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Interference migration using concurrent transmission for energy-efficient HetNets

Xiao MA[1], Min SHENG[2]*, Jiandong LI[2] & Jingwei XIN[1]

[1]*School of Physics and Information Technology, Shaanxi Normal University, Xi'an* 710119*, China;*
[2]*State Key Laboratory of Integrated Service Networks, Xidian University, Xi'an* 710072*, China*

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Abstract This paper explores the non-uniform distribution property of interference from the perspective of green communications. An interference migration strategy with concurrent transmission is proposed to transfer the interference among different interference regions. In particular, an interference intensity index is used to depict the non-uniform interference distribution. Then we derive the threshold for executing interference migration and the optimal transmission splitting probabilities for energy efficiency (EE) maximization. The results demonstrate that our strategy significantly improves the EE.

Keywords interference migration, energy efficiency, concurrent transmission, heterogeneous networks, mobile hotspot

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1 Introduction

Home base stations, i.e., femtocells, are widely used to improve indoor coverage and enhance network capacity. One of the main advantages of femtocells is the plug-and-play basis which allows users to deploy them anytime anywhere [1]. However, the mass deployment of the femtocells incurs strong co-tier and cross-tier interference which may deteriorate the system performance. On the other hand, due to the random deployment of femtocells and the unbalanced load distribution, the interference in different regions presents significant dissimilarity, i.e., some regions have severe interference but that of the other regions is slight. In other words, the distribution of interference is non-uniform. To satisfy the quality of service (QoS), users in severe interference region usually have to increase the transmission power at the cost of decreasing the energy efficiency (EE).

However, EE is becoming the key metric for designing wireless networks with the increasing awareness of environmental protection and price of energy [2]. Currently, most of the researches focus on EE of radio access technologies which contributes about 60% to 80% of the whole network energy consumption [3]. More importantly, the whole energy consumption of user equipments relies on the limited battery energy which determines its lifetime. This implies that EE is crucial to the usability of user equipments [4]. Furthermore, more than 60% users complain that the limited battery capacity is the most important factor

* Corresponding author (email: msheng@mail.xidian.edu.cn)

impeding their use of Data-Hungry Apps[1)]. Therefore, how to improve the EE is becoming increasingly important for the green communication. Interestingly, if we can effectively utilize this non-uniform interference distribution property in the interference limited wireless networks, the EE performance can be improved.

Recently, there has been a number of studies in the literature addressing different aspects of interference management in heterogeneous networks (HetNets) scenario [5]. The current interference management techniques could be mainly divided into two different categories: the Interference Cancellation and the Interference Mitigation.

The former one, which represents the class of techniques that cancel received interference from the received signal by decoding desired information, is defined by Andrews [6]. The interference cancellation can be further divided into two kinds of methods. One is successive interference cancellation [7] which detects one user per stage. The other one is the parallel interference cancellation [8] which detects all users simultaneously. Both kinds of techniques is that the characteristic knowledge of interference signal from all the interference source is required. This means that, the interference cancellation techniques can only deal with the interference which can be received directly and centrally controlled.

On the contrary, the aim of interference mitigation is to avoid the interference from the source [1] rather than cancel them in the receiver. The most existing studies on interference mitigation focus on spectrum splitting, fractional frequency reuse, power control, etc. [9]. In particular, the 3rd Generation Partnership Project (3GPP) suggested that different portions of spectrum should be used for different base stations especially for different femtocells [10]. The power control is another key method in the interference mitigation. The authors in [11] propose a distributed utility based approach to reduce the cross tier interference subject to the signal-to-interference-plus-noise ratio (SINR) values. In [12], an interference avoidance scheme is proposed to mitigate the inter cell interference at the cell edges.

However, the existing studies on the interference cancellation or mitigation can only handle the interference of the nearby cells or users, and little attention has been paid to deal with the non-uniform distribution of interference among different spatially separated regions. Fortunately, the advent of mobile hotspot (MH), which has been widely investigated from the aspect of load balance and energy efficiency [13–15], brings us a new opportunity to address the non-uniform interference distribution problem via concurrent transmission . In particular, concurrent transmission allows the user to connect with different base stations and transmit the traffic via these connections simultaneously. By adjusting the transmission rate of each connection, the user can shift transmission power among different connections.

