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Spectrum Allocation and Service Control for Energy Saving Based on Large-Scale User Behavior Constraints in Heterogeneous Networks

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Abstract

In heterogeneous networks (HetNets), energy saving is vital for a sustainable network development. Many techniques, such as spectrum allocation, network planning, etc., are used to improve the network energy efficiency (EE). In this paper, micro BSs utilizing cell range expansion (CRE) and spectrum allocation are considered in multi-channel heterogeneous networks to improve EE. Hotspot region is assumed to be covered by micro BSs which can ensure that the hotspot capacity is greater than the average demand of hotspot users. The expressions of network energy efficiency are derived under shared, orthogonal and hybrid subchannel allocation schemes, respectively. Particle swarm optimization (PSO) algorithm is used to solve the optimal ratio of subchannel allocation in orthogonal and hybrid schemes. Based on the results of the optimal analysis, we propose three service control strategies on the basis of large-scale user behaviors, i.e., adjust micro cell rang expansion (AmCRE), adjust micro BSs density (AmBD) and adjust micro BSs transmit power (AmBTP). Both theoretical and simulation results show that using shared subchannel allocation scheme in AmBD strategies can obtain maximal EE with a very small area ratio. Using orthogonal subchannel allocation scheme in AmCRE strategies can obtain maximal EE when area ratio is larger. Using hybrid subchannel allocation scheme in AmCRE strategies can obtain maximal EE when area ratio is large enough. No matter which service control strategy is used, orthogonal spectrum scheme can obtain the maximal hotspot user rates.

Keywords: Heterogeneous Networks, Spectrum allocation, Service control, User behavior

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1. Introduction

The global mobile communication industry is growing rapidly and this growth is accompanied by increased energy consumption of mobile networks [1]. As the world is getting more and more pollution, energy efficient transmission becomes a significant issue for green communications. Therefore, green wireless communication is considered as a promising method for reducing energy consumption to meet the increasing traffic demands.

In current wireless network, some users in hotspot regions may have higher traffic demand than in other regions in both temporal and spatial domains. This behavior is referred to as the large-scale user behavior [2]. Unsurprisingly, user behavior can have great effects on the network energy efficiency. Some service control strategies based on large-scale user behavior were proposed in our previous works [3]-[5].

In this paper, we investigate the effects of spectrum allocation and micro cell range expansion technology on improving energy efficiency. We assume that users in hotspot region are covered by micro BSs and the rates of hotspot users have minimum thresholds. Our main contributions of the paper are summarized as follows:

- *Derivation of Energy Efficiency under different Spectrum Allocation Schemes*
  We use stochastic geometry to evaluate the performance of the system in terms of the energy efficiency. We derive the SINR coverage and mean achievable rates of user in hotspot region and non-hotspot region. And we also give the expressions of network energy efficiency under shared, orthogonal and hybrid spectrum allocation schemes.
- *Energy Efficient Service Control Strategies*
  Three energy efficient service control strategies for large-scale user behavior are proposed, including AmCRE, AmBD and AmBTP. Simulation results show that with the increase of area ratio of hotspot region and non-hotspot region in AmCRE strategy, shared, orthogonal and hybrid scheme can obtain maximal EE but hotspot users which use orthogonal scheme always have larger rates than other schemes. In AmBD strategy, no matter how the area ratio changes, use shared scheme can obtain maximal EE but using shared spectrum scheme can only obtain minimal hotspot user rates. In AmBTP strategy, using orthogonal scheme can obtain maximal EE unless area ratio is very small and using orthogonal spectrum scheme can obtain maximal hotspot user rates unless area ratio is very large.

  Comparing the three service control strategies which use different spectrum allocation scheme, we find that using shared subchannel allocation scheme in AmBD strategy can obtain maximal EE when area ratio is very small. Using orthogonal subchannel allocation scheme in AmCRE strategy can obtain maximal EE when area ratio is larger. Using hybrid subchannel allocation scheme in AmCRE strategy can obtain maximal EE when area ratio is large enough. No matter which service control strategy is used, orthogonal spectrum scheme can obtain maximal hotspot user rates.

The layout of this paper is organized as follows. In Section 2, we review the previous work in energy efficient techniques and several service control strategies in heterogeneous network. In Section 3, we describe the two-tier network model, the spectrum allocation, user allocation and power consumption model. In Section 4, the energy efficiency of network is derived for the different spectrum allocation schemes. In Section 5, three service control scenarios are proposed based on large-scale user behavior. Section 6 illustrates the aforementioned analysis by numerical results, which are also corroborated by simulation. Finally, the paper is concluded in section 7.

2. Related Work

HetNet which includes macro BSs and low power micro BSs is shown to have higher spectrum efficiency and energy efficiency [6]. More and more researchers pay attention to the performance analysis and energy efficiency techniques [7]-[9].Network performance analysis in HetNet using stochastic geometry has gathered considerable attention [10]. The Poisson Point Process (PPP) [11]-[12] and Poisson Cluster Process (PCP) [13]-[14]are widely used to model the spatial distribution of BSs. M. Haenggi *et al.* [15] gave a tutorial on how to model and quantify interference, connectivity, outage probability, throughput and capacity of wireless network. J. G. Andrews *et al.* [16] expended the works and provided a new tractable model for k-tier downlink HetNet and gave simple mathematical expressions for the important metrics including Signal-to-Interference-plus-Noise-Ratio (SINR) coverage and average rate.

For energy efficient techniques, many important techniques like network planning, on-off BS operation and spectrum allocation were proposed. Deploying micro BSs can improve network energy efficiency [17]. However, if too many micro BSs are deployed, the trend of saving may be reversed because of extra embodied energy consumed by newly deployed BSs as well as overhead introduced in transmission [18]. Therefore, the number of micro BSs needs to be carefully planned in order to improve energy efficiency. D. Cao *et al.* [19] investigated the optimal deployment of micro BS with a tradeoff between capacity extension and energy saving. They also found that switch off macro BS can improve EE significantly when users have low traffic demands. BS sleep mode techniques are one of the major methods to reduce total energy consumption. J.Wu *et al.* [20] surveyed recent advancement in the research of BS sleep mode techniques and believed that sleep model in 5G cellular networks could be a research area with many innovative ideas in the foreseeable future. J. Peng *et al.* studied the energy saving problem by switching off some macro BSs in [21]. This scheme can significantly reduce BSs' energy consumption while guarantee the downlink coverage and user power consumption performance.

Spectrum allocation which focuses on reducing the cross tier interference can also save the energy of network. W. Cheung *et al.* [22] investigated the effect of spectrum allocation in two-tier networks where joint and disjoint subchannel allocation for open access femtocells and closed access femtocells respectively. Rao *et al.* [23] surveyed the recent findings in the area of energy efficient radio resource management in cellular networks. Najam Ul Hasan *et al.* [24] presented a network selection and channel allocation mechanism in order to increase revenue by accommodating more secondary users and catering to their preferences.

Several service control strategies which based on large-scale user behavior were presented in [3]. Y. Huang *et al.* presented closed-form formulas that establish the quantitative relationship between user behavior and energy efficient network configuration and proposed micro BS sleep control, coverage expansion control and coverage shrinking control strategies. He also proposed several dynamic transmit mode adjustment schemes based on large-scale user behavior in [25] and [26].

