBS j to PUE l, and $h_{k,n}^{{\rm P}_i{\rm M}}$, $h_{l_i,n}^{{\rm MP}_i}$, $h_{l_i,n}^{{\rm P}_j{\rm P}_i}$ represent the fading coefficients in RB n of the PBS i-MUE k, MBS-PUE l, PBS j-PUE l channels, respectively. We assume Rayleigh fading channels, so $h_{l_i,n}^{{\rm MP}_i}$, $h_{k,n}^{{\rm P}_i{\rm M}}$, $h_{l_i,n}^{{\rm P}_j{\rm P}_i} \sim \mathcal{CN}(0,1)$.

III. Conventional ICIC using ABS

We explain firstly the conventional ICIC scheme using reduced power ABSs [2].

In the macrocell/picocell HetNet downlink, ePUEs suffer from severe MBS interference since the transmissions from the MBS is received with higher power than the actual desired

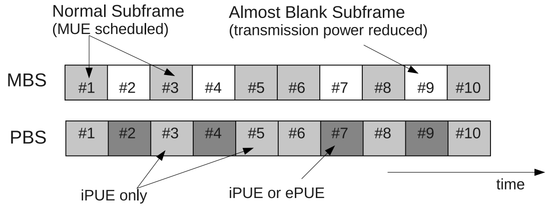

Fig. 3. Example of ABS for a macrocell/picocell HetNet employing CRE

transmission from their serving PBS. In order to mitigate this interference, MBS can reduce its transmit power in certain subframes termed ABSs, and the PBS schedules ePUEs within these protected subframes, as shown in Fig. 3

In this example, the ABS ratio is set to be 40% and MBS reduces its transmit power in ABSs. In these reduced power ABSs, ePUEs will experience less interference from the MBS. Therefore, each PBS is allowed to transmit to ePUEs during protected subframes #2, #4, #7, #9 for mitigating severe MBS interference and iPUEs during all subframes. To support this time-domain partitioning, PBSs need to obtain the information about the ABS patterns configured by the MBS. This information is exchanged between BSs using the X2 interface [1]. Note that since ePUEs can be allocated only within the protected subframes, the amount of usable resources/power for the MBS is severely restricted when there are large number of ePUEs due to the dense deployment of PBSs.

IV. Proposed Resource Allocation Scheme

We propose a self-organized resource allocation method based on [5][6][7]. In the proposed method, the normalized Proportional Fairness Scheduler (PFS) is performed by each PBS, i.e., the PUE whose instantaneous SNR of RB n, $\gamma_{l_i,n}$, divided by its mean SNR $\overline{\gamma}_{l_i,n}$ is maximum is selected at the picocell i, that is

$$l_i^*(n) = \underset{l}{\operatorname{argmax}} \frac{\gamma_{l_i,n}}{\overline{\gamma}_{l_i}}, \quad i = 1, \cdots, I. \tag{1}$$

To achieve ICIC, MBS estimates the ePUE's allocation mapping based on overheard CSI of ePUEs and reduces its transmit power in RBs where ePUEs are likely to be allocated. The proposed resource allocation at the MBS follows a two-step approach for RB and power allocation as in [9]. The detailed procedure is explained below.

A. Resource Block Allocation at the MBS

In the first step, the normalized PFS is performed by the MBS. The MUE whose instantaneous SNR of RB n, $\gamma_{k,n}$, divided by its mean SNR $\overline{\gamma}_{k,n}$ is maximum is selected, that is

$$k^*(n) = \underset{k}{\operatorname{argmax}} \frac{\gamma_{k,n}}{\overline{\gamma}_k}. \tag{2}$$

