Non-Uniform Pricing and Resource Allocation Economics for HetNet Based on Stackelberg Game

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***Abstract*— With the popularization of the two-layer distributed heterogeneous network between the macrocell and the femtocell, the interference problem in the heterogeneous network will become more and more complex. The interference of the femtocell base station (FBS) to the macrocell base station (MBS) limits the achievable rate throughput of the macrocell system. In this letter, a two-stage Stackelberg game was used to design a non-uniform pricing scheme to solve the problem. In order to get this scheme, it was first made that MBS management platform and femtocell system are equivalent. Then we set an incentive mechanism in both stages, and solve the optimization problem in two stages. In the first stage, MBS management platform charged for interference. In the second stage, the total benefit of the entire femtocell system could be get based on the cost and the benefit of each femtocell. FBS made a reasonable allocation of transmission power for each femtocell user (FUE) according to the total benefit. These two stages are mutually constrained and mutually supportive. Finally, we get Stackelberg equilibrium of the Stackelberg Game as a non-uniform pricing scheme. We use the simulation experiment to prove that this scheme is superior to the uniform pricing scheme.**

***Index Terms*— MBS, FUE, stackelberg game, non-uniform pricing.**

I. Introduction

WITH the rapid development of wireless technology and internet of things, more and more mobile devices access to the wireless network [1]. In order to improve the indoor service quality, cellular network with low cost and low power consumption has been widely used. At the same time, in order to increase capacity in the future, researches focused on building polymorphic and layered Heterogeneous Network (HetNet) [2]. To further increase coverage rate of indoor cellular networks, Liu *et al.* proposed applying OFDMA technology to cellular network deployment [3]. However, the interference from the femtocell to macrocell influnce the performance of the OFDMA femtocell system. In this case, MBS needs to charge from femtocell, and then decrease the use of frequency spectrum in HetNets.

To solve the economic problems in communication, Luong *et al.* proposed that the pricing models can solve the resource allocation problems in some communication networks [4]. Tang *et al.* studied the physical layer security of small cellular networks under interference constraints, and proposed to bring interference pricing into the constraint problem [5]. These studies have been used to price the interference, but they cannot solve the problem of power allocation and pricing interference simultaneously. The two problems are interrelated and counter to each other. To solve the problem of confrontation in communication network at the same time, some researchers have introduced game theory. Sun *et al.* proposed the power control problem between wireless nodes in the interference channel, and established a non-cooperative game model [6]. Zhan *et al.* used Stackelberg game to solve the incentive problem [7]. These studies prove that the game method can solve the adversary problem in network. We try to solve the problem of resource allocation and pricing interference in Hetnets with Stackelberg Game.

To solve the macrocell and femtocell revenue economic problem, this letter focuses on the interference pricing problem and the power allocation of macrocell-femtocell double-layer cellular communication system based on OFDMA technology. The model optimization problem is divided into two parts, one part is the pricing of macrocell to interference. The other part is the power allocation to FUEs. The two optimization problems relate to each other and conflict with each other. In summary, the main contributions of this letter include:

- We build a cross-layer interference rejection and resource allocation model of a double-layer HetNet. The benefit of MBS and the revenue of FUEs are considered in the model.
- We use a two-stage Stackelberg game to establish an optimization problem. In the first stage, the MBS of macrocell system prices the interference signal from femtocell. At this stage, we use the Lagrange multiplier method to solve the problem. In the second stage, the power obtained by FUE is used to evaluate the total benefit of FUE. After these two stages of optimization, we design a non-uniform pricing scheme, which can balance the benefits of MBS and FUEs.
- Simulation results show that the proposed scheme can make MBS and FUEs get the maximum benefits. Besides, our experiment researches the influnce of the transmission power threshold and total interference threshold on the maximum benefits.

II. System Model and Problem Formulation

In this section, we study a heterogeneous two-tier HetNet. The effect model of macrocell and FUEs was established.