3. System Model

3.1 Two-tier heterogeneous model

In this paper, we consider two kinds of regions (i.e., the hotspot region and non-hotspot region), which are covered by a two tier heterogeneous wireless network. We assume that non-hotspot region coverage is guaranteed by macro BSs and hotspot region coverage is guaranteed by micro BSs. The locations of macro BSs and micro BSs are modeled with independent homogeneous Poisson Point Processes (PPPs Φ_k with intensity λ_k , where $k=1$ for macro BSs and $k=2$ for micro BSs. The locations of users are modeled with another independent homogeneous PPP Φ_u with intensity λ_u. The transmit power of BSs is P_k and SINR threshold is τ. Without loss of generality, we assume that a typical user is located at the origin. The distance between a BS and the typical user is denoted as $\|x\|$ and the channel fading K_x is assumed to follow exponential distribution (Rayleigh fading), i.e. $K_x - \exp(1)$. The noise is assumed additive with power σ^2. The notations used in this paper are summarized in **Table 1.**

Table 1. Summary of Notation

Symbol	Description
k	Index of macro/micro BS tier, $k \in \{1,2\}$
l	Index of subchannel allocation, $l \in \{S,O,H\}$; S is the index of shared scheme; O is the index of orthogonal scheme and H is the index of hybrid scheme.
$\Phi_k;\Phi_u$	PPP of BSs of k^{th} k tier; PPP of mobile users
$\lambda_k;\lambda_u;\overline{\lambda_k}$	Density of BSs of k^{th} tier; density of mobile users; Thinning density of interference in multichannel system.
P_k	Transmit power of BSs of k^{th} tier
P_k^0	static power expenditure of BSs of k^{th} tier
$\|x\|$	Distance between a BS and a typical user
θ	CRE bias
W	Total available spectrum bandwidth
M	The total number of subchannels
$\eta_l,\eta_{l,opt}$	The ratio of subchannel allocation in l scheme; The optimal ratio of subchannel allocation in l scheme.
$M_{l,k}$ $M_{H,s}$	The number of available subchannels in l allocation of k^{th} tier; The number of shared subchannels in hybrid scheme.
S, R, τ	SINR coverage, mean achievable rate, SINR threshold
v_m	Ratio between the area of hotspot regions and that of non-hotspot regions
$\overline{v_m}$	Ratio between the coverage area of micro BSs and that of macro BSs

3.2 Spectrum Allocation

The total available spectrum has a bandwidth of W Hz and the available spectrum is evenly divided into M subchannels. We assume that each user only needs one subchannel for transmitting. When a user accesses its serving BS, the BS selects one of its available subchannels randomly and each subchannel selected in one BS is independent with other BSs. When the number of users is more than the number of available subchannels in a BS, they are served by timesharing with equal time proportion.

We investigate the following three subchannel allocation schemes:

- Shared subchannel allocation, where all subchannels are to be shared by both macro BSs and micro BSs.
- Orthogonal subchannel allocation, where macro BSs are allocated with subchannels that are not being used by the micro BSs.
- Hybrid subchannel allocation, where macro BSs specific subchannels, micro BSs specific subchannels and shared subchannels exist in system.

3.3 Signal-to-interference-plus-noise ratio

By employing the different spectrum allocation model described in Subsection 3.2, the downlink signal-to-interference-plus-noise ratio (SINR) at the typical user can be expressed as follows.

In shared allocation

$$\mathrm{SINR}_S = \frac{P_k K_x \| x \|^{-\alpha}}{\sum_{k=1}^{2} I_k + \sigma^2} \tag{1}$$

In orthogonal allocation

$$\mathrm{SINR}_O = \frac{P_k K_x \| x \|^{-\alpha}}{I_k + \sigma^2} \tag{2}$$

In hybrid allocation

$$\mathrm{SINR}_H = \mathbb{I}\left(l \in \{S\}\right) \frac{P_k K_x \| x \|^{-\alpha}}{\sum_{k=1}^{2} I_k + \sigma^2} + \mathbb{I}\left(l \in \{O\}\right) \frac{P_k K_x \| x \|^{-\alpha}}{I_k + \sigma^2} \tag{3}$$

where $\mathbb{I}(A)$ denotes the indicator of the event A, K_x is the channel power gain from the BS at a distance x, I_k denotes the cumulative interference from the k^{th} tier.

The cumulative interference power from tier k^{th} is $I_k = P_k \sum_{x \in \Phi_k \backslash s_l} K_x \| x \|^{-\alpha}$.

3.4 User allocation

In this paper, all the micro BSs can change their coverage by adjusting cell range expansion (CRE) bias θ. Users compare the biased received signal power from micro BSs with real received power from macro BSs and will associate to the bigger one. We define $\Re$ as the set of BSs that serves a typical user, which can be written as follow:

$$\Re = \begin{cases} \Re_1 & if \quad P_1 Z_1^{-\alpha} > P_2 \theta Z_2^{-\alpha} \\ \Re_2 & if \quad P_1 Z_1^{-\alpha} > P_2 \theta Z_2^{-\alpha} \end{cases} \tag{4}$$

where $Z_k \left(k \in \{1,2\}\right)$ is the distance of a typical user from the nearest BS of k^{th} tier.

3.5 Power consumption model

For BS power consumption, we apply the following linear approximation model:

$$P_{total} = P_k^0 + P_{k,\max} = P_k^0 + M \times P_k \tag{5}$$

where P_k^0 is the static power expenditure, P_k is the transmit power and M is the maximal number of subchannel in the system.

4. Analysis of Energy Efficiency

In this section, we derive the probability that a typical user associates with a BS, and characterize the distribution of users and subchannels in the system. These results are then utilized to analyze the distribution of SINR and average ergodic rate of different subchannel allocation.

4.1 Analysis of Distance

Let A_1 and A_2 denote the probability that a typical user associates with macro BS and micro BS respectively. In the following lemma, we derive the probability density functions of the distance between a typical user and it's serving BS.

Lemma 1: The probability that a typical user associate with macro BS and micro BS are

$$A_1 = \frac{\lambda_1}{\lambda_2 (\frac{P_2\theta}{P_1})^{\frac{2}{\alpha}} + \lambda_1}, \quad A_2 = \frac{\lambda_2}{\lambda_1 (\frac{P_1}{P_2\theta})^{\frac{2}{\alpha}} + \lambda_2} \quad . \tag{6}$$

The PDFs of the distance between a typical user and its serving BS are [27]

$$f_{Y_1}(y) = \frac{2\pi\lambda_1}{A_1} y \exp[-\pi(\lambda_2 (\frac{P_2\theta}{P_1})^{\frac{2}{\alpha}} y^2 + \lambda_1 y^2)] \tag{7}$$

$$f_{Y_2}(y) = \frac{2\pi\lambda_2}{A_2} y \exp[-\pi(\lambda_1 (\frac{P_1}{P_2\theta})^{\frac{2}{\alpha}} y^2 + \lambda_2 y^2)] . \tag{8}$$

Proof: See Appendix A

4.2 Statistics of Users and Subchannels

In our model, the locations of users are modeled with independent homogeneous PPP. Let U_k be the number of users accessing a BS. We denote the association area by c, the distribution of c which covered by k^{th} tier is [27]

$$f_k(c) = \frac{3.5^{3.5}}{\Gamma(3.5)} \frac{\lambda_k}{A_k} (\frac{\lambda_k}{A_k} c)^{2.5} \exp(-3.5 \frac{\lambda_k}{A_k} c) . \tag{9}$$

The probability generating function of the number of U_k is given by [28]

$$G(z) = \frac{3.5^{2.5}\Gamma(4.5)}{\Gamma(3.5)} (3.5 + \lambda_u \frac{A_k}{\lambda_k}(1-z))^{-3.5} \quad . \tag{10}$$

The distribution of U_k is given by the derivatives of $G(z)$ in [29]

$$\mathbb{P}(U_k = n) = \frac{G^{(n)}(0)}{(n)!} = \frac{3.5^{3.5}}{(n)!} \frac{\Gamma(n+3.5)}{\Gamma(3.5)} (\lambda_u \frac{A_k}{\lambda_k})^n (3.5 + \lambda_u \frac{A_k}{\lambda_k})^{-(n+3.5)} . \tag{11}$$

Because the subchannels are uniformly and independently selected by every BS, we can analyze one of them under different spectrum allocation schemes. Let $P_{S,k}$, $P_{O,k}$, $P_{H,k}$ denote the probability that a subchannel is used by a BS which belongs to k^{th} tier under Shared, Orthogonal and hybrid subchannel allocation.