B. Power Allocation at the MBS

In the second step, the power allocation at the MBS is performed over RBs already allocated to a specific MUE, so the user index will be dropped. Let p_n denote the power for RB n, and define $\mathbf{p} = [p_1, \cdots, p_N]^{\mathrm{T}}$. To maximize the sum-rate of the allocated MUEs, the following optimization problem is considered:

$$\mathbf{p}_{opt} = \underset{\mathbf{p}}{\operatorname{argmax}} \sum_{n=1}^{N} \log(1 + p_n \Gamma_n),$$
$$\text{s.t.} \sum_{n=1}^{N} p_n \le P_{\max}^{\mathrm{M}},\ p_n \ge 0,\ p_n \le \sigma_n \quad \forall n, \tag{3}$$

where Γ_n is the received SNR of RB n with unit power, and $P_{\max}^{\mathrm{M}}$ is the maximum transmit power of the MBS. σ_n denotes the power limitation for RB n, which is introduced to mitigate the interference to ePUEs. The optimal solution can be obtained via the iterative water-filling algorithm in [9].

C. Analysis of the Allocation Probability

In order to determine the power limitation σ_n in (3), we derive the probability that a RB n is allocated to an ePUE l. We drop the PBS index i in the following analysis, for sake of simplicity. Since the MBS overhears CSIs of all ePUEs in $\mathcal{A}_{\mathcal{D}}$, the allocation probability of ePUE l is set to 0 in the case for there is another ePUE j in $\mathcal{A}_{\mathcal{D}}$ and $\frac{\gamma_{j,n}}{\overline{\gamma}_j} > \frac{\gamma_{l,n}}{\overline{\gamma}_l}$. On the other hand, in the case for the PFS metric of ePUE l, $\frac{\gamma_{l,n}}{\overline{\gamma}_l}$, is maximum among these ePUEs, RB n is allocated to ePUE l when $\frac{\gamma_{l,n}}{\overline{\gamma}_l} > \frac{\gamma_{j,n}}{\overline{\gamma}_j}$ for all iPUE j in $\mathcal{A}_{\mathcal{P}}$. Therefore, in this case the MBS estimates that RB n will be allocated to ePUE l with probability

$$F(\gamma_{l,n}) = Pr\left[\tfrac{\gamma_{l,n}}{\overline{\gamma}_l} > \max_{j \in \mathcal{L}_{\mathcal{P}}} \tfrac{\gamma_{j,n}}{\overline{\gamma}_j} \mid \gamma_{l,n}, \overline{\gamma}_l\right]$$
$$= \prod_{j \in \mathcal{L}_{\mathcal{P}}} \int_C^{\infty} Pr\left[\frac{\gamma_{l,n}}{\overline{\gamma}_l} > \frac{\gamma_{j,n}}{\overline{\gamma}_j} \mid \gamma_{l,n}, \overline{\gamma}_l, \overline{\gamma}_j\right] f\left[\overline{\gamma}_j\right] d\overline{\gamma}_j$$
$$= \left(\int_C^{\infty} Pr\left[\frac{\gamma_{l,n}}{\overline{\gamma}_l} > \frac{\gamma_{j,n}}{\overline{\gamma}_j} \mid \gamma_{l,n}, \overline{\gamma}_l, \overline{\gamma}_j\right] f\left[\overline{\gamma}_j\right] d\overline{\gamma}_j\right)^{L_{\mathrm{iPUE}}} \tag{4}$$

due to the channel independency among UEs, where $f\left[\overline{\gamma}_j\right]$ denotes the probability density function of the average SNR $\overline{\gamma}_j$ for all ePUE j, and $\mathcal{L}_{\mathcal{P}}$ denotes the set of the iPUEs in $\mathcal{A}_{\mathcal{P}}$. The constant C is given by

$$C = \frac{1}{N_0} \frac{P_{\max}^{\mathrm{P}}}{N} \left(\frac{c}{4\pi f}\right)^2 \frac{1}{R_{\mathrm{Pico}}^{\alpha_{\mathrm{P}}}}, \tag{5}$$

where $P_{\max}^{\mathrm{P}}$ is the maximum transmit power of the PBS. With this constant, the average SNR of iPUE j, $\overline{\gamma}_j$, is assumed to satisfy

$$\overline{\gamma}_j = C \left(\frac{R_{\mathrm{Pico}}}{r_j}\right)^{\alpha_{\mathrm{P}}} \tag{6}$$

for the distance r_j from the PBS to the iPUE j, therefore $\overline{\gamma}_j \in [C, \infty)$.