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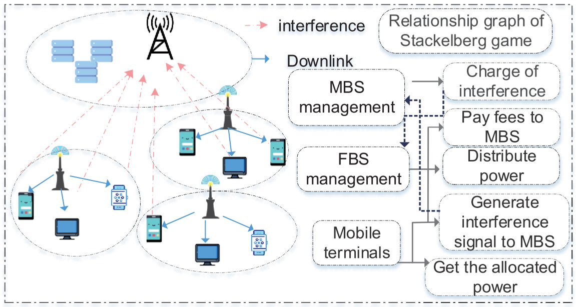

Fig. 1. Cross-layer interference rejection and resource allocation architecture.

A. Network Model

In this letter, we only consider the interference of downlink, the interference of downlink can be extended to uplink. The area $\mathcal{R}$ covered by MBS includes K femtocells. It is defined that there are K FBSs in the coverage range of macrocell, let $k \in \{1, 2, \cdots, K\}$. Without loss of generality, we assume that every signaling time slot has a user in femtocell in each component channel. There are N FUEs in femtocell k, i.e. $n \in \{1, 2, \cdots, N\}$. $h_{0,k}$ is defined to be channel gain from MBS to FBS k. $h_{k,n}$ is defined to be channel gain from FBS k to FUE n. To calculate the interference received by MBS, $p_{0,k}$ is defined to be the transmission power from MBS to FBS. $p_{k,n}$ is defined to be the transmission power from femtocell k to FUE n.

Normally, interference of the system includes the interference between macrocell and femtocell, the interference among femtocells generated by FBS, self-interference (SI) in femtocell according to the deployment of femtocell [8]. To define the optimal pricing and power allocation scheme of the HetNet system, we propose building a Stackelberg game model. The Stackelberg game model can realize the maximization of the joint benefit of macrocell and FUEs.

B. MBS and FUE Utility Model

In this subsection, we build a revenue model for leader macrocell. Firstly, we research the interference pricing pattern of macrocell. Q is defined to be the largest interference threshold MBS can bear. The goal of MBS is to sell interference quota as much as possible to FUEs in the restraint of interference threshold. $\sum_{k=1}^{K}\sum_{n=1}^{N} I(p_{k,n}) \leq Q$ can be used to express the restraint [8]. In above formula, $I(p_{k,n})$ is the interference from femtocell k to macrocell. And the interference is related to channel gain $h_{0,k}$ from MBS to FUE k and power $p_{k,n}$ from FBS k to FUE n in the femtocell. The interference can be expressed to be $I(p_{k,n}) = h_{0,k}p_{k,n}$. To control the received interference, MBS management platform prices interference and charges from femtocell system. The earnings of MBS can be expressed by the formula $U_{MBS} = \sum_{k=1}^{K}\sum_{n=1}^{N}(\mu_{0,k}I(p_{k,n}) - a_{0,k}p_{k,n})$. In the formula, $\mu_{0,k}$ is the price of interference $I(p_{k,n})$, $a_{0,k}$ is the additional power cost factor, $\Phi = \{\mu_{0,1}, \mu_{0,2}, \cdots, \mu_{0,K}\}$ is the price set. MBS can transmit price to FBS and FUEs by e-mail or information.