Inspired by non-uniform interference distribution and concurrent transmission, a novel strategy is proposed to enhance users' EE by transferring interference from the severe region to the slight region. We named this strategy as interference migration strategy. To our best knowledge, interference migration problem have not been studied in the universal-frequency-reuse HetNet. The main contributions of this paper are summarized as follows. (1) study the feasibility and effectiveness of interference migration by concurrent transmission in HetNet; (2) derive the interference intensity index threshold to perform interference migration; (3) obtain the closed-form expression for the optimal transmission power and the optimal transmission splitting probabilities of concurrent transmission.

For ease of understanding, we summarize the main abbreviations in Table 1. The rest of this paper is organized as follows. The system model is described in Section 2. Then, the interference migration for EE maximization problem is presented in Section 3. The performance of the proposed scheme is illustrated with simulation results in Section 4. Finally, conclusions are drawn in Section 5.

2 System model

2.1 HetNet model

As shown in Figure 1, we consider the uplink transmission in a three-tier HetNet, which consists of a macrocell base station, K femtocell base stations and an MH. The macrocell base station and its overlaid

1) Available online: zdc.zol.com.cn/201/2019387.html.

Table 1 Main abbreviations

CUE	Concurrent transmission user equipment
EE	Energy efficiency
HetNets	Heterogeneous networks
MH	Mobile hotspot
QoS	Quality of service
SINR	Signal-to-interference-plus-noise ratio

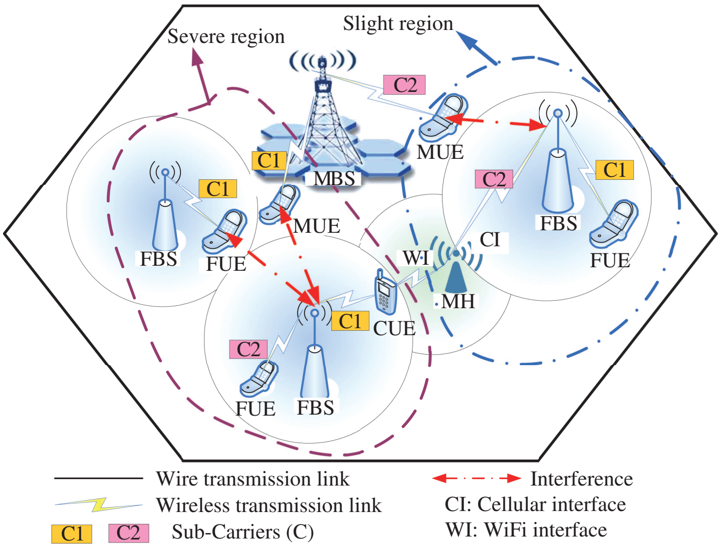

Figure 1 (Color online) HetNet scenario.

K femtocell base stations operate in the same spectrum. The spectrum is divided into different component carriers, each of which is the resource granularity for cellular networks. The MH, a novel multiprotocol device, is deployed in HetNet [16–19]. Specifically, it creates WiFi hotspot and connects WiFi user to the Internet via cellular backhaul. Therefore, the traffic of such user will be transmitted via a two-hop link. The first hop is from the user to MH via WiFi connection. The second one is from MH to base station via cellular interface.

In this three-tier HetNet, there exists a novel user equipment called concurrent transmission user equipment (CUE). Different with the traditional macrocell user equipment and femtocells user equipment, the CUE can establish the connections via base station and MH simultaneously. Consequently, the traffic of CUE can be split into subflows and transmitted via different interface concurrently. As shown in Figure 1, the CUE and MH access to different base stations. When concurrent transmission is executed, the CUE will distribute data packets to different interfaces with certain splitting probabilities, which determine the transmission rate of each connection. Then, the traffic will be transmitted via different base stations, carried through various networks, and finally merged in the destination.

2.2 Interference distribution model

We denote by $S(i)$ the serving base station of user i. Let $G_{i,S(j)}$ be the channel gain from user i to the serving base station of user j. We assume that the channel is the Rayleigh fading channel [20,21]. We refer to user j as an interference neighborhood of user i iff $G_{j,S(i)}P_j > \hat{\gamma}$, where P_j is the transmit power of user j, $\hat{\gamma}$ is the predefined interference threshold [22]. Furthermore, we define the set of all interference neighborhoods of user i as $\mathbb{N}_i$. To simplify the expression, we normalize the channel gains and noise power, i.e., $G'_{j,S(i)} = G_{j,S(i)}/G_{i,S(i)}$ and $n'_i = n_i/G_{i,S(i)}$, where n_i is the background noise power. Accordingly, the normalizing interference plus noise of user i is defined as follows:

$$v_i = \sum_{j\in\mathbb{N}_i} G'_{j,S(i)}P_j + n'_i. \tag{1}$$

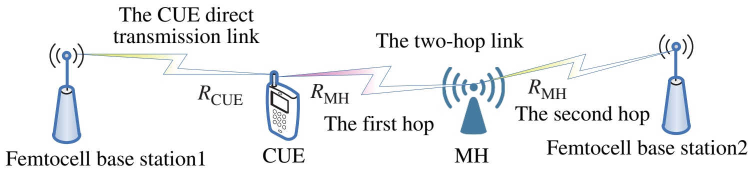

Figure 2 (Color online) The concurrent transmission of CUE.

Let $\mathbb{N}_C$ and $\mathbb{N}_M$ denote the interference neighborhood sets of CUE and MH. Because CUE and MH can access to different base stations which are deployed in different locations, $\mathbb{N}_C$ and $\mathbb{N}_M$ may distribute in different spatial regions. Furthermore, due to the random deployment of femtocell base stations and the unbalanced load distribution, the interference may present great difference between these two sets. Therefore, interference of different spatial regions may distribute non-uniformly. To depict non-uniform interference distribution, we define the term of interference intensity index $\zeta_{C,M}$ which is expressed as follows:

$$\zeta_{C,M} = \frac{\nu_{_C}}{\nu_{_M}} = \frac{\sum_{k\in\mathbb{N}_C} G'_{k,S(C)}P_k + n'_{_C}}{\sum_{j\in\mathbb{N}_M} G'_{j,S(M)}P_j + n'_{_M}}, \tag{2}$$

where $\nu_{_C}$ and $\nu_{_M}$ are the interference plus noise of CUE and MH. In particular, when $\zeta_{C,M} > 1$, the CUE suffers severer interference than MH. We refer to $\nu_{_C}$ and $\nu_{_M}$ as the severe set and slight set, and vice versa for $\zeta_{C,M} < 1$.

By exploiting concurrent transmission, the CUE can transfer interference from the severe set to slight set. Note that, in order to achieve the maximum EE, the interference should be migrated only when the interference intensity index exceeds a certain threshold.

2.3 Energy efficiency performance criteria

We mainly focus on the EE of CUE which will implement the interference migration strategy. Since the data of CUE is transmitted by both CUE and MH, the power consumed by MH should be taken into account. Accordingly, the EE of CUE can be defined as the ratio of transmission rate to the total power consumption [23,24]:

$$\eta_{\rm EE}^{\rm CUE} = \frac{R}{P} = \frac{R_{\rm CUE}+R_{\rm MH}}{P_{\rm CUE}+P_{\rm MH}} = \frac{W_c\log_2(1+P_{\rm CUE}^{\rm tr}/v_{_C}) + W_c\log_2(1+P_{\rm MH}^{\rm tr}/v_{_M})}{P_{\rm CUE}^{\rm tr}+P_{\rm CM}^{\rm tr}+P_{\rm MH}^{\rm tr}+P_{\rm CUE}^{\rm cst}+P_{\rm MH}^{\rm cst}} \quad \text{(bit/Joule)}, \tag{3}$$

where R is the data rate requirement of user, which is determined by the user's traffic. Besides, W_c denotes the transmission bandwidth, $R_{\rm CUE}$ and $R_{\rm MH}$ denote the transmission rate of the subflows transmitted by CUE directly and via the two-hop link, respectively. $P_{\rm CUE}^{\rm cst}$ and $P_{\rm MH}^{\rm cst}$ represent the fixed circuit power of CUE and MH. $P_{\rm CM}^{\rm tr}$ is the power consumption of CUE on the WiFi interface. $P_{\rm CUE}^{\rm tr}$ and $P_{\rm MH}^{\rm tr}$ are the power consumed by CUE and MH on cellular interfaces.

Note that, the concurrent transmission allows the user to connect with different kinds of base stations and transmit the traffic via these connections simultaneously. See Figure 2 for example, when the concurrent transmission has been implemented by CUE, the whole traffic of CUE will be split into two sub-flows. One sub-flow will be transmitted via the CUE direct link. And we denote the rate of this direct link as $R_{\rm CUE}$.