As we assume Rayleigh fading channels, $\gamma_{j,n}$ follows an exponential distribution with mean $\overline{\gamma}_j$, thus

$$Pr\left[\frac{\gamma_{l,n}}{\overline{\gamma}_l} > \frac{\gamma_{j,n}}{\overline{\gamma}_j} \mid \gamma_{l,n}, \overline{\gamma}_l, \overline{\gamma}_j\right] = 1 - \exp\left(-\frac{\gamma_{l,n}}{\overline{\gamma}_l}\right).$$

TABLE I
SIMULATION PARAMETERS

Carrier frequency f	2GHz
System bandwidth	10MHz
Number of RBs N	50
Radius of the macrocell R_{Macro}	289m
Radius of the picocell R_{Pico}	25m
Width of the area $\mathcal{A}_{\mathcal{D}}$ D	15m
Distance between MBS and PBS	150m
Maximum transmit power of MBS	46dBm
Maximum transmit power of PBS	30dBm
Antenna gain of MBS	14dBi
Antenna gain of PBS	5dBi
Path loss exponent $\alpha_{\text{M}}, \alpha_{\text{P}}$	3.7
Noise power N_0	-174dBm/Hz
Number of PBS I	1
ABS ratio	0.2, 0.5, 0.8

Using this, $F(\gamma_{l,n})$ is obtained as

$$F(\gamma_{l,n}) = \left(1 - \exp\left(-\frac{\gamma_{l,n}}{\overline{\gamma}_l}\right)\right)^{L_{\text{iPUE}}}. \quad (7)$$

With the allocation probabilities $F(\gamma_{l_i,n})$ of every ePUE of each PBS, we set the power limitation σ_n in the power allocation problem (3) under the allocation probability threshold p as follows:

$$\begin{cases} \delta/\overline{\gamma}_{l_i}^{\text{MP}_i} & \text{if } \exists i \text{ s.t. } (\exists l_i \in \mathcal{L}_{\mathcal{D}} \text{ s.t. } F(\gamma_{l_i,n}) \geq p), \\ P_{\max}^{\text{M}} & \text{otherwise,} \end{cases} \quad (8)$$

where $\mathcal{L}_{\mathcal{D}}$ denotes the set of the ePUEs in $\mathcal{A}_{\mathcal{D}}$ and $\overline{\gamma}_{l_i}^{\text{MP}_i}$ represents the average path loss from the MBS to ePUE l of the PBS i. $\overline{\gamma}_{l_i}^{\text{MP}_i}$ can be estimated from the received power of CSI feedback signals at the MBS. With this method, we can determine the power limitation σ_n which mitigates the interference to ePUEs.

V. NUMERICAL RESULTS

In this section, we evaluate the performance of the proposed method by computer simulations with the parameters listed in Table I [10]. We consider a PBS placed at 150m distance from the MBS. The radius of the original picocell area $\mathcal{A}_{\mathcal{P}}$ is fixed to $R_{\text{Pico}} = 25$m so that the average RSRP from the MBS and the PBS are equal at the edge of the area $\mathcal{A}_{\mathcal{P}}$. In the simulations, the width of the area $\mathcal{A}_{\mathcal{D}}$ is fixed to $D = 15$m, which is equivalent to a CRE bias of 10dB following the radius of the range-expanded picocell coverage fixed to 40m in [11]. We assume the number of MUEs, iPUEs, ePUEs to be $46, 12, 4$, respectively, although similar performance gains were also obtained for different numbers of UEs. All channels undergo Rayleigh fading. We set the path loss exponents $\alpha_{\text{M}}, \alpha_{\text{P}}$ to $\alpha_{\text{M}} = \alpha_{\text{P}} = 3.7$ for urban macrocell model [12]. UEs feedback their CSI to their serving BSs in every frame, and we assume low-mobility scenarios where the channel variations are small over a few frames. δ in (8) is set to -115dBm [6].