Then, we build a utility model of the follower FUE. The utility of femtocell has two parts. In one part, interference expense paid to MBS is used as the negative effect of the FUE. In the other part, the transmission power from the femtocell to users is the earning of the FUE. The contribution of the transmitted power is represented by the signal interference plus noise ratio (SINR) received by FBS. To calculate transmission speed, we calculate the SINR firstly. The SINR received by FBS is defined as $\gamma_{n,u}$. When considering the interference of macrocell, the background noise at FBS is defined as σ_k^2. The noise produced in SI of FBS can be defined as σ_{SI}^2. At the same time, we consider the interference signal from other FUEs and FBS, these interferences cause received SINR at FUE to be affected by the transmitted power of different FUEs. Because of loss on the route, channel power gain attenuates with the increase of distance between users. The received SINR at FUE n is defined to be $\gamma_{k,n} = \frac{p_{k,n}h_{k,n}}{\sum_{i\neq k}\sum_{j\neq n} p_{i,j}h_{k,n}+\sigma_k^2+\sigma_{SI}^2}$. The total transmission power of each femtocell is limited, so we define the threshold of transmission power of each femtocell as P_{max}^k, and $\sum_{n=1}^{N} p_{k,n} \leq P_{max}^k$. In femtocell, the transmission speed from FBS to FUE can be obtained $r_{k,n} = \log_2(1 + \gamma_{k,n})$. In this case, a reasonable power allocation strategy is needed to weight the final profit of MBS and users. The utility function of FUE k can be defined as below $U_{FUE} = \lambda r_{k,n} - \mu_{0,k}I(p_{k,n})$, where λ is the utility gain of each unit of transmission speed.

C. Problem Formulation

Because the amount of interference purchased by FUE is related to the price of MBS customization, the revenue of MBS and FUE are correlated. For MBS, revenues are obtained by charging FUE, but high price lowers the interference quota purchase by FUE. And FUE pays for transmission rate. Therefore, we can make a Stackelberg game model between MBS and FUE [9]. MBS management platform needs to find a reasonable price, in order to obtain transmitted power, FUE buys a certain amount of interference based on the price. the price must be accepted by FUEs and maximize the earning obtained by MBS and FUE. The pricing optimization function of MBS is:

$$\mathbf{P1}: \underset{\Phi}{\text{maximize}} \quad U_{MBS} \tag{1}$$

$$\text{subject to} \quad C1: \mu_{0,k} \geq 0. \tag{2}$$

P_{max}^k is defined to be the maximum transmission power FBS can distribute. Therefore, the total power distributed to FUEs must be smaller than the maximum transmission power. The effect function of users is:

$$\mathbf{P2}: \underset{\mathbf{p_{k,n}}}{\text{maximize}} \; U_{FUE} \tag{3}$$

$$\text{subject to } C2: \sum_{k=1}^{K}\sum_{n=1}^{N} I(p_{k,n}) \leq Q \tag{4}$$

$$C3: \sum_{n=1}^{N} p_{k,n} \leq P_{max}^k \tag{5}$$

$$C4: p_{k,n} \geq 0. \tag{6}$$

III. Power Distribution and Pricing Schemes

In order to solve the optimization model for Stackelberg game, we need to find Stackelberg equilibrium (SE) point firstly. At the SE point, MBS and FUE can get ideal benefits, and we get the non-uniform price of MBS. SE of Stackelberg game is got from Nash equilibrium (NE) of FUE and MBS [10]. In this section, the existence of NE will be proved. And the optimal solution of each subproblem can be obtained by step.

A. FUE-Subgame

Theorem 1: Optimization problem $\mathbf{P2}$ *is a convex optimization problem.*

Proof: The objective function of FUE-subgame is defined to be $f(p_{k,n}) = \sum_{n=1}^{N}(\lambda r_{k,n} - \mu_{0,k} I(p_{k,n}))$. Then, it is proved that the objective function is a concave function. We calculate Hessian matrix of $f(p_{k,n})$. When $n \neq \tilde{n}$, we can get $\frac{\partial^2 f(p_{k,n})}{\partial p_{k,n}\partial p_{k,\tilde{n}}} = 0$. Then calculate the elements on the diagonal line of Hessian matrix: $\frac{\partial^2 f(p_{k,n})}{(\partial p_{k,n})^2} = -\frac{\lambda h_{k,n}^2}{\ln 2(\Theta_{k,n}^4 + p_{k,n}h_{k,n}\Theta_{k,n}^2)^2}$, where $\Theta_{k,n}^2 \doteq \sum_{i\neq k}\sum_{j\neq n} p_{i,j}h_{k,n} + \sigma_k^2 + \sigma_{SI}^2$. Obviously, the derivative of $\Theta_{k,n}^2$ is not related to $p_{k,n}$. $f(p_{k,n})$ is a concave function got by the Hessian matrix.