Lemma 2: The probability that a subchannel is used by k^{th} tier BS which derive like [30] is given by in the following.

In Shared subchannel allocation:

$$P_{S,k} = \frac{1}{M}\sum_{n=1}^{\infty}\min\{\mathrm{n}, M\}\mathbb{P}\{U_k = n\}, \tag{12}$$

In Orthogonal subchannel allocation:

$$P_{O,k} = \frac{1}{M_{O,k}}\sum_{n=0}^{\infty}\min\{\mathrm{n}, M_{O,k}\}\mathbb{P}\{U_k = n\}, k \in \{1,2\}, \tag{13}$$

In hybrid subchannel allocation

$$P_{H,k} = \frac{\sum_{n=1}^{\infty}\min\{\mathrm{n}, M_{H,k} + M_{H,s}\}\mathbb{P}\{U_k = n\}}{M_{H,k} + M_{H,s}}, k \in \{1,2\} \ . \tag{14}$$

4.3 SINR Coverage

Using the instantaneous SINR given in subsection **3.3**, we can obtain the conditional SINR coverage of the hotspot region and the non-hotspot region. The conditional SINR coverage is defined as the probability that the received SINR is larger than a predefined threshold τ . The SINR coverage of a randomly located user under different subchannel allocation schemes is obtained by

$$S_{l,k}(\tau) = \int_{y \geq 0} \mathbb{P}(SINR_l > \tau \mid \Re \in \Re_k, Y_k = y)\, f_{Y_k}(y)dy \tag{15}$$

where $l \in \{S, O, H\}, k \in \{1,2\}$.

4.3.1 Non-hotspot user SINR coverage

For any active non-hotspot user served by a macro BS, it must be occupying one subchannel of the macro BS. The following lemma gives the conditional SINR coverage in different subchannel allocation schemes, when a typical user is a non-hotspot user.

Lemma 3: For a non-hotspot user, the SINR coverage in different spectrum allocation schemes can be given in the following.

In shared allocation

$$\begin{aligned} S_{S,1}(\tau) &= \int_{y \geq 0} \mathrm{P}(SINR_S(\Re \in \Re_1) > \tau)\, f_{Y_1}(y)dy \\ &= \int_{y \geq 0} \frac{2\pi\lambda_1}{A_1} y \exp\left[-\frac{\tau\sigma^2}{P_1 y^{-\alpha}} - \pi\lambda_1 y^2 \left(P_{S,1}\tau^{\frac{2}{\alpha}} \int_{\frac{1}{(\tau)^{\frac{2}{\alpha}}}}^{\infty} \frac{1}{1+u^{\frac{\alpha}{2}}}du + 1\right) - \pi\lambda_2 y^2 (\frac{P_2}{P_1})^{\frac{2}{\alpha}} \left[P_{S,2}\tau^{\frac{2}{\alpha}} \int_{\left(\frac{\theta}{\tau}\right)^{\frac{2}{\alpha}}}^{\infty} \frac{1}{1+u^{\frac{\alpha}{2}}}du + \theta^{\frac{2}{\alpha}}\right]\right] dy, \end{aligned} \tag{16}$$

In orthogonal allocation

$$\begin{aligned} S_{O,1}(\tau) &= \int_{y \geq 0} \mathrm{P}(SINR_O(\Re \in \Re_1) > \tau)\, f_{Y_1}(y)dy \\ &= \int_{y \geq 0} \frac{2\pi\lambda_1}{A_1} y \exp\left[-\frac{\tau\sigma^2}{P_1 y^{-\alpha}} - \pi\lambda_1 y^2 \left(P_{O,1}\tau^{\frac{2}{\alpha}} \int_{\frac{1}{(\tau)^{\frac{2}{\alpha}}}}^{\infty} \frac{1}{1+u^{\frac{\alpha}{2}}}du + 1\right) - \pi\lambda_2 (\frac{P_2\theta}{P_1})^{\frac{2}{\alpha}} y^2\right] dy, \end{aligned} \tag{17}$$

In hybrid allocation

$$S_{H,1}(\tau) = \frac{M_{H,1}}{M_{H,1} + M_{H,s}} S_{O,1}(\tau) + \frac{M_{H,s}}{M_{H,1} + M_{H,s}} S_{S,1}(\tau) \ . \tag{18}$$

Proof: See Appendix B

Corollary 1: With noise ignored, $\frac{\tau\sigma^2}{P_1 y^{-\alpha}} \to 0$, the SINR coverage of a non-hotspot user in shared and orthogonal subchannel allocation are

$$S_{S,1}(\tau)=\frac{\lambda_1}{A_1}\frac{1}{\lambda_1\left(P_{S,1}F(\tau)+1\right)+\lambda_2(\frac{P_2}{P_1})^{\frac{2}{\alpha}}\left[P_{S,2}F_1(\tau)+\theta^{\frac{2}{\alpha}}\right]} \tag{19}$$

$$S_{O,1}(\tau)=\frac{\lambda_1}{A_1}\frac{1}{\lambda_1\left(P_{O,1}F(\tau)+1\right)+\lambda_2(P_2\theta/P_1)^{\frac{2}{\alpha}}} \tag{20}$$

where $F(\tau)=\tau^{\frac{2}{\alpha}}\int_{\frac{1}{(\tau)^{\frac{2}{\alpha}}}}^{\infty}\frac{1}{1+u^{\frac{\alpha}{2}}}du$, $F_1(\tau)=\tau^{\frac{2}{\alpha}}\int_{\left(\frac{\theta}{\tau}\right)^{\frac{2}{\alpha}}}^{\infty}\frac{1}{1+u^{\frac{\alpha}{2}}}du$

4.3.2 Hotspot user SINR coverage

Hotspot user is served by a micro BS and only occupies one subchannel of this micro BS. The following lemma gives the conditional SINR coverage in different subchannel allocation, when a typical user is non-hotspot user.

Lemma 4: For a hotspot user, the SINR coverage in different spectrum allocation schemes can be given by

In shared allocation

$$S_{S,2}(\tau)=\int_{y\geq 0}\mathrm{P}(SINR_S\left(\Re\in\Re_2\right)>\tau)f_{Y_2}(y)dy$$

$$=\int_{y\geq 0}\frac{2\pi\lambda_2}{A_2}y\exp\left[-\frac{\tau\sigma^2}{P_2y^{-\alpha}}-\pi\lambda_1y^2(\frac{P_1}{P_2})^{\frac{2}{\alpha}}\left[P_{S,1}\tau^{\frac{2}{\alpha}}\int_{\frac{1}{(\tau_1\theta)^{\frac{2}{\alpha}}}}^{\infty}\frac{1}{1+u^{\frac{\alpha}{2}}}du+\left(\frac{1}{\theta}\right)^{\frac{2}{\alpha}}\right]-\pi\lambda_2y^2\left[P_{S,2}\tau^{\frac{2}{\alpha}}\int_{\frac{1}{(\tau)^{\frac{2}{\alpha}}}}^{\infty}\frac{1}{1+u^{\frac{\alpha}{2}}}du+1\right]\right]dy, \tag{21}$$