With these settings, the following schemes are evaluated:

· *Conventional ABS* (conv. ABS (rate=β)) :
The conventional ICIC scheme explained in section III, where MBS reduces its transmit power in $100\beta\%$ subframes.

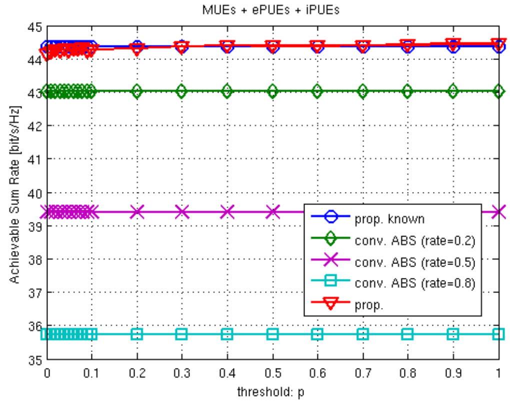

Fig. 4. The achievable sum-rate of all UEs

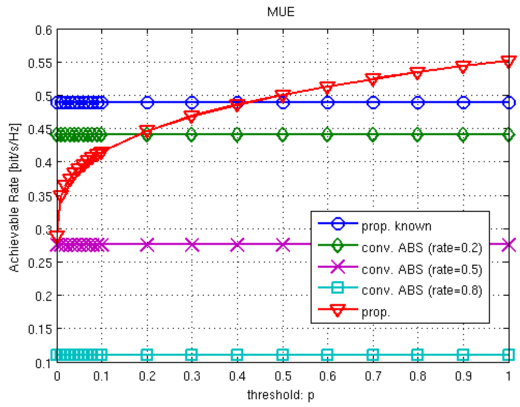

Fig. 5. The individual user rate for MUE

Note that ePUEs can only use protected subframes, while iPUEs can use all subframes. With this restriction, each BS performs PFS scheduling and then determines power allocation by the water-filling algorithm.

· *Proposed scheme* (prop.) :
The proposed scheme explained in section IV. MBS estimates the allocation probabilities of ePUEs based on overheard CSI and solves the power allocation problem (3) by the iterative water-filling algorithm.

· *Proposed scheme, allocation known* (prop. known) :
The proposed method assuming a perfect knowledge of the RB allocation of all PUEs, where MBS reuses the RBs used by ePUEs with limited power.

First, Fig. 4 shows the achievable sum-rate of all UEs versus the allocation probability threshold p. From Fig. 4, we observe that regardless of the threshold p, *Proposed scheme* achieves $3\%, 12\%, 24\%$ higher performance than *Conventional ABS* for ABS rates $\beta = 0.2, 0.5, 0.8$, respectively.

Next, since the goal of the proposed method is to improve the MUE/ePUE rate trade-off while maximizing the total throughput, we evaluate the individual user rates for MUE and ePUE, shown in Fig. 5, 6. From these figures, we observe that both the achievable rate of MUE and that of ePUE are improved by using the threshold $p \in [0.2, 1], p \in [0, 1], p \in [0, 0.4]$ for $\beta = 0.2, 0.5, 0.8$, respectively.

However, from Fig. 7, we observe that the achievable rate of iPUE in *Proposed scheme* is at worst $21\%, 27\%, 32\%$