The other one will be transmitted via the two-hop link. Let R_1 and R_2 denote the data rate of the first hop and the second hop, respectively. Furthermore, $R_{\rm MH}$ is the target rate of the two-hop link. Therefore, we can see $R_1 = R_2 = R_{\rm MH}$. In other words, the $R_{\rm MH}$ can be expressed by either R_1 or R_2. We denote the power consumed on the first hop and the second hop as $P_{\rm CM}^{\rm tr}$ and $P_{\rm MH}^{\rm tr}$, respectively. Due to the Short-distance and interference free of the WiFi link transmission, the $P_{\rm CM}^{\rm tr}$ is much lower than $P_{\rm MH}^{\rm tr}$ [25,26]. We ignore $P_{\rm CM}^{\rm tr}$ when we calculate the energy consumed by CUE in the two-hop link. In fact, we investigate the influence of $P_{\rm CM}^{\rm tr}$ on EE via our simulation result, and find out that the impact of $P_{\rm CM}^{\rm tr}$ is ignorable. Therefore, we can express the transmission rate of second hop as $R_{\rm MH} = W_c\log_2(1+P_{\rm MH}^{\rm tr}/v_{_M})$.

3 EE maximization interference migration

In this section, we will first illustrate the basic idea for interference migration through concurrent transmission. Then, the EE maximization problem and the solution will be represented. Finally, we will propose the concurrent transmission interference migration Strategy.

3.1 Basic idea

Generally speaking, the high data rate requires high SINR. There are two approaches to improve SINR: to increase the transmit power, or to decrease the interference. The former one is not a sensible approach, because increasing the transmit power of one UE will cause a severer interference to others. Then, the others have to increase their own power in order to guarantee their QoS. This power adjustment process is a vicious circle and will cause extremely high power consumption. On the other hand, if we can reduce the interference on the transmission of UE, it can decrease the transmit power. And the total interference in this region becomes slight which will lead to a virtuous circle. Obviously, the second approach is more advisable.

Unfortunately, the total interference is hardly reduced especially when the traditional power control strategies have been already implemented. However, by executing the concurrent transmission, the MH can bridge the different interference neighborhood sets. The CUE can transfer the power from severe set to slight set by shifting the splitting probabilities. In other words, although the total interference is hard to reduce, we can still balance the interference among different spatially separated region by decreasing the interference of one region and correspondingly increasing that of another region. Accordingly, the interference is migrated among different regions. More importantly, the EE can be improved by interference migration even when the total interference is not reduced.

3.2 Problem formation and solution

The user's data rate is determined by the application type. To obtain the minimum power consumption, users prefer to transmit with the minimum transfer rate which can guarantee their QoS. Hence, no matter what interference management technology has been implemented, the data rate will not be changed. Consequently, maximizing EE is equivalent to minimizing power consumption. Therefore, to maximize EE of CUE, we model the problem of interference migration as

$$\begin{aligned} \mathrm{P1}: \min P &= P_{\mathrm{CUE}}^{\mathrm{tr}} + P_{\mathrm{MH}}^{\mathrm{tr}}, && (4)\\ \text{s.t. } R_{\mathrm{CUE}} + R_{\mathrm{MH}} &= W_c \log_2(1 + P_{\mathrm{CUE}}^{\mathrm{tr}}/v_C) + W_c \log_2(1 + P_{\mathrm{MH}}^{\mathrm{tr}}/v_M) = R_{\mathrm{req}}, && (5)\\ 0 &\leqslant P_{\mathrm{CUE}}^{\mathrm{tr}} \leqslant P_{\mathrm{CUE}}^{\max}, && (6)\\ 0 &\leqslant P_{\mathrm{MH}}^{\mathrm{tr}} \leqslant P_{\mathrm{MH}}^{\max}, && (7) \end{aligned}$$

where R_{req} is the user's data rate requirement, $P_{\mathrm{CUE}}^{\max}$ and $P_{\mathrm{MH}}^{\max}$ denote the maximum power of CUE and MH, respectively. To satisfy the QoS of CUE, the total transmission rate should be equal to the data rate requirement, i.e., R_{req}. Thus, we have $R_{\mathrm{CUE}} + R_{\mathrm{MH}} = R_{\mathrm{req}}$, where $R_{\mathrm{CUE}} + R_{\mathrm{MH}}$ is the total transmission rate of CUE. In other words, Eq. (5) denotes that the QoS of CUE should be satisfied. Eqs. (6) and (7) represent that the power of CUE and MH must be non-negative and less than their maximum power.

To solve P1, we first derive the solution without constraints (6) and (7) which will be investigated in the next subsection.