The constraint conditions are continuous, so it is proved that the optimization problem $\mathbf{P2}$ is a convex optimization problem. □

Theorem 2: The optimal solution of optimization problem $\mathbf{P2}$ *is* $p_{k,n} = \frac{\lambda}{\ln 2\mu_{0,k}h_{0,k}} - \frac{\Theta_{k,n}^2}{h_{k,n}}$. *Besides,* $p_{k,n}$ *meets the following conditions*:

$$\sum_{k=1}^{K}\sum_{n=1}^{N} h_{0,k}p_{k,n} \leq Q, \sum_{n=1}^{N} p_{k,n} \leq P_{max}^{k}. \tag{7}$$

Proof: To solve the optimization problem $\mathbf{P2}$, the form of $\mathbf{P2}$ can be changed as the following:

$$\mathbf{P3}: \underset{\mathbf{p_{k,n}}}{\text{minimize}} \; -U_{FUE} \tag{8}$$
$$\text{subject to } C2, C3, C4. \tag{9}$$

Set Langrange function to be:

$$\begin{aligned} &L(p_{k,n}, \beta_1, \beta_2) \\ &= -\sum_{n=1}^{N}(\lambda \log_2\left(1 + \frac{p_{k,n}h_{k,n}}{\Theta_{k,n}^2}\right) - \mu_{0,k}h_{0,k}p_{k,n}) \\ &\quad + \beta_1\left(\sum_{k=1}^{K}\sum_{n=1}^{N} h_{0,k}p_{k,n} - Q\right) \\ &\quad + \beta_2\left(\sum_{n=1}^{N} p_{k,n} - P_{max}^{k}\right) - \beta_3 p_{k,n}. \end{aligned} \tag{10}$$

Langrange function needs to meet the following KKT conditions:

$$\begin{aligned} &\beta_1\left(\sum_{k=1}^{K}\sum_{n=1}^{N} h_{0,k}p_{k,n} - Q\right) = 0,\; \beta_2\left(\sum_{n=1}^{N} p_{k,n} - P_{max}^{k}\right) = 0, \\ &\frac{\partial L}{\partial p_{k,n}} = 0, -\beta_3 p_{k,n} = 0, \quad \beta_1, \beta_2, \beta_3 \geq 0. \end{aligned} \tag{11}$$

In the following, we get the value of $p_{k,n}$ by analyzing KKT conditions. Firstly, $\beta_3 p_{k,n} = 0$ can be obtained from KKT conditions. We set every FUE to have task transmission, so $p_{k,n} \neq 0$ and $\beta_3 = 0$. According to $\frac{\partial L}{\partial p_{k,n}} = 0$, then we can get the value $p_{k,n} = \frac{\lambda}{\ln 2(\mu_{0,k}h_{0,k} + \beta_1 h_{0,k} + \beta_2)} - \frac{\Theta_{k,n}^2}{h_{k,n}}$. The value of β_1 and β_2 can be divided into two groups:

- $\beta_1 = 0, \beta_2 = 0$. In this case, $P_{k,n}$ meeting the conditions of (7). The value of $p_{k,n}$ is

$$p_{k,n}^{*} = \frac{\lambda}{\mu_{0,k}h_{0,k}\ln 2} - \frac{\Theta_{k,n}^2}{h_{k,n}}. \tag{12}$$