In orthogonal allocation

$$S_{O,2}(\tau)=\int_{y\geq 0}\mathrm{P}(SINR_O\left(\Re\in\Re_2\right)>\tau)f_{Y_2}(y)dy$$

$$=\int_{y\geq 0}\frac{2\pi\lambda_2}{A_2}y\exp\left[-\frac{\tau\sigma^2}{P_2y^{-\alpha}}-\pi\lambda_2y^2\left(P_{O,2}\tau^{\frac{2}{\alpha}}\int_{\frac{1}{(\tau)^{\frac{2}{\alpha}}}}^{\infty}\frac{1}{1+u^{\frac{\alpha}{2}}}du+1\right)-\pi\lambda_1(\frac{P_1}{P_2\theta})^{\frac{2}{\alpha}}y^2\right]dy, \tag{22}$$

In hybrid allocation

$$S_{H,2}(\tau)=\frac{M_{H,2}}{M_{H,2}+M_{H,s}}S_{O,2}(\tau)+\frac{M_{H,s}}{M_{H,2}+M_{H,s}}S_{S,2}(\tau). \tag{23}$$

Proof: See Appendix B

Corollary 2: With noise ignored, $\frac{\tau\sigma^2}{P_1y^{-\alpha}}\to 0$, the SINR coverage of a hotspot user in shared and orthogonal subchannel allocation are

$$S_{S,2}(\tau)=\frac{\lambda_2}{A_2}\frac{1}{\lambda_1(\frac{P_1}{P_2})^{\frac{2}{\alpha}}\left[P_{S,1}F_2(\tau)+(1/\theta)^{\frac{2}{\alpha}}\right]+\lambda_2\left[P_{S,2}F(\tau)+1\right]} \tag{24}$$

$$S_{O,2}(\tau)=\frac{\lambda_2}{A_2}\frac{1}{\lambda_2\left[P_{O,2}F(\tau)+1\right]+\lambda_1(P_1/P_2\theta)^{\frac{2}{\alpha}}} \tag{25}$$

where $F(\tau)=\tau^{\frac{2}{\alpha}}\int_{\frac{1}{(\tau)^{\frac{2}{\alpha}}}}^{\infty}\frac{1}{1+u^{\frac{\alpha}{2}}}du$, $F_2(\tau)=\tau^{\frac{2}{\alpha}}\int_{\frac{1}{(\tau\theta)^{\frac{2}{\alpha}}}}^{\infty}\frac{1}{1+u^{\frac{\alpha}{2}}}du$

4.4 Mean Achievable Rates

Based on the conditional SINR coverage defined in **lemma 3** and **lemma 4**, we derive the expressions of the subchannel ergodic rates in different subchannel allocation schemes.

Lemma 5: The ergodic rate is given by

$$R_{l,k} = \int_{x=0}^{\infty} \frac{S_{l,k}(x)}{1+x} dx, l \in \{S, O, H\}, k \in \{1, 2\}, \tag{26}$$

Proof: For a positive random variable X , $E\{X\} = \int_0^{\infty} P\{X > t\} dt$. Since we have

$$\begin{aligned} R_{l,k} &= \int \mathbb{E}\{\ln(1+SINR)\} f_{Y_k}(y) dy \\ &= \int \int_0^{\infty} \mathbb{P}\{\ln(1+SINR) > \tau\} f_{Y_k}(y) d\tau dy \\ &= \int \int_0^{\infty} \mathbb{P}\{SINR > e^{\tau} - 1\} f_{Y_k}(y) dy d\tau \\ &= \int_0^{\infty} S_{l,k}(e^{\tau} - 1) d\tau \overset{(a)}{=} \int_0^{\infty} \frac{S_{l,k}(x)}{1+x} dx \end{aligned}$$

where (a) replacing $x = e^{\tau} - 1$.

Using (26), user ergodic rates in different subchannel allocation are given in following corollary.

Corollary 3: For a typical user, the ergodic rates under different subchannel allocation schemes of k^{th} tier are

$$R_{S,k} = E\left[\frac{W}{M}\log\{1+SINR_{S,k}\}\right] = \frac{W}{M}\int \frac{S_{S,k}(x)}{1+x} dx, \tag{27}$$

$$R_{O,k} = E\left[\frac{W}{M}\log\{1+SINR_{O,k}\}\right] = \frac{W}{M}\int \frac{S_{O,k}(x)}{1+x} dx, \tag{28}$$

$$R_{H,k} = \frac{M_{H,k}}{M_{H,k} + M_{H,s}} R_{O,k} + \frac{M_{H,s}}{M_{H,k} + M_{H,s}} R_{S,k}. \tag{29}$$

If the number of users is no greater than the number of available subchannels in a BS, each user exclusively occupies one subchannel. However, if the number of user is more than the number of available subchannels in a BS, users are served by timesharing with equal time proportion. So the mean achievable rate of a user under different subchannel allocation schemes of k^{th} tier is

$$\overline{R}_{l,k} = \gamma_{l,k} R_{l,k}, l \in \{S, O, H\}, k \in \{1, 2\} \tag{30}$$

where $\gamma_{l,k}$ is the probability that a user occupies a subchannel in l^{th} spectrum allocation scheme.

$$\gamma_{S,k} = \frac{\sum_{n=1}^{M} P\{U_k = n\} + \sum_{n=M+1}^{\infty} \frac{M}{n} P\{U_k = n\}}{1 - P\{U_k = 0\}}, \tag{31}$$

$$\gamma_{O,k} = \frac{\sum_{n=0}^{M_{O,k}} P\{U_k = n\} + \sum_{n=M_{O,k}+1}^{\infty} \frac{M_{O,k}}{n} P\{U_k = n\}}{1 - P\{U_k = 0\}}, \tag{32}$$

$$\gamma_{H,k} = \frac{\sum_{n=0}^{M_{H,k}+M_{H,s}} P\{U_k = n\} + \sum_{n=M_{H,k}+M_{H,s}+1}^{\infty} \frac{M_{H,k} + M_{H,s}}{n} P\{U_k = n\}}{1 - P\{U_k = 0\}}. \tag{33}$$

4.5 Energy Efficiency

The power consumption of the macro/micro BS is given by $\lambda_k\left(P_{l,k}M_{l,k}O_k+P_k^0\right)$, where λ_k is the density of BS, $P_{l,k}$ is the probability that a subchannel is used in l subchannel allocation of k^{th} tier, and $M_{l,k}$ is the number of subchannels in l subchannel allocation of k^{th} tier.

Theorem 1: The energy efficiency in different subchannel allocation is defined as follow:

$$EE_l=\frac{\lambda_u\sum_{k=1}^{2}\left(A_k\overline{R}_{l,k}\right)}{\sum_{k=1}^{2}\lambda_k\left(P_{l,k}M_{l,k}P_k+P_k^0\right)},l\in\{S,O,H\},k\in\{1,2\} \tag{34}$$

where $P_{l,k}$ is the probability of a subchannel used and $M_{l,k}$ is the number of subchannel allocated in l subchannel allocation of k^{th} tier. Specially, the number of subchannels in hybrid scheme of k^{th} tier is $M_{H,k}+M_{H,s}$ and $M_{H,s}$ is the number of shared subchannels in hybrid scheme.

In the following, we introduce the optimal subchannel allocation method in orthogonal and hybrid allocation scheme.