Through re-arrangement of (5), it becomes

$$P_{\mathrm{CUE}}^{\mathrm{tr}} = \frac{v_C v_M 2^{R_{\mathrm{req}}/W_c}}{v_M + P_{\mathrm{MH}}^{\mathrm{tr}}} - v_C. \tag{8}$$

Substituting (8) into P1, we have

$$\min P = \frac{v_C v_M 2^{R_{\mathrm{req}}/W_c}}{v_M + P_{\mathrm{MH}}^{\mathrm{tr}}} - v_C + P_{\mathrm{MH}}^{\mathrm{tr}}. \tag{9}$$

Let P' denote the first derivative of P with respect to $P_{\mathrm{MH}}^{\mathrm{tr}}$. The optimal power of CUE and MH for cellular interface, which is expressed as (11) and (12), can be derived by

$$P' = \frac{-v_C v_M 2^{R_{\mathrm{req}}/W_c}}{(v_M + P_{\mathrm{MH}}^{\mathrm{tr}})^2} + 1 = 0, \tag{10}$$

$$P_{\mathrm{MH}}^{*} = \sqrt{v_C v_M 2^{R_{\mathrm{req}}/W_c}} - v_M, \tag{11}$$

$$P_{\mathrm{CUE}}^{*} = \sqrt{v_C v_M 2^{R_{\mathrm{req}}/W_c}} - v_c. \tag{12}$$

According to (11) and (12), we can determine the threshold beyond which the interference should be migrated.

Theorem 1. The interference should be migrated, iff the data rate requirement of CUE is larger than $W_c\,|\log_2(\zeta_{C,M})|$.

Proof. Note that power is non-negative. We assume that $\zeta_{C,M} \leqslant 1$, i.e., $v_C \leqslant v_M$. According to (11) and (12), we get $P_{\mathrm{CUE}}^{*} \geqslant P_{\mathrm{MH}}^{*}$. So we should only guarantee $P_{\mathrm{MH}}^{*} \geqslant 0$. By setting $P_{\mathrm{MH}}^{*} \geqslant 0$, we can derive the threshold of R_{req} as

$$R_{\mathrm{req}} \geqslant W_c \log_2(v_M/v_C) = W_c \log_2(\zeta_{M,C}). \tag{13}$$

On the contrast, for $\zeta_{C,M} > 1$, i.e., $v_C > v_M$, the similar result can be derived

$$R_{\mathrm{req}} \geqslant W_c \log_2(v_C/v_M) = W_c \log_2(\zeta_{M,C})^{-1}. \tag{14}$$

This theorem indicates that whether the interference should be migrated or not depends on the interference intensity index and user's data rate requirement.

3.3 Concurrent transmission interference migration strategy

According to the above analysis, the interference migration strategy consists of three major phases: (a) measure the interference of v_C directly and receive that of v_C which is measured by MH; (b) calculate the optimal splitting probabilities based on the R_{req}, v_C and v_M; (c) split the traffic into subflows, and distribute them to different interfaces with the calculated probabilities.

The core of interference migration strategy is phase (b) which will be explained in detail as follows under the condition $\zeta_{C,M} \leqslant 1$. We consider that the maximum power of CUE can satisfy the user's requirement, with the help of admission control schemes. In addition, the power consumption of CUE for interference migration strategy is no more than that for single CUE transmission strategy. Therefore, the constraint $P_{\mathrm{CUE}}^{\mathrm{tr}} \leqslant P_{\mathrm{CUE}}^{\max}$ can be satisfied, and only $P_{\mathrm{MH}}^{\max}$ should be considered.

Denote $\Psi = \{\varphi_C, \varphi_M\}$ as the set of splitting probabilities of CUE, where φ_C and φ_M represent the probabilities for cellular and WiFi interfaces, respectively. Obviously, $\varphi_C + \varphi_M = 1$. Based on Theorem 1, phase (b) can be divided into the following three cases:

(1) $R_{\mathrm{req}} \leqslant W_c \log_2(\zeta_{M,C})$. The whole traffic will be transmitted by CUE via cellular interface directly, and concurrent transmission will not be executed. Therefore, $\varphi_C = 1$ and $\varphi_M = 0$.