- if $\beta_1 \neq 0$ or $\beta_2 \neq 0$, $C2$ and $C3$ will bind each other. Specifically, $C2$ can be converted to $\sum_{k=1}^{K} h_{0,k}\sum_{n=1}^{N} p_{k,n} \leq Q$. When $\beta_1 \neq 0$, $\sum_{k=1}^{K} h_{0,k}\sum_{n=1}^{N} p_{k,n} = Q \leq \sum_{k=1}^{K} h_{0,k}P_{max}^{k}$. When $\beta_2 \neq 0$, $\sum_{k=1}^{K} h_{0,k}\sum_{n=1}^{N} p_{k,n} = \sum_{k=1}^{K} h_{0,k}P_{max}^{k} \leq Q$. However, the values of P_{max}^{k} and Q are determined by the hardware conditions of communication device. They may not satisfy the constraint between the two values. Therefore, the way of getting values is invalid.

To sum up, formula (12) is the solution of optimization problem $\mathbf{P2}$, and constraint condition of the solution is formula (7). □

B. MBS-Subgame

Bring formula (12) into formula (1), we can get

$$\begin{aligned} U_{MBS} = \sum_{k=1}^{K}\sum_{n=1}^{N}\Bigg(&\left(\frac{\lambda}{\ln 2} + \frac{a_{0,k}\Theta_{k,n}^2}{h_{k,n}}\right) \\ &- \left(\frac{\Theta_{k,n}^2 h_{0,k}\mu_{0,k}}{h_{k,n}} + \frac{\lambda a_{0,k}}{\mu_{0,k}h_{0,k}\ln 2}\right)\Bigg). \end{aligned} \tag{13}$$

For convenience, we express formula (13) as $f(\mu_{0,k}) = \sum_{k=1}^{K}\sum_{n=1}^{N}\left(a_1 - \left(a_2\mu_{0,k} + \frac{a_3}{\mu_{0,k}}\right)\right)$. The first derivative of this function is $\frac{\partial f}{\partial \mu_{0,k}} = -a_2 + \frac{a_3}{\mu_{0,k}{}^2}$, and the second derivative is $\frac{\partial^2 f}{\partial \mu_{0,k}^2} = -\frac{1}{\mu_{0,k}{}^4} < 0$. Obviously, the function has a maximum value, and the maximum point is $(\sqrt{\frac{a_3}{a_2}}, 0)$. So MBS makes the optimal pricing $\mu_{0,k}^{*,1} = \frac{1}{h_{0,k}}\sqrt{\frac{N\lambda a_{0,k}}{\ln 2\sum_{n=1}^{N}\frac{\Theta_{k,n}^2}{h_{k,n}}}}$.

Based on $C3$, we can get $\mu_{0,k}^{*} \geq \mu_{0,k}^{*,2} = \frac{N\lambda}{\left(P_{max}^{k} + \sum_{n=1}^{N}\frac{\Theta_{k,n}^2}{h_{k,n}}\right)\ln 2 h_{0,k}}$. Based on $C2$, we can get $\mu_{0,k}^{*} \geq \mu_{0,k}^{*,3} = \frac{N\lambda}{\ln 2\left(h_{0,k}\sum_{n=1}^{N}\frac{\Theta_{k,n}^2}{h_{k,n}} + \frac{Q}{K}\right)}$. There are two cases where we can find the optimal solution of $\mu_{0,k}$ based on formula (12):

- When $\sum_{k=1}^{K} h_{0,k}P_{max}^{k} \leq Q$, total power constraint of each femtocell can be only considered. In this case,

$$\mu_{0,k}^{*} = \min\left\{\mu_{0,k}^{*,1}, \mu_{0,k}^{*,2}\right\}. \tag{14}$$

- When $\sum_{k=1}^{K} h_{0,k}P_{max}^{k} > Q$, we only consider the interference constraint MBS can bear

$$\mu_{0,k}^{*} = \min\left\{\mu_{0,k}^{*,1}, \mu_{0,k}^{*,3}\right\}. \tag{15}$$

C. Stackelberg Equilibrium

Based on the above two sections, we can determine the SE of the Stackelberg game between FUEs and MBS. Therefore, we prove the existence of NE below.