1) Optimal ratio of subchannel allocation in orthogonal scheme

Macro BSs and micro BSs have specific subchannels in orthogonal allocation. The total number of subchannels is fixed and equal to $M_{O,1}+M_{O,2}$. It is obvious that the increasing of $M_{O,1}$ can improve the throughput of tier one but weaken the throughput of tier two. On the other hand, the increasing of $M_{O,2}$ can improve the throughput of tier two but weaken the throughput of tier one. So, there exists an optimal ratio ($\eta_{O,opt}$) of $M_{O,1}$ and $M_{O,2}$ to maximize EE_O. Micro BSs expansion can improve the usage rate of micro BSs' subchannel but excessive expansion decrease the probability that a user occupies a subchannel. So, there also exists an optimal CRE bias $\theta_{O,opt}$ to maximize EE_O.

2) Optimal ratio of subchannel allocation in hybrid scheme

Macro BSs and micro BSs have specific subchannels $M_{H,k}$ and shared subchannels $M_{H,s}$ in hybrid allocation scheme. Note that the total subchannel M is fixed and equals to $M_{H,1}+M_{H,2}+M_{H,s}$. Thus, when $M_{H,s}$ increases, $M_{H,1}$ or $M_{H,2}$ will be decreased. In our model, we need to maximize EE and improve the hotspot rates to our best. Furthermore, according to the analysis of previous related works [31], the optimal bandwidth allocation can be achieved when macro BSs only use shared frequency band. Therefore, the optimal specific subchannel of macro BSs is $M_{H,1}=0$. When $M_{H,s}$ increases one subchannel by decreasing $M_{H,2}$ one subchannel, the rates of hotspot user decrease $\gamma_{H,2}\left(R_{O,2}-R_{S,2}\right)$ and the rates of non-hotspot user increase $\gamma_{H,1}R_{S,1}$. Hence, there is an optimal ratio ($\eta_{H,opt}$) of $M_{H,s}$ and $M_{H,2}$ to maximize EE_H. So, there also exists an optimal CRE bias $\theta_{H,opt}$ to maximize EE_H and we use particle swarm optimization (PSO) algorithm to solve this continuous problem.

To our knowledge, no closed-form expressions can be derived for the general case when using stochastic geometry, therefore we select particle swarm optimization (PSO) algorithm to solve this continuous problem.

The algorithm mainly contains four steps. Firstly, initialize the parameters of PSO. For example, the size of population, particles' velocities and locations, objection function values and the optimal value, etc. Secondly, the total cost is calculated for each particle and the local best solution is obtained. Thirdly, find the global best solution of the current iteration. Finally, the particles's velocity and location are updated to start next iteration. The algorithm terminates when the maximum iteration time is reached or the error requitement is satisfied.

5. Service Controls Strategies Based on Large-scale User Behavior

In this section, we present three service control strategies which used to adjust large-scale user behavior. The ratio between the area of hotspot region and that of non-hotspot region is denoted as v_m . The ratio between the area of micro BSs and that of macro BSs is denoted as $\overline{v_m}$. We simply call v_m area ratio in the following sections. We assume that no matter how the area ratio changes, hotspot regions are always covered by micro BSs ($v_m = \overline{v_m}$).The hotspot user's rates have a predefined threshold R_0 . Note that R_0 is a designed parameter which is chosen to satisfy certain quality of service requirements of hotspot users. No matter how the area ratio changes, hotspot traffic demands are always guaranteed by micro BSs.

Theorem 2: The ratio between the area of micro BSs and macro BSs is given by $\overline{v_m} = \frac{A_2}{A_1} = \frac{\lambda_2}{\lambda_1}\left(\frac{P_2\theta}{P_1}\right)^{\frac{2}{\alpha}}$. We assume that hotspot user must be served by micro BSs. So, the expression of area ratio v_m is

$$v_m = \frac{\lambda_2}{\lambda_1}\left(\frac{P_2\theta}{P_1}\right)^{\frac{2}{\alpha}}. \tag{35}$$

By analysing user behaviors, the probability that a user associates to macro BSs and micro BSs can be simplified to:

$$A_1 = \frac{1}{v_m+1}, A_2 = \frac{v_m}{v_m+1} \tag{36}$$

According to (35) and (36), the relationships between area ratio and SINR coverage in shared and orthogonal allocation are

$$S_{S,1}(\tau) = \frac{v_m+1}{\left(P_{S,1}F(\tau)+1\right)+v_m\left[P_{S,2}F_1(\tau)\theta^{-\frac{2}{\alpha}}+1\right]}, S_{S,2}(\tau) = \frac{v_m+1}{\left[P_{S,1}F_2(\tau)\theta^{\frac{2}{\alpha}}+1\right]+v_m\left[P_{S,2}F(\tau)+1\right]}.$$

$$S_{O,1}(\tau) = \frac{v_m+1}{\left(P_{O,1}F(\tau)+1\right)+v_m}, \quad S_{O,2}(\tau) = \frac{v_m+1}{v_m\left[P_{O,2}F(\tau)+1\right]+1}.$$

We consider that the macro BSs' density and the macro BSs' transmit power are fixed. Only on the CRE bias, the density of micro BSs and the transmit power of micro BSs can be adjusted. Using these adjustable parameters can change the coverage area of micro BSs. Hence, with the change of area ratio v_m , there exists three ways to ensure that the area of micro BSs equals to the area of hotspot. And the hotspot traffic demands are greater than rates threshold R_0 . Based on the large-scale user behavior, we can summarize the system configuration strategies as follows.

5.1 Scenario 1: Adjusted CRE bias (AmCRE)

In this subsection, we consider the case that the density and the transmit power of micro BSs are both fixed and only CRE bias θ can be adjusted to make sure that hotspot region is covered by micro BSs. Using (35), CRE bias can be expressed as

$$\theta = \left(\frac{v_m \lambda_1}{\lambda_2} \right)^{\frac{\alpha}{2}} \frac{P_1}{P_2}. \tag{37}$$

The increase of area ratio v_m leads to the exponential growth of CRE bias. Substituting (37) to (34), the energy efficiency in AmCRE strategy is defined as follows:

$$EE_l = \frac{\lambda_u \left(\overline{R}_{l,1}(v_m) + v_m \overline{R}_{l,2}(v_m) \right)}{(v_m + 1) \sum_{k=1}^{2} \lambda_k \left(P_{l,k}(v_m) M_{l,k} P_k + P_k^0 \right)}. \tag{38}$$

5.2 Scenario 2: Adjusted micro BSs density (AmBD)

In this subsection, we consider the case that the transmit power of micro BSs and the CRE bias are both fixed and only the density of micro BSs can be adjusted. Using (35), micro BSs density can be expressed as

$$\lambda_2 = v_m \lambda_1 \left(\frac{P_1}{P_2 \theta} \right)^{\frac{2}{\alpha}}. \tag{39}$$

The micro BSs density increases monotonically with the increase of the area ratio v_m. Substituting (39) to (34), the energy efficiency in AmBD strategy is defined as follow:

$$EE_l = \frac{\lambda_u \left(\overline{R}_{l,1}(v_m) + v_m \overline{R}_{l,2}(v_m) \right)}{(v_m + 1) \lambda_1 \left[\left(P_{l,1}(v_m) M_{l,1} P_1 + P_1^0 \right) + v_m \left(P_1 / P_2 \theta \right)^{\frac{2}{\alpha}} \left(P_{l,2}(v_m) M_{l,2} P_2 + P_2^0 \right) \right]}. \tag{40}$$

5.3 Scenario3: Adjusted micro BSs transmit power (AmBTP)

In this subsection, we consider the case that the density of micro BSs and the CRE bias are fixed and only the transmit power of micro BSs can be adjusted. Using (35), micro BSs density can be expressed as

$$P_2 = \left(v_m \frac{\lambda_1}{\lambda_2} \right)^{\frac{\alpha}{2}} \frac{P_1}{\theta}. \tag{41}$$

Micro BSs' transmit power is often smaller than the macro BSs' transmit power in general case. Therefore, it is not applicable when area ratio is large enough in this scenario. If CRE bias $\theta=1$, the scope of application of this scenario is $v_m < \frac{\lambda_2}{\lambda_1}$.