(2) $R_{\mathrm{req}} > W_c \log_2(\zeta_{M,C})$ and $P_{\mathrm{MH}}^{*} \leqslant P_{\mathrm{MH}}^{\max}$. In this condition, the concurrent transmission should be executed. The transmit power of CUE and MH should be set according to (11) and (12), respectively. Then, the Ψ can be calculated by

$$\begin{cases} \varphi_C = W_c \log_2(1 + P_{\mathrm{CUE}}^{*}/v_C)/R_{\mathrm{req}}, \\ \varphi_M = W_c \log_2(1 + P_{\mathrm{MH}}^{*}/v_M)/R_{\mathrm{req}}. \end{cases} \tag{15}$$

(3) $R_{\mathrm{req}} > W_c \log_2(\zeta_{M,C})$ and $P_{\mathrm{MH}}^{*} > P_{\mathrm{MH}}^{\max}$. To guarantee constraint (7), the power of MH should be modified to $p_{\mathrm{MH}}^{\max}$. In this condition, Ψ is expressed as

$$\begin{cases} \varphi_C = 1 - \varphi_M, \\ \varphi_M = W_c \log_2(1 + P_{\mathrm{MH}}^{\max}/v_M)/R_{\mathrm{req}}. \end{cases} \tag{16}$$

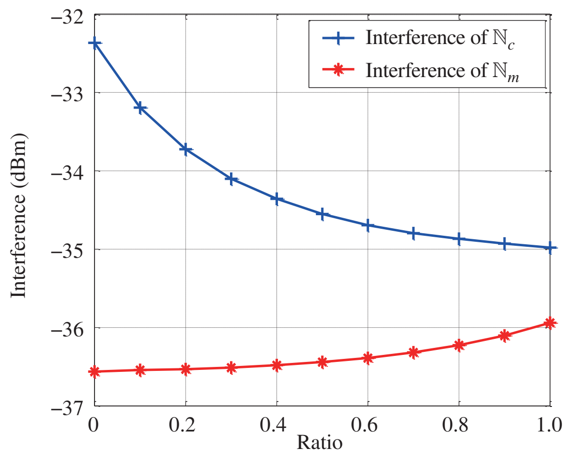

Figure 3 (Color online) Interference of different IR.

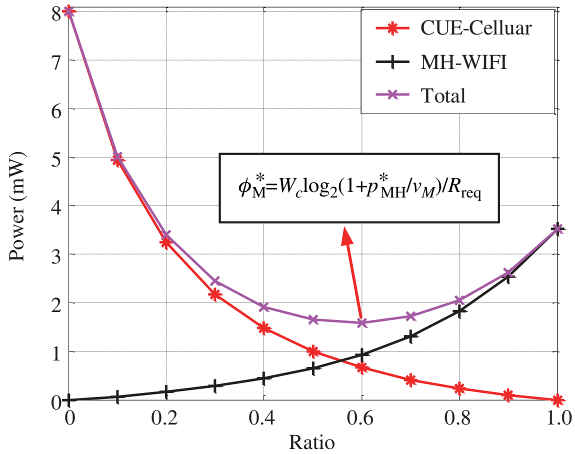

Figure 4 (Color online) Power performance.

4 Performance evaluation

In this section, we will provide the simulations to evaluate the effects of the proposed strategy. We consider a HetNet, in which there are one macrocell user equipment and one femtocells user equipment belonging to sets $\mathbb{N}_C$ and $\mathbb{N}_M$, respectively, i.e., $\mathbb{N}_C = \{\text{MUE}\}$ and $\mathbb{N}_M = \{\text{FUE}\}$. The bandwidth of component carrier is 180 KHz (the bandwidth of PRB for LTE), and the channels are frequency-flat slow fading Rayleigh channel. We first show the feasibility and effectiveness of interference migration by concurrent transmission. Assume that the data rate requirement of macrocell user equipment, CUE and femtocells user equipment are 1.4 Mbps, 700 kbps and 1.2 Mbps, respectively.

Figure 3 shows interference of $\mathbb{N}_C$ and $\mathbb{N}_M$ with different splitting probability of WiFi interface, i.e., φ_M. It can be seen that the interference gradually migrates from $\mathbb{N}_C$ to $\mathbb{N}_M$ with the increase of φ_M. This illustrates that even though the total interference may not be mitigated, the interference can still be migrated among different sets through concurrent transmission.

The optimality of the interference migration strategy is verified in Figure 4 which shows the power consumption with different φ_M. The 'Total' curve represents the sum power of CUE and MH. The $\mathbb{N}_C$ suffers more severe interference than $\mathbb{N}_M$ because of the higher data rate requirement of macrocell user equipment. Plenty of energy can be saved by transferring part of the interference from $\mathbb{N}_C$ to $\mathbb{N}_M$ through concurrent transmission. Especially, the minimum power can be obtained by adopting the optimal splitting probabilities, which is consistent with our analysis.