Theorem 3: Nash equilibrium of the Stackelberg Game is existent.

Proof: In order to prove that the SE of the game is existent, we need to prove that the solution of the two sub-games is existent. The optimization problem of followers and leader has NE if the following two conditions can be met [6], [9], [11]: (1) The definition domain of $p_{k,n}$ must be compact, nonempty, convex. (2) Optimization objective function must be continuous and quasi-concave.

Firstly, it has been proved that the objective function of optimization problem $\mathbf{P2}$ is a concave function, which indicates that the objective function meets the condition (2). Besides, $0 \leq p_{k,n} \leq P_{max}^k$ can be obtained from the optimization problem $\mathbf{P2}$. The definition domain of $p_{k,n}$ is compact, nonempty, convex. In this way, it is proved that the optimization problem $\mathbf{P2}$ has solution.

Nextly, for the leader, because $\frac{\partial^2 f}{\partial \mu_{0,k}^2} < 0$, the optimization problem $\mathbf{P1}$ has unique solution. And then the NE of optimization problem $\mathbf{P1}$ and $\mathbf{P2}$ is existent. □

Because $\Theta_{k,n}$ is related to $p_{k,-n}$, $\mu_{0,k}^*$, and $p_{k,n}^*$ can not be obtained by formula (12), (14) and (15) directly. We designed an Stackelberg game iterative algorithm (SGIA) to obtain the end value of SE. In SGIA, $\Theta_{k,n}(t) = \sum_{i\neq k}\sum_{j\neq n} p_{i,j}(t)h_{k,n} + \sigma_k^2 + \sigma_{SI}^2$, $\mu_{0,k}^{*,1}(t) = \frac{1}{h_{0,k}}\sqrt{\frac{N\lambda a_{0,k}}{\ln 2\sum_{n=1}^N \frac{\Theta_{k,n}(t-1)^2}{h_{k,n}}}}$, $\mu_{0,k}^{*,2}(t) = \frac{N\lambda}{\left(P_{max}^k+\sum_{n=1}^N\frac{\Theta_{k,n}(t-1)^2}{h_{k,n}}\right)\ln 2 h_{0,k}}$, $\mu_{0,k}^{*,3}(t) = \frac{N\lambda}{\ln 2\left(h_{0,k}\sum_{n=1}^N \frac{\Theta_{k,n}(t-1)^2}{h_{k,n}}+\frac{Q}{K}\right)}$. The convergence of the algorithm and the uniqueness of NE are proved by simulation.

Algorithm 1 SGIA

Input: $t = 0$, $T_{max} = 30$, $\mu_{0,k}(1)$, $p_{k,n}(1)$.
Output: $\mu_{0,k}^*$, $p_{k,n}^*$

for $t = 2, 3, \cdots, T_{max}$ **do**
  for $k = 1, 2, \cdots, K$ **do**
    for $n = 1, 2, \cdots, N$ **do**
      if $\sum_{k=1}^K h_{0,k}P_{max}^k \leq Q$ **then**
        $\mu_{0,k}^*(t) = \min\left\{\mu_{0,k}^{*,1}(t), \mu_{0,k}^{*,2}(t)\right\}$
      else
        $\mu_{0,k}^*(t) = \min\left\{\mu_{0,k}^{*,1}(t), \mu_{0,k}^{*,3}(t)\right\}$
      $p_{k,n}^*(t) = \frac{\lambda}{\mu_{0,k}(t)h_{0,k}\ln 2} - \frac{\Theta_{k,n}(t-1)^2}{h_{k,n}}$
      if $p_{k,n}^*(t) - p_{k,n}^*(t-1) < \varepsilon$ **then**
        $\mu_{0,k}^* = \mu_{0,k}^*(t)$,
        $p_{k,n}^* = p_{k,n}^*(t)$
return $\mu_{0,k}^*$, $p_{k,n}^*$;