Substituting (41) to (34), the energy efficiency in AmBTP strategy becomes:

$$EE_l = \frac{\lambda_u \left(\overline{R}_{l,1}(v_m) + v_m \overline{R}_{l,2}(v_m) \right)}{(v_m + 1) \left[\lambda_1 \left(P_{l,1}(v_m) M_{l,1} P_1 + P_1^0 \right) + \lambda_2 \left(P_{l,2}(v_m) M_{l,2} \left(v_m \frac{\lambda_1}{\lambda_2} \right)^{\frac{\alpha}{2}} \frac{P_1}{\theta} + P_2^0 \right) \right]}. \tag{42}$$

6. Numerical Results

In this section, simulation results are presented to validate the theoretical analysis and justify the effectiveness of the proposed schemes. Although the expression of energy efficiency can be formulated analytically, no closed-form expressions can be derived for the general case. In that case, we resort to numerical evaluation as a means to better understand the behavior of energy efficiency under different scenarios.

For the numerical evaluation, the maximal transmit power of macro BSs and micro BSs is assumed to be 43dBm and 33dBm, respectively. The macro BS density is $\lambda_1 = 1$ per square km and the micro BS density is $\lambda_2 = 5$ per square km. The static power consumption of macro BSs and micro BSs is $P_1^0 = 50dBm$ and $P_2^0 = 40dBm$ respectively. The path loss exponent is assumed $\alpha = 4$. The total number of subchannels is $M = 40$. For the convenience of analysis, we ignore the noise power (i.e., $\sigma^2 = 0$).

6.1 Validation of analysis

In **Fig. 1**, we validate our analysis by comparing the SINR coverage for different subchannel allocation schemes obtained from both the analysis and Monte-Carlo simulation. It can be seen that analytical results match the simulation results very well, which corroborates the accuracy of our theoretical analysis. Therefore, from now on, we use the analytical expressions to evaluate the system performance.

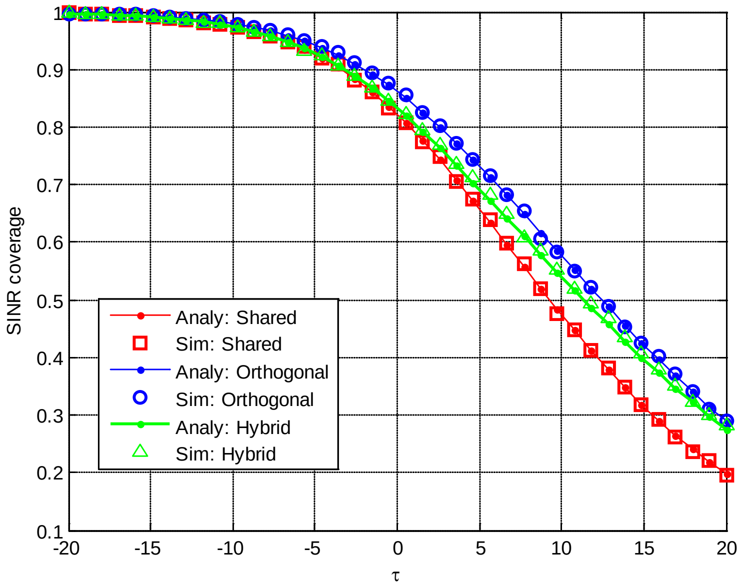

Fig. 1. Analysis vs simulation: SINR coverage under different subchannel allocation, where $M = 40$, $\theta = 1$, $\eta_O = 0.175$, $\eta_H = 0.175$, $M_{H,1} = 0$, $\lambda_u = 50\lambda_1$.

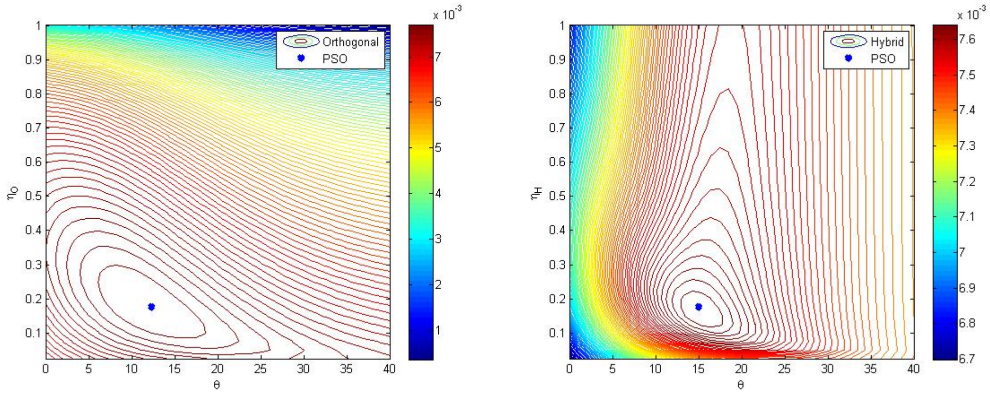

Fig. 2. Contour of EE vs optimal value obtained by PSO algorithm: (a) EE under Orthogonal allocation scheme. (b) EE under Hybrid allocation scheme, where $M = 40$, $\lambda_2 = 5\lambda_1$, $P_1 = 10P_2$, $\tau = 0.5$

In **Fig. 2**, the contour of EE which use orthogonal and hybrid spectrum allocation scheme and the optimal value of EE obtained by PSO algorithm are shown. It can be seen that the location of optimal value which obtained by PSO is very close to the highest value that obtained by analysis, which corroborates the accuracy of our PSO algorithm. Therefore, the optimal CRE bias θ and the optimal spectrum allocation ratio η_O and η_H can be used in the next service control strategies.

6.2 Scenario 1: Adjusted CRE bias (AmCRE)

Fig. 3 shows the effect of varying the area ratio v_m on the energy efficiency for the shared, orthogonal and hybrid subchannel allocation. Area ratio v_m is covered by micro BSs and micro BSs coverage expansion or shrinked by adjusts CRE bias θ. From this figure, it can be seen that shared allocation scheme has the biggest EE when area ratio v_m is very small. In this case, the area of hotspot region is very small and the number of hotspot user is smaller than the number of available subchannels which micro BS can provide. Hence, many micro BSs subchannels are not used and the interferences from micro BSs can be ignored. Using shared allocation scheme can provide more subchannels to user than other schemes and then using shared scheme has the biggest EE.

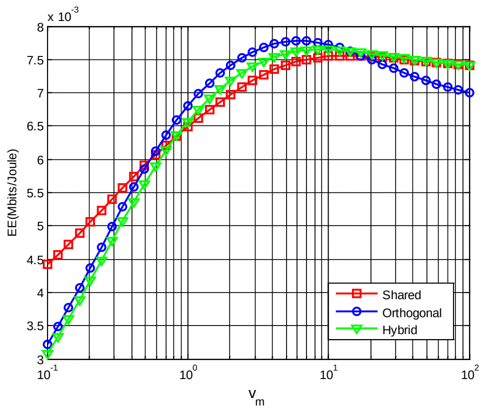

Fig. 3. EE vs v_m : EE under different subchannel allocation schemes in scenario 1 where orthogonal and hybrid allocation scheme use the optimal allocation ratio which obtained from PSO algorithm.