Figure 5 shows the EE of different UEs with interference migration. For the optimal splitting probabilities, the EE of CUE and macrocell user equipment is improved. More importantly, although the EE of femtocells user equipment is degraded slightly, the total EE of all UEs is still improved by interference migration. This because that the slight interference region can tolerate part of the extra interference which is migrated from the severe interference region.

In Figures 6 and 7, we show the influence of the interference of $\mathbb{N}_C$, and compare the performance of interference migration with the single link transmission strategies. In this simulation, we keep the data rate of CUE at 350 kbps and the femtocells user equipment's power at 30 mW. The horizontal axis is the power of macrocell user equipment which changes from 1 to 400 mW. The macrocell user equipment dominates the SINR of CUE since it is the only UE in $\mathbb{N}_C$.

Figure 6 shows the EE of CUE with different strategies. The black curve represents the EE performance of interference migration strategy. The blue and red curves are that of single link transmission without interference migration via cellular and WiFi interfaces, respectively. Consistent with Theorem 1, the cellular interface of CUE should be used exclusively when $W_c \log_2(\psi_{M,C}) \geqslant R_{\text{req}}$. With the rise of macrocell user equipment's power, the interference should be migrated to the relatively slight set $\mathbb{N}_M$ when $W_c \log_2(\psi_{M,C}) < R_{\text{req}}$. As a result, the EE performance of interference migration is better than that of the single transmission strategies. With further increasing of macrocell user equipment's power, the whole

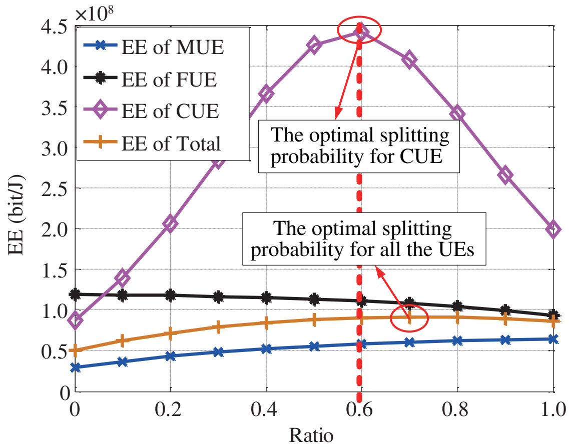

Figure 5 (Color online) The EE performance of different UEs.

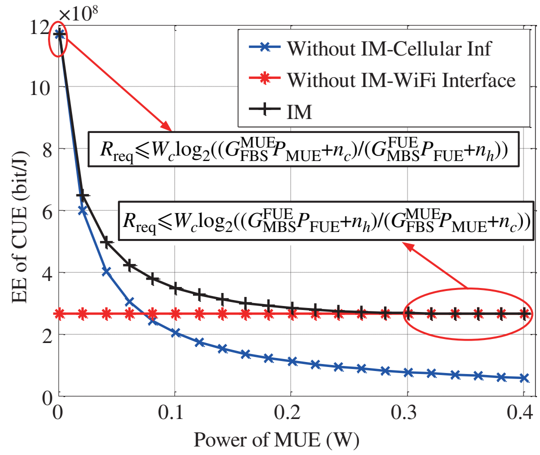

Figure 6 (Color online) The EE performance of macrocell user equipment.

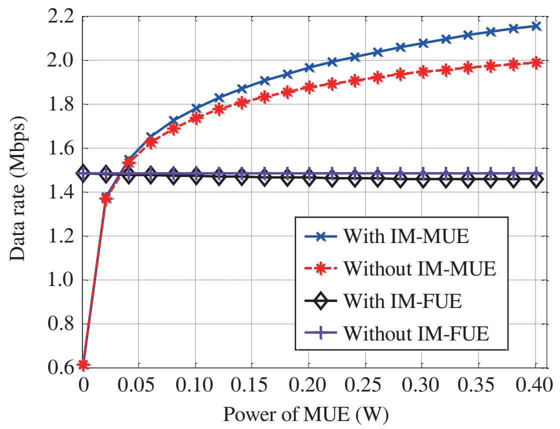

Figure 7 (Color online) Throughput performance.