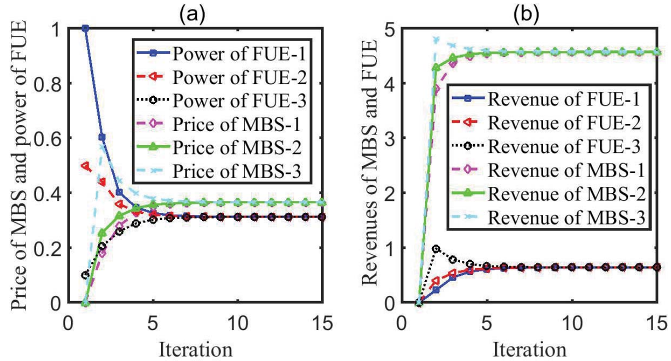

Fig. 2. As the number of iterations increases, changes of (a) price of MBS and power of FUE, and (b) the total revenue of FUE and MBS.

IV. Simulations and Performance Analysis

In this section, we prove the convergence of SGIA through simulation experiments. We also analyze the influence of total interference constraint, total power constraint and the number of FUEs on the total revenues of MBS and FUE.

A. Convergence of the Algorithm

We assume that the Rayleigh fading channel gains are modeled as i.i.d. unit-mean exponentially distributed random variables. We assume that the MBS has a coverage radius of 500 meters. We set $N = 10$ FBS in coverage range. The coverage range of each FBS is 5 meters. The distance between 10 FBS and MBS is $50 - 500$ meters. And $h_{0,k} = \frac{\beta}{d_{0,k}^2}$, where $\beta = 30$, $d_{0,k}$ is the distance between FBS and MBS. Similarly, we can get $h_{k,n}$. We set bandwidth $B = 10MHz$. For convenient calculation, the total interference is set to be $\Theta_{k,n}^2 = \frac{BN_0}{N}$,where $N_0 = -173dBm/Hz$. the utility gains is set to be a constant in range $[0, 1]$.

In order to prove the convergence of SGIA, we use simulation experiments to obtain the transmission power and the price of MBS as the algorithm updates. In the initialization stage of the algorithm, the transmission power allocated to every FUE is set to different values, and the price of MBS customization is set to 0. According to the results of Fig. 2(a), as the number of iteration updates, the transmission power and interference price converge to a certain point, that is, SGIA converges. In Fig. 2(b), we map the total revenue of FUE and MBS to the interval $[0, 5]$. If different initial values are chosen, the total revenue of FUE and MBS get unique ideal benefits synchronously. This indicates that the value of NE is unique.

B. Price and Power Allocation

As shown in Fig. 3, when $\sum_{k=1}^K h_{0,k}P_{max}^k \leq Q$, we compare the non-uniform pricing scheme with two types of uniform pricing scheme. In the uniform pricing scheme, $U_{0,k}^{max}$ and $U_{0,k}^{min}$ are the maximum and minimum values of $\mu_{0,k}$, respectively. In addition, $U_{0,k}^{ran}$ are a price random selection between $U_{0,k}^{max}$ and $U_{0,k}^{min}$. Experimental results show that the non-uniform pricing scheme is optimal.

For uniform pricing scheme, the total revenue of MBS and FUE have no change, this is because $u_{0,k}$ and $p_{k,n}$ have

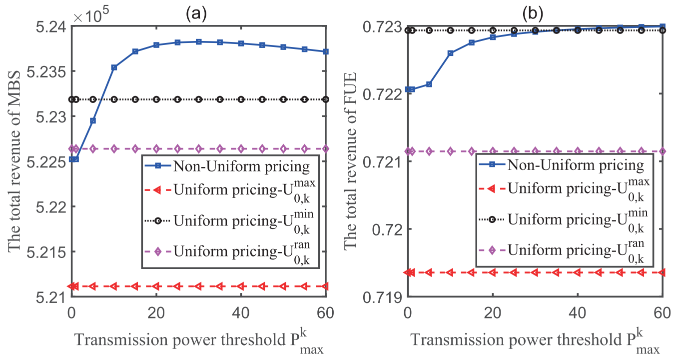

Fig. 3. The influence of total disturbance constraint Q on (a) the total revenue of MBS, and (b) the total revenue of FUE.