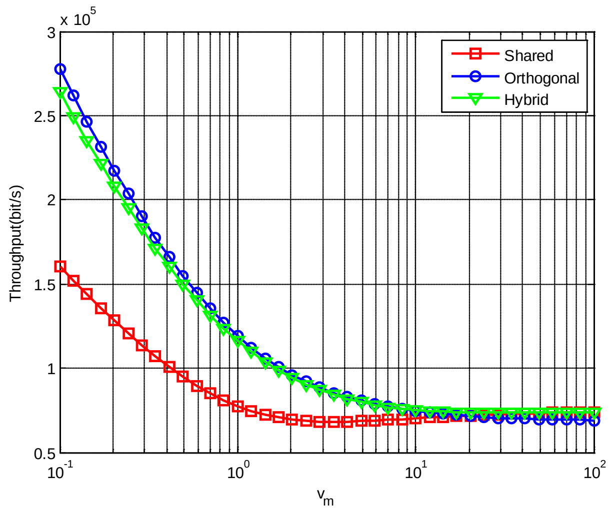

Fig. 4. hotspot user rates vs v_m under different subchannel allocation in scenario 1.

With the increase of area ratio v_m, the hotspot region and hotspot user has grown a lot. Shared allocation scheme causes a lot of interference. Orthogonal allocation scheme has much less number of subchannels in a BS. But the influence of interference exceeds the influence of the available subchannels' number. So, the orthogonal allocation scheme becomes the best solution.

Using hybrid allocation scheme can obtain the best EE When the area ratio v_m is very big. At this time, the number of non-hotspot users is much less than the hotspot users. Micro BSs should be occupyied enough subchannels the more the better in order to maximize EE. Therefore, shared and hybrid allocation schemes are better than orthogonal scheme in EE. Non-hotspot users use fewer subchannels and create lower interference in hybrid scheme than in shared scheme. That is why hybrid scheme is excellent than other schemes when area ratio is very big.

Fig. 4 depicts the effect of increasing the area ratio v_m on the hotspot user rates in scenario 1. It can be seen from the figure that the rates of orthogonal and hybrid allocation scheme are always greater than the shared scheme. The hotspot rates are monotonically decreased with the increasing of area ratio.

When the area ratio v_m becomes very large, hotspot users have the same rates in any schemes. Because the number of hotspot users is very large at this time and the probability that users occupy a subchannel $\gamma_{l,k}$ is very small in any scheme and $\gamma_{S,k} \approx \gamma_{O,k} \approx \gamma_{H,k}$.

6.3 Scenario 2: Adjusted micro BSs density (AmBD)

In **Fig. 5,** the EE achieved by different subchannel allocation schemes is shown. As can be observed from the figure, shared scheme EE is much better than other schemes. With the increasing of area ratio v_m, the EE tends to be uniform.

In this scenario, we use adjust the density of micro BSs to guarantee the request of hotspot region. When the area ratio v_m is very small, the density of micro BS will be small. Users have more subchannels to use in shared scheme than other schemes. When the area ratio v_m is large enough ($v_m > 5$), many micro BSs are deployed in system and users have enough subchannel to use in any cell. In this scenario, there is no difference using any subchannel schemes.

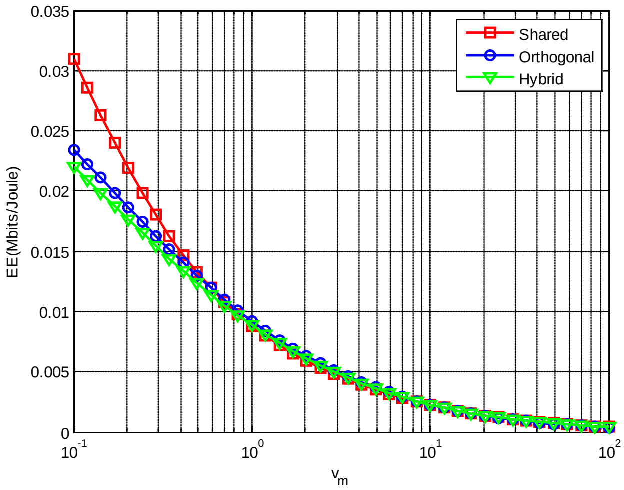

Fig. 5. EE vs v_m : EE under different subchannel allocation schemes in scenario 2 where orthogonal and hybrid allocation scheme use the optimal allocation ratio which obtained from PSO

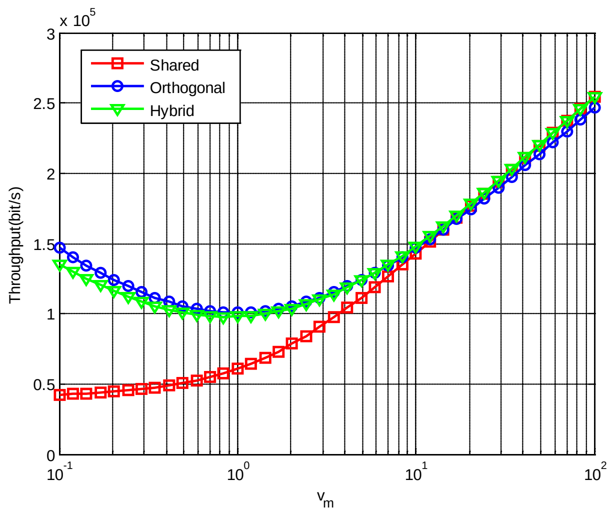

Fig. 6. hotspot user rates vs v_m under different subchannel allocation in scenario 2

Fig. 6 depicts the effect of increasing area ratio v_m on the hotspot user rates. With the increasing of v_m , the hotspot rates are monotonically increasing in shared scheme. In orthogonal and hybrid scheme, the hotspot rates are monotonically decreasing when $v_m < 1$ and monotonically increasing when $v_m > 1$. When area ratio is large enough, users have same rates in different schemes. The density of micro BS is very large and almost every user is served by a micro BS at this time. So, every user has enough subchannels to transmit date in any subchannel scheme and there is no difference in using any subchannel schemes.

6.4 Scenario 3: Adjusted micro BSs transmit power (AmBTP)

In **Fig. 7**, the EE achieved by different subchannel allocation schemes have been shown by adjusting micro BSs transmit power. It is shown that orthogonal allocation scheme almost achieves the best EE at any area ratio v_m. Only when area ratio is very small ($v_m = 0.1$), EE achieved by shared scheme is bigger than orthogonal scheme.

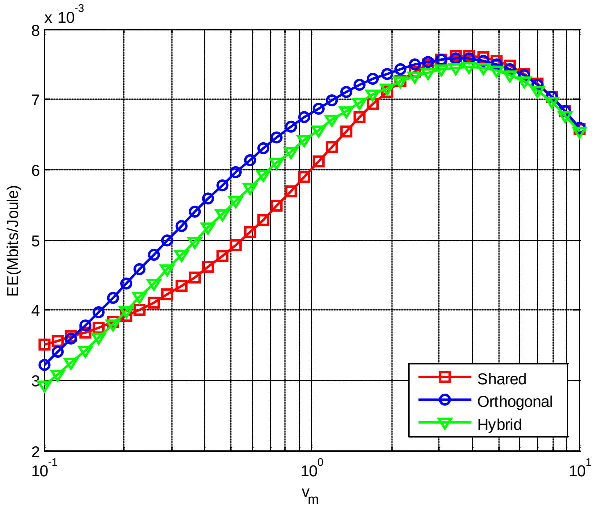

Fig. 7. EE vs v_m : EE under different subchannel allocation schemes in scenario 3 where orthogonal and hybrid allocation scheme use the optimal allocation ratio which obtained from PSO