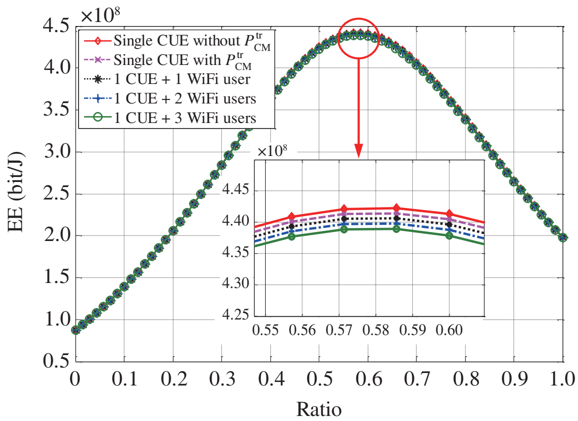

Figure 8 (Color online) The influence of interference in WiFi network.

traffic will be transmitted by MH when $W_c \log_2(\psi_{M,C})^{-1} \geqslant R_{\rm req}$. It can be seen that the interference migration strategy dominates the single link transmission strategies for all interference conditions.

The simulation of Figure 7 was undertaken to examine the throughput performance of the proposed interference performance. We compared the throughput performance of macrocell and femtocells user equipments with and without interference migration strategy, which are represented by the lines with cross and asterisk markers respectively. It can be seen that, with the increase of macrocell user equipment's power, the throughput of macrocell user equipment with interference migration strategy is higher than that without interference migration strategy remarkably. This is because that the macrocell user equipment locates in the interference severe region. When the interference migration strategy has been implemented, the interference will be transferred out from this region via the CUE. The interference in this region will be reduced. Therefore, the transmission performance, such as throughput, will be improved. More importantly, the heavier interference in severe region, the more gain we can obtain.

On the other hand, as we described above, the aim of interference migration strategy is not to reduce the total interference, but to transfer the interference from one region to another region. Accordingly, as the interference reduces in the severe region, the interference in slight region will be increased. However, though the CUE transfers parts of the interference into the slight region, the throughput of femtocells user equipment, which located in the slight region, almost dose not decrease. This phenomenon means that the slight interference region can tolerate some extra interference. Therefore, the proposed interference migration strategy can improve the performance of UE in server interference region without degradation that of UE in slight region. In particular, the line crossing implies that two regions almost suffer the same interference. This means that, it is not necessary to implement the interference migration.

In the above analysis, we ignore the transmission power of the WiFi interface (i.e., $P^{\rm tr}_{\rm CM}$) to obtain some insights into this system. In the simulation of Figure 8, we consider the influence of $P^{\rm tr}_{\rm CM}$, and investigate the EE performance of CUE when 2–4 WiFi users exist in the HetNet. It can be seen that, due to the short-distance of the WiFi link transmission, the influence of $P^{\rm tr}_{\rm CM}$ on the EE performance is very limited. Therefore, the $P^{\rm tr}_{\rm CM}$ can be neglected in the analysis, while the conclusion drawn above still stand. In fact, if we consider the influence of $P^{\rm tr}_{\rm CM}$ on EE performance, the nonuniform interference distribution phenomenon still exists, and the interference migration can obtain the distribution diversity gain.

5 Conclusion and future work

In this paper, a novel interference management strategy, namely the interference migration, has been proposed to deal with the interference non-uniform distribution phenomenon. The interference migration is the process of transferring the interference from one region to another region by implementing the concurrent transmission. Furthermore, we use the energy efficiency to measure the performance of the proposed strategy. The simulation results show that, although the total interference is hard to reduce, the proposed strategy can still balance the interference among different spatially separated region, and improve the energy efficiency performance remarkably.

Furthermore, to obtain some insights into this system, we use the scenario with single mobile hotspot and single CUE to analyze the property of the proposed strategy. In practical systems, there may exist more than one mobile hotspot and CUE with much more complex channel conditions. By introducing the multiple hotspots selection scheme, the proposed strategy can be easily extended to the single CUE and multiple mobile hotspots scenario. While, for the multiple CUE scenario, due to the mutual interference and the limited knowledge among different CUEs, the problem becomes more complex and can not be solved directly with the method described in this paper. Nonetheless, the nonuniform interference distribution phenomenon still exists, and the interference migration should still obtain the distribution diversity gain. In the future work, we will concentrate upon dealing with the problems in multiple CUEs scenario with complex channel conditions.

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Conflict of interest The authors declare that they have no conflict of interest.

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