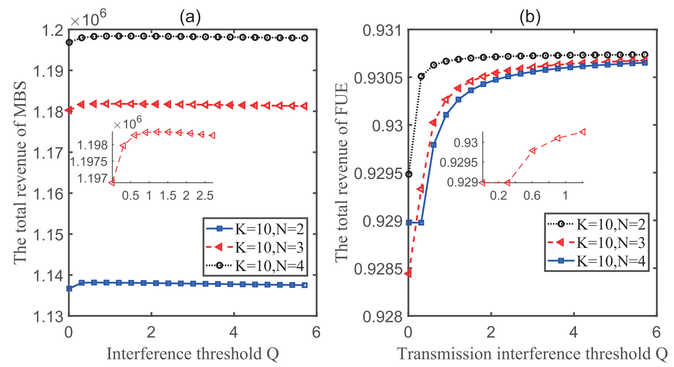

Fig. 4. Influence of transmission power threshold on (a) the total revenue of MBS, and (b) the total revenue of FUE.

nothing to do with P_{max}^k. In Fig. 3, as the transmission power threshold P_{max}^k increases, the total revenue of MBS firstly stays the same, then increases and finally decreases. And the total revenue of FUE firstly remains constant, then increases, and finally stabilizes. According to (12) and (14), the price firstly stays the same and then decreases, $p_{k,n}$ firstly stays the same and then increases. Because the power needed by FUE and channel gain are limited, $p_{k,n}$ will not go to keep increasing, the growth speed of $P_{k,n}$ decreases gradually. These results can be explained from an economic perspective: if the total amount of goods provided by MBS increases, in the beginning, MBS does not lower the price. As competition increases, the price of the good declines, more people will purchase it, and the quantity of the commodity purchased by every people will also be larger. Nevertheless, the final number of people and commodities purchased by every people will be steady.

As shown in Fig. 4, when $\sum_{k=1}^{K} h_{0,k} P_{max}^k > Q$, the change of total revenue of MBS and FUE is similar to that of $\sum_{k=1}^{K} h_{0,k} P_{max}^k \leq Q$. From the perspective of economics, when Q increases, the quantity of goods that users can buy is increases. In the initial stage, the purchasing power bought by FUEs remains unchanged. However, as the surplus grew, operators cut prices. With the change of the price $\mu_{0,k}$, the purchasing power bought by FUEs will firstly remain constant, then increase and finally stabilize. According to the experimental results, within the interference threshold range of MBS, the number of users can be appropriately increased, thus increasing the revenue of MBS and FUE.

V. Conclusion

Balancing the revenue of MBS and FUEs system directly affects the resource allocation capability. In this letter, we build a cross-layer interference rejection and resource allocation model of double-layer HetNet. In the model, we consider the revenue of MBS and FUE at the same time. And two optimization functions are set up to maximize the revenue. Based on the two-stage Stackelberg game, the optimization problems are solved. In the solution process, according to the size of interference constraint and maximum transmission power constraint, the optimization problems are divided into two categories. SE of the Stackelberg game is got based on KTT conditions, Lagrangian function, and SGIA. SE is used as a non-uniform pricing scheme. In the simulation experiment, we proved that the non-uniform pricing scheme can bring more benefit to MBS and FUE comparing with uniform pricing schemes. And properly increasing the number of users, transmission power threshold, and interference threshold can improve the efficiency.

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