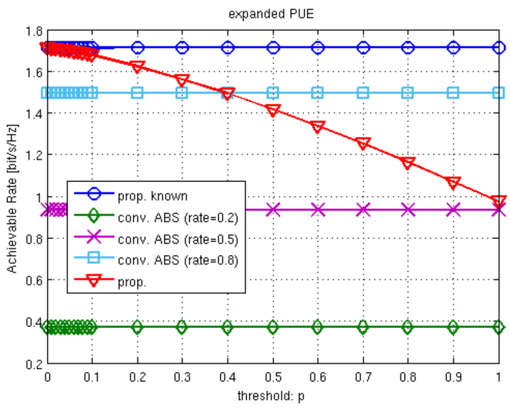

Fig. 6. The individual user rate for ePUE

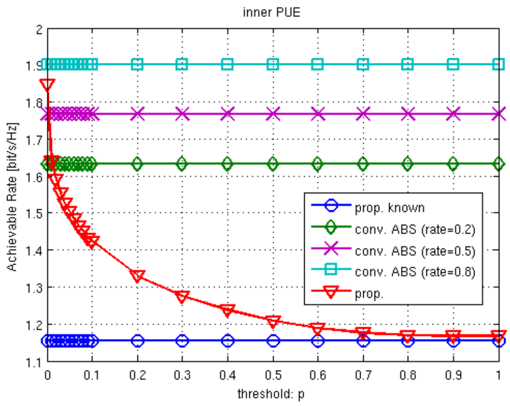

Fig. 7. The individual user rate for iPUE

lower than those of *Conventional ABS* for $\beta = 0.2, 0.5, 0.8$, respectively. This is because in *Conventional ABS* schemes, the SINR values of iPUEs, who are allocated in protected subframes, are improved since iPUEs also suffer from MBS interference.

Finally, we evaluate the Jain's Fairness Index (JFI) in Fig. 8. Here, JFI is calculated as

$$\mathrm{JFI}(R_1, R_2, \cdots, R_{N_{\mathrm{UE}}}) = \frac{(\sum R_j)^2}{N_{\mathrm{UE}} \sum R_j^2}, \tag{9}$$

where N_{UE} is the total number of MUEs and ePUEs and iPUEs, i.e. $N_{\mathrm{UE}} = K + L_{\mathrm{iPUE}} + L_{\mathrm{ePUE}}$, and R_j is the achievable rate of UE j. We can see from Fig. 8 that *Proposed scheme* achieves higher fairness compared to *Conventional ABS* as long as $p \in [0.2, 1]$.

Thus, by using the allocation probability threshold $p \in [0.2, 0.4]$, *Proposed scheme* achieves better performance than *Conventional ABS* in terms of sum-rate of all UEs, individual user rates for MUE and ePUE, and overall user fairness, regardless of the ABS rate β.

Finally, the advantages of the *Proposed scheme* are achieved over a wide range of values of p, showing its robustness. Hence, the proposed scheme lends itself well towards practical implementation.

VI. Conclusion

In this paper, we have proposed a self-organized resource allocation strategy that mitigates the interference experienced by ePUEs in the macrocell/picocell overlay HetNet employing CRE. In the proposed method, MBS predicts the ePUE's RB allocation based on their overheard CSI feedback intended to PBS, and reduces its transmit power in RBs where ePUE's allocation probability is estimated to be high. The RB allocation probability of ePUEs was analyzed. Simulation results have shown that the proposed scheme could outperform the conventional ABS method in terms of sum-rate of all UEs, individual user rates for MUE and ePUE, and overall user fairness, over a wide range of values of the allocation probability threshold p.

In the future work, we will further investigate how to determine the threshold p, and provide the specific design of the control signaling for the proposed scheme. We will also design new algorithms for dealing with picocell-picocell interference issues.

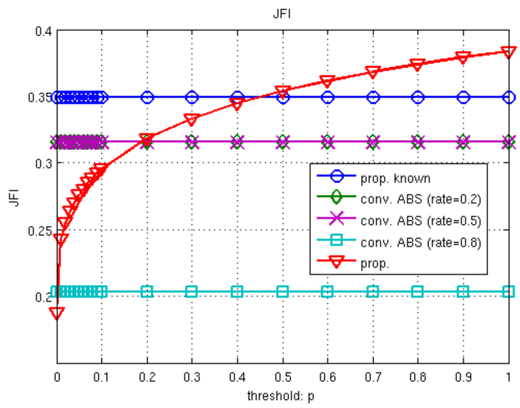

Fig. 8. Jain's fairness index

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