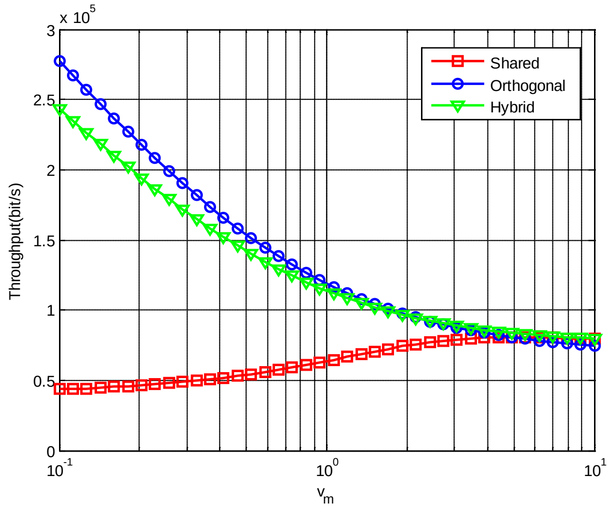

Fig. 8. hotspot user rates vs v_m under different subchannel allocation in scenario 3

Fig. 8 shows the effect of varying area ratio on the hotspot user rates in scenario 3. From the figure, we can see that the hotspot rates are monotonically increasing in shared scheme and decreasing in orthogonal and hybrid schemes. When the area ratio is large enough, users have the same rates in different schemes.

Comparing the results of the above figures, we found that using shared subchannel allocation scheme in AmBD strategies can obtain the maximal EE when area ratio is very small; Using orthogonal subchannel allocation scheme in AmCRE strategies can obtain the maximal EE when area ratio is larger; Using hybrid subchannel allocation scheme in AmCRE strategies can obtain the maximal EE when area ratio is large enough; No matter which service control strategie is used, orthogonal spectrum scheme can obtain the maximal hotspot user rates.

7. Conclusion

In this paper, we analyzed the system transmission performance in two-tier heterogeneous network and derived the expression of energy efficiency under shared, orthogonal and hybrid subchannel allocation schemes. Simple analysis of the optimal subchannels allocation in orthogonal and hybrid scheme was given and we used particle swarm optimization (PSO) algorithm to solve this optimization problem. In order to satisfy large-scale user behavior, we proposed three service control strategies and defined the network EE in different strategies. Simulation results validate the theoretical analysis and demonstrate that the proposed service control strategies have their own advantages in different area ratio of hotspot region and non-hotspot region. These results can be used to help people determine which subchannel allocation scheme and service control strategy should be used to achieve maximal EE with the change of large-scale user behavior.

Appendix A

Using the definition of user allocation, the probability that a typical user associate with macro BS and micro BS are

$$A_1 = \mathrm{P}(P_1 Z_1^{-\alpha_1} > P_2 \theta Z_2^{-\alpha_2}),$$
$$A_2 = \mathrm{P}(P_1 Z_1^{-\alpha_1} < P_2 \theta Z_2^{-\alpha_2}).$$

Following the proof of **Lemma 1** in [26] with the proper changes, A_1 and A_2 can be obtained and can be simplified to (6).Let Y_k denote the distance between the typical user and the service BS, then following the proof of **Lemma 2** in [26] with the proper changes, (7) and (8) can be obtained.

Appendix B

Using the SINR of the non-hotspot user which employs shared allocation scheme, we can calculate the CCDF as follow**:**

$$\begin{aligned}\mathbb{P}\left(SINR_S\left(\Re\in\Re_1\right)>\tau\right)&=\mathbb{P}\left(\frac{P_1K_y y^{-\alpha}}{\sum_{k=1}^{2}I_k+\sigma^2}>\tau\right)=\mathbb{P}\left(K_y>y^{\alpha}P_1^{-1}\tau\left\{\sum_{k=1}^{2}I_k+\sigma^2\right\}\right)\\&\overset{(a)}{=}\mathbb{E}\left[\exp\left(-y^{\alpha}P_1^{-1}\tau\left\{\sum_{k=1}^{2}I_k+\sigma^2\right\}\right)\right]\overset{(b)}{=}\exp\left(-\frac{\tau\sigma^2}{P_1y^{-\alpha}}\right)\prod_{k=1}^{2}\mathrm{E}\left[\exp\left(-y^{\alpha}P_1^{-1}\tau I_k\right)\right]\\&\overset{(c)}{=}\exp\left(-\frac{\tau\sigma^2}{P_1y^{-\alpha}}\right)\prod_{k=1}^{2}L_{I_y}\left(y^{\alpha}P_1^{-1}\tau\right)\end{aligned} \tag{43}$$

where (a) follows the channel fading power $K_x - \exp(1)$, and (b) follows the independence of interference I_k and (c) follows the definition of Laplace transform.

Using the SINR expression of (2), the CCDF of orthogonal scheme can be calculated as follow:

$$\mathrm{P}\left(SINR_O\left(\Re\in\Re_1\right)>\tau\right)=\exp\left(-\frac{\tau\sigma^2}{P_1y^{-\alpha}}\right)L_{I_y}\left(y^{\alpha}P_1^{-1}\tau\right). \tag{44}$$

Following the proof of [29] with the proper changes, the Laplace transform of interference can be given by

$$L_{I_k}(s) = \exp(-2\pi\overline{\lambda_k}\int_{z_{kl}}^{\infty}\frac{v}{1+(sP_k)^{-1}v^{\alpha}}dv)$$

where $\overline{\lambda_k} = P_{l,k}\lambda_k, l \in \{S,O,H\}, k \in \{1,2\}$. $\overline{\lambda_k}$ is the thinning density of interference. z_k is the lower bound on distance of the closest interference in k^{th} tier. It can be given by

$$\begin{cases} if \quad \Re \in \Re_1, \quad z_1 = y, \quad z_2 = (\frac{P_2\theta}{P_1})^{\frac{1}{\alpha}} y \\ if \quad \Re \in \Re_2 \quad z_2 = y \quad z_1 = (\frac{P_1}{P_2\theta})^{\frac{1}{\alpha}} y \end{cases}$$

Let $v^2(sP_k)^{-\frac{2}{\alpha}} = u$, the Laplace transform can be simplified as

$$L_{I_k}(s) = \exp[-\pi\overline{\lambda_k}(sP_k)^{\frac{2}{\alpha}}\int_{\frac{z_k^2}{(sP_k)^{\frac{2}{\alpha}}}}^{\infty}\frac{1}{1+u^{\frac{\alpha}{2}}}du] \tag{45}$$

.

Substituting (7) (45) (43) into (15), we can obtaine the non-hotspot user SINR coverage when using shared allocation scheme.

Substituting (7) (45) (44) into (15), we can obtaine the non-hotspot user SINR coverage when using orthogonal allocation scheme.

Similarly, we can obtain the probability that SINR coverage of hotspot user is greater than threshold in shared and orthogonal allocation schemes.

$$\mathrm{P}\left(SINR_S\left(\Re \in \Re_2\right) > \tau\right) = \exp\left(-\frac{\tau\sigma^2}{P_2 y^{-\alpha}}\right)\prod_{k=1}^{2} L_{I_y}\left(y^{\alpha}P_2^{-1}\tau\right) \tag{46}$$

and

$$\mathrm{P}\left(SINR_O\left(\Re \in \Re_2\right) > \tau\right) = \exp\left(-\frac{\tau\sigma^2}{P_2 y^{-\alpha}}\right) L_{I_y}\left(y^{\alpha}P_2^{-1}\tau\right) \cdot \tag{47}$$

Therefore, Substituting (8) (45) (46) into (15) and substituting (8) (45) (47) into (15) the SINR coverage of hotspot user in shared and orthogonal allocation schemes can be obtained.

In hybrid allocation scheme, specific subchannels and shared subchannels are used as the same probability. So, the hybrid SINR coverage can be described as piecewise liner representation.

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